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Advances in Materials Technology: MONITOR

Issue Number 11 1987/4

HIGH TEMPERATURE SUPERCONDUCTIVE MATERIALS

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4. NATIONAL AND REGIONAL EFFORTS AND PROGRAMMES:

Dear Reader,

This is the eleventh issue of UNIDO's state-of-the-art series in the field of materials entitled Advances in Materials: Monitor. This issue is devoted to one of the "hottest" subjects, namely to High Temperature Superconductive Materials. Prof. David Caplin from the Physics Department, Imperial College in London, wrote the leading article for this issue.

In each issue of this series, a selected material or group of materials is featured and an expert assessment made on the technological trends in those fields. In addition, other relevant information of interest to developing countries is provided. In this manner, over a cycle of several issues, materials relevant to developing countries could be covered and a state-of-the-art assessment made.

We appreciate all the returned filled-out questionnaires with your comments and suggestions. Some readers suggested that it might be of interest and benefit for the other readers to publish readers' experiences in the development of new materials, especially in developing countries. Further suggestions were received to have an exchange of information on the experiences in technology transfer. Any more comments and suggestions are always welcome.

We like to mention to our readers the possibilities of advertising in our Monitor. Advertising in the Monitor enables us to offer you the opportunity of giving your potential partners and customers in the developing countries more information on your products and services. This activity is non-profit oriented and aims at meeting additional expenses related to preparation, publishing and mailing of the Monitor. All the necessary information related to advertising can be found at the end of the Monitor.

Department for Industrial Promotion,
Consultations and Technology

1. THE NEW SUPERCONDUCTORS

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Summary

Recent developments in superconductivity, which have pushed the superconducting transition temperature up above the boiling point of liquid nitrogen (-196 C), are described. At first sight, the new materials, which are metal oxides, look extremely attractive for applications. However, fabricating them in usable form presents major problems.

The applications of conventional superconductors to both resistance-less current carrying, as in superconducting magnets and cables, and to devices, such as SQUIDs, are described. The possibilities for the replacement of conventional superconductors, or of conventional conductors, by the new materials are examined. It may well be that superconducting devices made from them are easier to achieve than, for example, high-temperature superconducting magnets. These devices would be a lot more portable than those using conventional superconductors, and could find application in, for example, magnetic surveying.

Although there have been reports of superconductivity at yet higher temperatures, none of them have so far been substantiated.

1. Introduction

Since the early months of 1987, the world's newspapers have carried headlines promising cheaper electricity, to be brought about by the new breed of superconductors. It is most certainly true that the science of superconductivity has taken a sudden, and totally unexpected, leap forward with the discovery of materials that retain their superconductivity to much higher temperatures than were previously thought possible. Indeed, in recognition of this watershed, which has stimulated thousands of scientists in practically every country of the world to work on superconductivity, the 1987 Nobel Prize for Physics was awarded to Georg Bednorz and Karl Müller for their discoveries at the IBM Laboratories in Zürich.

Solid state physicists, who had thought that the fundamental science of superconductivity was pretty well sorted out, have been presented with a new and exciting problem: how to understand what is going on in these novel superconductors. But the excitement has spread into industry and commerce too, where the prospect of electrical conductors without any electrical resistance has led to claims of revolutionary prospects for power generation, transport and so on.

The purpose of this article is to describe what superconductivity is about, why it is intrinsically a low-temperature phenomenon, to outline the progress of the last year, and to examine in some detail the prospects for technological application of the new superconductors.

2. Conventional superconductors

Superconductivity has been known for nearly 80 years. It was discovered during the systematic exploration of the behaviour of matter at ultra-low temperatures by the Dutch physicist Kamerlingh Onnes. His work was connected closely with the problem of liquefaction of gases, first oxygen and nitrogen, and later neon, hydrogen, and finally helium. At these low temperatures, it is more natural to work with the absolute temperature scale, denoted by K to commemorate the 19th century physicist Lord Kelvin. On the absolute scale, absolute zero (which is at -273°C on the Centigrade or Celsius scale) is 0 K, so that there are no negative temperatures; the ice point (0°C) becomes 273 K. The boiling points of some common gases are listed in table 1.

Kamerlingh Onnes had been following the behaviour of the electrical resistivity of metals as they are cooled down. As is well known, the resistivity of pure metals is approximately linear in temperature at ambient temperatures (figure 1); when the temperature is lowered, the thermal vibrations of the atoms diminish, and so reduce the scattering of the conduction electrons. At low enough temperatures, only scattering from chemical impurities and crystalline defects remains, and the resistivity levels off to a constant value (the residual resistivity). Thus, ordinary copper conductor that is used for electrical cable has a resistivity that drops from 1.7×10^{-8} ohm m at room temperature to 2×10^{-9} ohm m at 77 K, and typically to 2×10^{-10} ohm m at 20 K or below. If extreme care is taken in purifying the copper, the residual resistivity can be reduced by a further factor of 100 or so. Other metals, such as aluminium and silver, show similar behaviour.

Kamerlingh Onnes' discovery in 1911 was the extraordinary one that the resistivity of mercury dropped sharply to zero at 4.1 K (figure 2). Superconductivity, as it came to be called, was soon found to be widespread amongst the metallic elements, although the transition temperature T_c varies from a small fraction of a degree above absolute zero to 9.2 K for niobium. However, some groups of elements never become superconducting: magnetic metals like iron and nickel; the alkali metals sodium, potassium, etc.; the noble metals copper, silver and gold. Thus, the good room-temperature conductors such as copper and aluminium either fail to become superconducting or have low transition temperatures; on the other hand, the metals with a high T_c are those, such as lead and mercury, that have high resistivity at room temperature. The reasons for this correlation became apparent many years later (see section 7).

How low is the resistance of a superconductor? Kamerlingh Onnes' experiments, which measured the voltage drop along a wire carrying current, showed that it was less than about a ten-thousandth of the resistance in the normal state (metals are described as being either in the normal state when they display their usual resistive behaviour, or in the superconducting state). A more sensitive test is to induce a current in a superconducting ring, and monitor the magnitude of the current using the magnetic field it generates. In a normal metal, the electrical resistance causes the induced current to decay in a fraction of a second. On the other hand, in a superconductor, these currents show no decay over a period of a year or more, which implies that the resistivity in the superconducting state must be less than about 10^{-25} ohm m.

Thus, superconductivity is a remarkable phenomenon; the current-carrying electrons proceed totally unimpeded! Even when some impurities are added deliberately, the material usually remains a superconductor, although the transition temperature may be altered (figure 4). In its early years, the 1930s and 1940s, solid state physics tended to focus on pure metals, leaving the study of alloys and intermetallic compounds (in an intermetallic compound the different atomic species have distinct sites within the crystallographic structure) to the metallurgists. So it was not appreciated until the mid-1930s that large numbers of metallic alloys and intermetallic compounds are superconducting, and some were then discovered that have substantially higher transition temperatures than the elemental superconductors (table II). Until 1986, the record T_c was 23 K for Nb_3Ge.

Given a material of zero resistance, the natural question to ask of a superconductor is how much current can it carry? Unfortunately, it turns out that above a certain current, the critical current, there is a reversion from the superconducting to the normal state, and in the elemental superconductors, these critical currents are too low to be useful. Furthermore, magnetic fields also suppress superconductivity, and again for the elemental superconductors the critical field B_c is too small to have any practical application (table II, the Earth's magnetic field is about 10^{-4} tesla, that of a conventional laboratory electromagnet is about 1 tesla).

However, the superconducting alloys and compounds that were discovered around 1960 included materials, such as Nb-Ti and Nb_3Sn, that retained their superconductivity and substantial current-carrying capacity to very high magnetic fields. It is these materials that have been developed over the last two decades, and have found quite wide application.

3. The new superconductors

Since 1960 or so, most solid state physicists had convinced themselves that the fundamentals of superconductivity were well understood, and that no significant improvement in transition temperature above 30 K could be expected. For this reason, interest and activity in the fundamental aspects of superconductivity declined steeply. However, a small minority were not satisfied that all had been explained, and took the example of the metallic oxide $Ba(Pb\text{-}Bi)O_3$ to heart. This compound had been shown in 1975 to be superconducting at about 13 K - by no means a world record, but unexpectedly high for a material of that composition and structure. It was by exploring this avenue that early in 1986 Bednorz and Müller came across the ternary oxide $(La\text{-}Sr)CuO_4$, which appeared to become superconducting at about 35 K. The parent binary oxide $LaCuO_4$ is not superconducting, but partial replacement of La by Sr, indicated in the chemical formula by (La-Sr), yields the superconducting phase. By the end of the year, this result was confirmed independently by a number of other laboratories, and immediately the race was on to find even higher transition temperatures. In January 1987, Chu's group in Houston discovered that a mixture of yttrium, barium and copper oxides produced material with superconducting behaviour at 92 K, and a few weeks later the superconducting phase was identified as the oxide $YBa_2Cu_3O_7$, whose structure is shown in figure 3. It is a concomitant of a high T_c that the material has also a high critical field, and that is certainly the case for both $(La\text{-}Sr)\ CuO_4$ and $YBa_2Cu_3O_7$ (see table II).

Naturally, in the year since Chu's discovery, literally thousands of oxide mixtures have been made and tested, but at the time of writing, there are no confirmed materials that have any higher transition temperatures. Certainly, there have been dozens of reports of higher temperature superconductivity, some of them in newspapers, and occasionally in scientific journals, but so far none of them satisfy the test of true stable superconductivity.

4. Cyrogenic aspects

The conventional superconductors, those known prior to 1986, all used liquid helium for cooling even if they had transition temperatures above the boiling point of hydrogen. The reason is that the performance of a superconductor, in particular the critical current density (the current per unit cross-sectional area of conductor at which the material ceases to be superconducting), deteriorates rapidly as the transition temperature T_c is approached, so the operating temperature is usually held at 0.7 T_c or less. Liquid helium is expensive, typically not less than $2 per litre in large quantities in industrialized countries, and, because it has to be air-freighted in fragile and costly storage vessels, 10 or 20 times higher in price in small quantities in less-industrialized regions. Furthermore, some specialist training is needed if it is to be used efficiently.

Even without any further advance, a crucial barrier for the wider application of superconductivity has now been crossed, because the $YBa_2Cu_3O_7$ superconductor *can* be usefully cooled with liquid nitrogen. The superconductive performance is less good than that at lower temperatures, because 77 K is only about 0.8 T_c, but it can be enhanced by reducing the liquid nitrogen temperature to about 65 K (0.7 T_c) by pumping on it with a simple rotary pump. Liquid nitrogen is very widely available, being used in tonnage quantities, and the price can be as low as $0.05 per litre; equally important, it can be transported in simple and robust storage containers, and can be handled with little training.

Both helium and nitrogen are inert cryogenic liquids, so that safety precautions are simple; this is in contrast to liquid hydrogen and liquid oxygen (the latter is particularly dangerous).

Although the use of a cryogenic liquid is usually the cheapest and easiest means of cooling, with the new superconductors it is possible to use instead closed-cycle refrigerators that can provide cooling down to 10 or 20 K. These machines require only electrical power, and small ones, with a cooling power of several Watts at 20 K, cost about $10,000.

5. Fabrication of the new superconductors

Although the superconductive properties of the new materials are closely analogous to those of conventional superconductors, the means of making them are very different. Above all, $(La\text{-}Sr)CuO_4$ and $YBa_2Cu_3O_7$ are ceramics, and the whole range of ceramics technology, both traditional and modern, can be applied to them. Fortunately, related compounds such as $LaCuO_4$ and $LaNiO_4$ have been studied extensively over the last 10 years or so; they have been of interest to the oxide chemists, and have found wide application as catalysts in organic chemistry. Also, many of these oxides are oxygen fast-ion conductors, that is, the oxygen ions are sufficiently mobile to contribute quite high ionic conductivities at temperatures of 300 or 400° C.

Thus, the first of the new superconducting materials were made with a simple ceramics "mix, grind and fire" approach, which is readily accessible with only rather limited facilities. Although a couple of trials are usually enough to obtain material that is superconducting, its properties are almost invariably poor. In particular, the critical current density tends to be extremely low. To focus on $YBa_2Cu_3O_7$, a number of materials problems have now become apparent:

(i) The reaction of the mixed oxides of Y, Ba and Cu to form the ternary oxide must be carried out below 950 C, for otherwise the ternary oxide decomposes. At this temperature, all the components are solid, and solid state reactions are notoriously slow. Therefore, the starting materials have to be mixed very thoroughly, preferably on an extremely fine (sub-micron) scale.

(ii) There are several common contaminant phases, such as silica from the grinding process, alumina from crucibles, and so on. There are also phases that may be formed by reaction with atmospheric moisture and/or carbon dioxide that are stable at the firing temperature. Any or all of these phases tend to migrate to grain boundaries, and form electrically-insulating layers.

(iii) The phase that forms at the firing temperature is actually $YBa_2Cu_3O_6$, (the "green phase"), which is semiconducting rather than metallic, and certainly not superconducting. Furthermore, its structure is tetragonal instead of orthorhombic. In order to obtain superconducting material, annealing in oxygen at considerably lower temperatures is required, as illustrated in the phase diagram of figure 4. There is very strong evidence that the occupancy of the oxygen sites shown in figure 3 is crucial to the superconductivity. Both the structural phase transformation and the insertion of oxygen cause the lattice parameters to alter significantly, so that at the boundary between two grains of different crystal orientation, substantial strain develops, perhaps enough to cause microcracks. The phase transformation itself invariably introduces large numbers of twin boundaries; whether these affect superconductivity is not yet established.

(iv) As far as obtaining a good superconductor is concerned, a dense material, free of voids and cracks, is required. On the other hand, in a dense material the insertion of oxygen is limited by the bulk diffusion rate. Although this diffusion rate is relatively high - as mentioned earlier, the materials are fast-ion conductors - the rate does diminish exponentially with temperature. Thus, in order to ensure that the oxygen stoichiometry is as close as possible to 7, it is necessary to anneal below about 400 C for long periods.

(v) There may be a more fundamental limitation associated with grain boundaries and free surfaces: the actual structure, interatomic distances, oxygen stoichiometry, and so on, at a boundary or a surface will be slightly different from those of bulk material. Depending upon the crystallographic orientation of the boundary or surface, the structure change may be enhanced or diminish superconductivity.

(vi) There is the question of the compatibility of the superconductor to other materials, as at the junction to ordinary copper conductor, or at the interface between a thin film and its substrate. This question has both chemical and physical dimensions: Is there a chemical reaction or change in stoichiometry? Does differential thermal expansion cause the superconducting material to crack? Is there good electrical contact between the two materials? Are there electrochemical effects when current is passed from one to the other?

(vii) Finally, there are seemingly mundane, but all-important, questions about the material: Its resistance to atmospheric corrosion, mechanical strength, brittleness, toxicity. and so on.

This list is certainly long, and at first sight a depressing one. However, it is important to appreciate that many of the problems have been encountered before by the ceramicists. In other materials, approaches have been found that overcome these problems, and now a great deal of routine systematic work is being done on $YBa_2Cu_3O_7$, trying out those techniques, and if they do not succeed, exploring new ones.

For fundamental studies of $YBa_2Cu_3O_7$ and $(La-Sr)CuO_4$, single crystals are needed, mm in size or larger. Over the last few months, several laboratories have succeeded in growing such crystals, and rapid improvements have been made in their degree of perfection, measured for example by the temperature and width of the superconducting transition.

When one looks in detail at potential applications,
it becomes apparent that the new materials will be needed in a number of different forms:

(a) Bulk polycrystalline material, with emphasis on clean grain boundaries and high density, and perhaps also with some degree of texturing (preferential alignment of crystallite orientations). The preparative routes that are being investigated here aim at achieving homogeneity on a microscopic scale by chemical or physical means, rather than by mechanical mixing and grinding. They include: Co-precipitation from aqueous or organic solution of Y, Ba and Cu salts, such as nitrates and citrates. Freeze drying of such solutions. Co-decomposition of mixed Y, Ba and Cu organometallics. Mist pyrolysis, in which mixed precursors are sprayed into a hot zone. These techniques aim also at producing the stoichiometric powder mixture in very fine (sub-micron) particles, so that the sintering stage can be accomplished at lower temperatures.

A novel technique has been reported recently by Bell Laboratories, but full details are not yet available. The stoichiometric mixture is heated and cooled extremely rapidly, and produces bulk material that has significantly higher critical current density than that of other bulk materials (figure 8).

(b) Tapes, cables, wires and filaments for use as conductor, probably with a substantial degree of crystallite texturing, and again having clean grain boundaries and high density. Preliminary attempts have been made to fabricate wires using methods analogous to those that have been successful with Nb-Ti and Nb_3Sn superconductors: Bulk $YBa_2Cu_3O_7$ material is crushed, and then packed into a silver tube; the tube is swaged down and annealed in oxygen (to which silver is permeable at high temperatures). Most attempts have produced wire that is superconducting, but with extremely low critical currents; recently, however, Hitachi has reported fabrication of a wire with J_c greater than about 10^8 amps m^{-2}. An approach perhaps better suited to the new materials is to use the proprietary processes that have been developed over many years to make filaments of other ceramics; certainly this route is being attempted, but little information has been published.

(c) Thin films for electronics and devices. Here, the many techniques that have been developed for semiconductors are being tried out: Co-evaporation of the metals and simultaneous oxidation. Sputtering in all its forms. Molecular beam epitaxy. Metal organic chemical vapour deposition. So far, it seems that one of the simplest techniques, laser ablation, works the best. Here, a high-power laser pulse is used to ablate a target of the correct composition, and the ablation products are condensed on a nearby substrate. As with all thin film processes, the subsequent thermal and oxygen annealing of the thin film are crucial. Strontium titanate appears to be the most satisfactory substrate, in that there is less chemical reaction with the film than occurs with quartz or sapphire substrates; however, the cost of strontium titanate, typically \$200 per cm^2, is a major problem.

6. Applications

6.1 Background

Although it is important to remain open to totally new ideas for areas in which the new superconductors may find a use, one should first of all examine those applications where conventional superconductors have been considered, and in some cases, are actually used. Thus, in relation to conventional superconductors, the new materials may extend their range of application, or give enhanced performance, or they may move superconductivity into totally new areas.

In the space of this short article, it is not possible to describe potential applications and their feasibility in more than brief outline; however, some more detailed studies are available (see the bibliography), and as the material parameters become better defined, the economic benefits can be costed more precisely.

Most of the media publicity has been directed at the high current side of potential applications: magnets, generators and motors, transmission cables and so on. However, there is another, electronic, side to superconductivity that has developed with conventional superconductors over the last 20 years, and in which the new materials may well make an earlier contribution.

6.2 Power applications

Here, the superconductive property that is being used is that of being able to carry a high current, often in a high magnetic field, without dissipation. These applications came about only with the advent of the high critical field conventional superconductors such as Nb-Ti and Nb_3Sn nearly 30 years ago. Almost all the commercially available superconductors are manufactured from these two materials, and their performance has been improved considerably over the years. Although there are compounds such as Nb_3Ge that have higher T_cs, the metallurgical difficulties of preparing them in wire or tape form have inhibited their use.

The reader will have noticed from table II that the very high critical fields of the alloy superconductors are more than would be expected from the elemental superconductors by simply scaling with T_c; the reason is that something rather different is happening in these materials when a field is applied, compared with an elemental superconductor like Pb. When a magnetic field is applied to a superconductor (figure 5a), the magnetic flux is unable to penetrate the material because, as required by Faraday's Law of Electromagnetic Induction, screening currents are set up in a surface layer that exclude it. This flux exclusion is analogous to the skin effect in ordinary conductors, where alternating magnetic fields and currents are confined to the surface layer for the same reason; however, in an ordinary conductor, the finite resistance causes the eddy currents to decay with time, so that steady currents and fields do eventually penetrate uniformly. In a superconductor, the eddy currents, usually called screening currents in this context, persist indefinitely.

There is one further subtle aspect of a superconductor: if the magnetic field were to be applied before the material was cooled into its superconducting state (figure 5b), and the flux had penetrated fully, the eddy current argument would suggest that the flux would be stuck there when the material became superconducting. In fact, on going through the superconducting transition, the magnetic flux is expelled. In practice this flux expulsion, which is known as the Meissner effect, is never total, because invariably the sample contains some defects that trap, or "pin", the flux lines. However, observation of at least a partial Meissner effect is an important diagnostic test of true superconductivity.

Most elemental superconductors exclude magnetic flux from their interior until the applied field exceeds the critical field B_c; equally, they show a more or less complete Meissner effect up to this field. These are known as Type I superconductors. However, the technically useful Type II superconductors behave rather differently (figure 6): at the lower critical field B_{c1}, magnetic flux begins to penetrate the material to form a mixed state; it is only at a substantially higher field, the upper critical field B_{c2}, that reversion to the normal state is complete. Because exclusion of magnetic flux costs magnetostatic energy (the flux lines can be thought of as being elastic, and as figure 5 shows, flux exclusion requires the flux lines to be stretched), the mixed state reduces this cost, and thereby allows a Type II material to retain its superconductivity to much higher applied fields. It has been well-established that both $(La-Sr)CuO_4$ and $YBa_2Cu_3O_7$ are extreme Type II superconductors, where the ratio of upper to lower critical fields is huge, 10^3 or more.

There are two important consequences to the penetration of magnetic flux inside the technically useful materials:

(i) When a current is carried, there is the usual Lorentz force between it and the magnetic flux, as shown in figure 7. This force acts on the flux lines (in a direction perpendicular to both field and current), and, unless pinned, the flux lines move. This process is known as flux creep. Moving flux, by Faraday's Law of Induction, sets up a voltage which appears along the length of the conductor, and so introduces Joule heating. Flux pinning is strongest at low temperatures, and flux moves much more easily as the temperature approaches T_c, causing J_c to drop sharply. It is this effect which is probably responsible for the poor performance of $YBa_2Cu_3O_7$ conductors at 77 K (figure 8).

A great deal of materials development effort has gone into the conventional superconductors Nb-Ti and Nb_3Sn so as to maximize the density of pinning centres for the flux, and thereby increase J_c. Useful pinning centres include fine-scale precipitates of other phases, grain boundaries, dislocation tangles, etc. The success of this work in improving the critical current density as a function of magnetic field is indicated in figure 8. The new materials are being improved rapidly too, but there is still an enormous amount to be done before usable, reliable conductors are available. In particular, no specific flux pinning centres have yet been identified.

(ii) For most power applications, AC operation is greatly to be preferred to DC. Consider a Type II conductor, in the case that the only magnetic field is the self-field (figure 9); every half-cycle, the direction of the current, and therefore of the associated field, reverses. The magnetic flux penetrates the material (because the self-field is well above B_{c1}), but is partially pinned, and this again leads to dissipation. These AC losses have been a major barrier to the use of conventional superconductors for AC purposes; some success has been obtained with cables composed of thousands of ultra-fine filaments of micron diameter, and a similar approach will be needed with the new materials.

Let us then look at a range of applications, progressing from those that are technically least stringent, for example low current and low applied field, to those that are most demanding:

6.2.1 Flux transformers

All conventional transformers work only at AC; however, there are circumstances where DC transformers are useful, transforming signal rather than power, as indicated in figure 10. Both current levels and applied magnetic fields are extremely low, milliAmps and milliTesla or less. Signal transformers of this kind wound from conventional superconducting wires have been used extensively with SQUID sensors (see 6.3.3); reliable flux transformers made from $YBa_2Cu_3O_7$ should soon be available, and could extend the usefulness of the SQUID sensors themselves.

6.2.2 Magnetic shielding

It is sometimes important to contain the stray magnetic field of large-scale magnetic machinery; for example, in hospitals the stray fields of MRI scanners (see 6.2.5) can be a problem. The usual solution is to surround the magnetic source with sheets of soft iron, but the sheer weight of the iron is a difficulty. The idea of using thick films of the new superconductor, perhaps plasma sprayed, as a magnetic shield, is an attractive one particularly if the magnetic source already has some cryogenic cooling associated with it. The shielding is then provided by the (persistent) screening currents in the superconductor described earlier. The converse problem, of preventing stray fields entering, is also of laboratory and medical interest (see 6.3.3); helium-cooled superconducting lead shields have quite often been used in laboratory work, and are extremely effective. For these shielding applications, the applied fields are always rather low; the current densities obviously depend upon the magnitude of the field to be screened and the thickness of superconducting film. Thick films, perhaps on the order of 1 mm, might be needed.

6.2.3 Superconducting interconnects

In high-speed digital devices, as used in very fast computers, the propogation delay along the conductors between chips is beginning to become important. As gallium arsenide devices, which are several times faster than silicon, come into use (largely for military applications, where the substantial additional cost is not an inhibitory factor), this delay becomes more significant. In principle, some gain can be achieved with superconducting interconnects, and the prospect of cooling the entire board to liquid nitrogen temperatures is quite an attractive one, as many semiconductor devices perform better at those temperatures. As far as the superconductor is concerned, the applied fields are negligibly small, but the current densities as used at present with copper interconnects are rather high, up to 10^9 Amps m^{-2}. The problems here are likely to those associated with microcircuit processing and compatibility between materials, rather than the superconductor itself. It has to be borne in mind also that, if a cryogenic approach is envisaged, the use of ordinary copper conductor at 77 K gives a substantial gain anyway (figure 1).

6.2.4 High-power cables

Detailed studies were made in the 1960s and 1970s of the economics of underground superconducting cables, and prototype cables were constructed. The cost advantage that has to be considered is that over underground copper cables, possibly cooled with liquid nitrogen to reduce their resistivity (figure 1). With conventional superconductors, some cost advantages were visible for cables of very high power, thousands of MVA, as might be used in the most densely industrialized regions. For superconductors to be of interest, current densities of about 10^9 Amps m^{-2} are needed, and the magnetic fields are very modest, being just the self-field. Perhaps because of uncertainties about reliability, particularly under fault conditions, no superconducting cable has ever been put into service. Given that the cost advantage is likely to be no more than marginal, that the range of application is limited, and that reliability is a prime factor in electrical distribution systems, the widespread incorporation of the new superconductors into electrical transmission would seem to be a long way off.

6.2.5 Generators and motors

A large number of motor and generator configurations, both AC and DC, have been considered for incorporation of (conventional) superconducting windings, almost always in a manner to diminish the AC currents and fields in the superconductor itself. A large (2 MW) low-speed DC motor was constructed in the 1960s, and various prototype generators have been, and are being built. The elimination of resistive losses contributes only a small economic gain; the indirect advantages of the use of the superconductor, such as the greater compactness of the machine, and consequent savings in construction and infrastructure costs, appear to be the more important. A great deal more needs to be known about the new materials before the prospects for their use in these machines can be assessed reliably.

6.2.6 Magnets

It is convenient to divide consideration of magnets into low and high precision, where the precision refers to how tightly the field must be controlled. For low fields (≲ 1 tesla) the competition is with iron-cored electromagnets; for higher fields and large volumes, it is with water-cooled solenoids. The Joule heating in a solenoid of interior volume V m^3 (internal cross-section times length) wound from copper conductor and generating a field B Tesla is of order $10^4 B^2 V$ Watts; not only must this electrical power be paid for, but it must be removed efficiently from all parts of the winding so as to prevent runaway overheating.

Low-precision magnets. Magnetic separation is a widely dispersed industrial technique, used to clean magnetic impurities from other minerals (e.g., rare earth contaminants from china clays, pyrites from coal), and more sophisticated extensions have been considered, for example to separation of red cells (which are weakly magnetic because of the iron they contain) from blood. Prototype machines using conventional superconductors have been built, and it would seem likely that this is an area where the new materials could make an early impact, once good wire or tape conductor becomes available. The advantages of simplified cooling would make it much easier to site magnetic separators close to production sites.

High-precision magnets. It is in this area that the advent of Nb-Ti and Nb_3Sn superconductors has made its mark. In research laboratories, steady fields above 1 tesla are now almost always obtained using helium-cooled superconducting solenoids, which are available for fields up to 15 tesla, and an internal bore of 100 mm or more. At these high fields, an iron core makes almost no contribution to the field, and is never used. Note that a 15 tesla copper solenoid of 100 mm bore would consume electrical power of order 1 MW, and so would require also a major investment in the cooling circuit (pumps, filters, deionisers, etc.). Furthermore, in a solenoid the winding can be tailored to provide a very exacting specification on the field profile, for example uniformity to 1 part per million or better over small regions, which is needed for the nuclear magnetic resonance (NMR) magnets used in chemical and biochemical research. Frequently, these laboratory superconducting magnets are used in persistent mode (figure 11) by short-circuiting the winding with a superconducting switch; this mode of operation not only saves on cooling (because it eliminates the Joule heating in the current leads, and indeed enables these leads, which conduct substantial amounts of heat into the cryogenic fluid, to be physically withdrawn), but it provides a field of great stability, far greater than is attainable with a current supply.

The greatest commercial impact of these superconducting magnets has been in the medical field, where solenoids of very large volume, up to 1 m bore, and 1 to 2 tesla field are used in whole-body nuclear magnetic resonance scanners, now known as Magnetic Resonance Imaging (MRI) scanners; well over a thousand scanners have been built world-wide. The other large-scale application has been to magnets for particle accelerators, where provision for some superconducting magnets has been included in machines that are now being built.

In most of these applications, where the magnets are being used in a sophisticated and complex environment, the advantages of liquid nitrogen cooling over that with liquid helium are marginal, so that $YBa_2Cu_3O_7$ will not easily replace Nb-Ti and Nb_3Sn. The higher critical field of the new materials suggest that they could be useful above the 15 tesla available with conventional superconducting magnets. However, at these high fields the Lorentz force between the field and the current-carrying conductor becomes very large, so that the mechanical strength of the superconductor becomes the limiting factor. So far, the mechanical behaviour of the new superconductors is poor, and limits severely their possible application.

This discussion is intended to be illustrative of the problems that arise with applying superconductors, and of the likely impact of the new materials, rather than to be exhaustive. Other applications that are being assessed include: large-scale energy storage systems, levitation magnets for trains, power transformers, fault current limiters in electrical distribution systems, and magnets for compact X-ray synchrotrons. The reader is referred to the relevant papers listed in the bibliography for further information.

6.3 Electronic and quantum aspects of superconductivity and their application

As we shall discuss in section 7, superconductivity is more than simply the absence of electrical resistivity. Other facets of superconductivity have led to the development of several families of devices.

6.3.1 Giaever junctions

To a limited degree, superconductors resemble semiconductors, in that their electron energy spectrum contains an energy gap Δ; the size of the gap is related to the superconducting transition temperature T_c by the relationship $2e\Delta = \kappa k_B T_c$, where e is the electronic charge, K_B is Boltzmann's constant, and κ is a number equal to about 4 for the conventional superconductors, and perhaps as large as 8 for the new materials. Thus, junctions between a superconductor and a normal metal, or between two pieces of superconductor, separated by a thin layer (a couple of nm) of insulator, show highly non-linear voltage-current characteristics (figure 12a). With conventional superconductors, these Giaever junctions have been known for nearly 30 years. For example, a Nb to Nb junction, with a T_c of 9 K, has a gap of 3×10^{-3} eV (electron Volts), which corresponds in terms of photon energy to frequencies on the order to 500 GHz. Consequently, the non-linear characteristic of these junctions can be used for detection and mixing of microwaves up to similar frequencies, that is, to wavelengths of 1 mm or less. Where low noise is at a premium, as in radio astronomy, these junctions have been much used.

A Giaever junction based on $YBa_2Cu_3O_7$ should, because of the much larger energy gap, be usable to frequencies on the order of 10 THz, or wavelengths of 100 μm or less, i.e. the far-infra-red region of the spectrum. The applications would be in radio-astronomy, and, to a far larger extent, in military communications, sensors, etc. Whether a useful Giaever junction can be manufactured from the new materials is still unknown.

6.3.2 Josephson junctions

One of the most remarkable features of superconductivity is that, as Josephson predicted in 1962 (work for which he was later awarded a Nobel Prize), a supercurrent can flow through the insulator of a superconductor-superconductor Giaever junction (figure 12a), although the magnitude of the critical current is very small, typically μAmps. Similar behaviour is observed if the two pieces of superconductor are connected through a narrow bridge, a micron or less in width, of superconductor. One important application uses the possibility of feeding a Josephson junction with a constant current, and switching it from the zero voltage state to the dissipative state. With conventional superconductors, this switching can be very fast and involve low power dissipation. On this basis, during the 1970s IBM developed a superconducting computer, although it was abandoned a few years ago because of the difficulty of ensuring reliability of vast numbers of junctions. Crude Josephson junctions have been made with the new materials, but because of fabrication difficulties and other more fundamental reasons, it seems unlikely that they will be used in logic devices for a long time to come.

When a Josephson junction is irradiated with electromagnetic radiation of frequency ν, the voltage-current characteristic develops structure (figure 12b) at voltage intervals δV given precisely by the Josephson relationship $h\nu = n\,2e\delta V$, where n is Planck's constant and n is an integer; numerically, the relationship corresponds to 484 MHz irradiation giving structure at 1μ Volt intervals. Because frequencies are easy to measure with high precision, this AC Josephson effect is now utilized in many national standards laboratories to provide a voltage standard. Given some development of junction fabrication with $YBa_2Cu_3O_7$, we can anticipate that such voltage standards will become rather more widely available and portable; however, there seems to be little need for them ever to become commonplace.

6.3.3 Superconducting Quantum Interference Devices - SQUIDs

One further feature of superconductivity that reflects its quantum nature is that a ring of superconductor threaded by magnetic flux forces that flux to be quantised (magnetic flux is field times area, or more strictly, the integral of the field over the area) in units of h/2e, which is equivalent to 2.07×10^{-15} Weber. The Earth's magnetic field is about 10^{-4} tesla, so that the flux quantum corresponds to the earth's field through a loop of area 2×10^{-11} m^2, or say 5 μm in diameter. Superconducting devices, SQUIDs, have been developed over the last 20 years, mostly using niobium as the superconductor, that allow this quantization to be used in measurement (figure 13). In principle, SQUIDs could be used to monitor the ambient magnetic field, but in practice they are constructed inside a magnetic shield, and the signal is fed into a small coil that alters the magnetic flux seen by the superconducting ring. SQUIDs can be used to monitor minute changes in magnetic field, electrical current, voltages, etc. For 15 or more years, SQUIDs have been available commercially, and now cost, complete with the associated electronics, $5,000 to $10,000.

Areas in which SQUID sensors have found application include: Ultrasensitive laboratory measurements of electrical and magnetic properties. Geomagnetic surveying for minerals, archeological searches, and (by the military) submarine detection. One rapidly developing field is biomagnetism, where the magnetic fields associated with muscular and nervous activity are extremely small, but large enough to be monitored using SQUIDs (figure 14). This technique complements the monitoring of physiological electric fields, as in an electrocardiogram (ECG) or in an electroencephalogram (EEG), by providing a magnetocardiogram (MCG) or a magnetoencephalogram (MEG), and may be particularly useful for certain kinds of neurological disorder, such as epilepsy.

SQUID devices utilizing the new superconductors and operating at liquid nitrogen temperatures have already been demonstrated, and several groups are attempting to produce reliable SQUIDs using thin film techniques. Here again, the outstanding problems are material ones. Because of the higher operating temperature, $YBa_2Cu_3O_7$ SQUIDs have a noise level significantly greater than that of SQUIDs constructed from conventional superconductors, but they are of course still extremely sensitive. The main advantages of liquid nitrogen temperature operation are those of portability, so one can forsee that a rapid expansion in the use of SQUIDs for magnetic surveying. In sophisticated medical applications, such as magnetoencephalography, sensitivity really is at a premium (figure 14) and the additional cost of liquid helium is a less important factor, so that ceramic SQUIDs may not be useful here. However, hybrid systems with a $YBa_2Cu_3O_7$ flux transformer (see 6.2.1) having one end at 77 K, and the other end coupled into a niobium SQUID at 4 K may have advantages: the relaxed cooling constraints at 77 K mean a much smaller thickness of thermal shielding, and by allowing a closer approach to the magnetic source, help to locate its position more precisely. In almost all situations where SQUIDs are used, their extreme sensitivity to magnetic fields requires that they be carefully screened from ambient field fluctuations (which arise from power lines, electrical machinery, passing vehicles, etc., and typically have magnitude 10^{-7} Tesla). Magnetic screening with superconductors, as described in 6.2.2, is often used, and the new materials could play a role here.

7. Superconductors, past, present and future

Are we about to see room temperature superconductors? Obviously, if we were to do so, the economic implications would be enormous. However, a T_c of 300 K would be insufficient, because to obtain reasonable performance, the operating temperature should be no more than about 0.7 T_c (see section 4); thus for room temperature applications, a T_c above about 400 K would be required. We discuss here what is known about the mechanism of superconductors and what limits the transition temperature T_c.

It took more than 40 years from the discovery of superconductivity to understand it at a microscopic level. It became clear gradually that the superconducting state is a distinct phase in the true thermodynamic sense (as solids, liquids and gases are distinct phases), and that the conduction electrons that carry the electrical current in a normal metal condense into a more ordered state in the superconductor. The ability of the conduction electrons to move through the crystal lattice without dissipation is a reflection of their ordered state.

The effect of temperature is always to cause disorder, and when the thermal fluctuations are large enough, there is a phase transition from the more ordered state, e.g. a solid, to a less ordered one, e.g. a liquid. The stronger the bonding in the ordered state, the higher the temperature of the transition. Thus strongly bonded solids, such as diamond, melt at much higher temperatures than weakly bonded materials, such as ice. In the case of a conventional superconductor, the "glue" that keeps the conduction electrons together in the superconducting state is an interaction between those electrons and the vibrations of the atoms in the crystal. This is the electron-phonon interaction of the Bardeen-Cooper-Schrieffer (generally abbreviated to BCS) theory of 1957, and is the same interaction that is responsible for the resistivity of a metal at ambient temperatures; hence the correlation (see section 2) between high resistivity at room temperature and a high superconducting transition temperature. One of the vital pieces of direct evidence that pointed to the involvement of atomic vibrations in conventional superconductivity was the isotope effect: In general, different isotopes do have almost identical chemical and physical properties; however, it was discovered 40 years ago that the superconducting transition temperatures <u>do</u> depend on isotopic mass M_{ion}. For a given element, separated isotopes have T_cs that scale as $\sqrt{M_{ion}}$.

The electronic structure of normal metals is now understood in great detail, as is the nature of the lattice vibrations, and also the basis of the electron-phonon interaction. Thus, in principle, and to a large degree in practice, the superconducting T_c can be calculated for an element or a compound with a fair degree of accuracy. Conversely, the question can be posed, and answered, of what is the maximum attainable T_c with the BCS electron-phonon mechanism; the answer seems to be not much above 30 K. Thus the discovery by Bednorz and Müller of superconductivity at 35 K in $(La-Sr)CuO_4$ raised the question immediately of whether the same mechanism was at work as in conventional superconductors; the transition temperature of 92 K in $YBa_2Cu_3O_7$ gave even greater stimulus to the search for other mechanisms. However, the structure of these oxides (figure 3) suggests that the conduction electrons are concentrated around the Cu-O bonds, so that there might be an exceptionally large electron-phonon coupling involving the vibrations of the O atoms (at any given temperature, the lighter the atom the larger the amplitude of vibration; in both (La-Sr)CuO_4 and $YBa_2Cu_3O_7$, the O atoms are four times lighter than the next heaviest atoms). Thus, a more direct test of the relevance of the electron-phonon mechanism was provided by a search for the isotope effect in the new materials. It turns out that when ^{18}O is substituted for ^{16}O in (La-Sr)CuO_4, T_c is lowered, but three or four times less than would be predicted by the BCS theory. In $YBa_2Cu_3O_7$, the effect is proportionately even smaller. The present situation therefore is that most physicists believe that some mechanism other than the BCS interaction has to have the prime responsibility for superconductivity in the new materials, perhaps one involving electron-electron interactions of the kind that in many metal oxides are responsible for producing magnetic ordering. Certainly, the chemistry of the new materials is important, and a number of suggestions have been made as to why it is that copper oxides are the crucial component.

The search for materials with yet higher T_cs has been going on for a year or so; some of it totally empirical, and at the lowest level consisting of no more than preparing hundreds of mixtures of metal oxides. Other work is better focused, looking perhaps for oxides where the oxygen environment of the copper has some particular configuration, or following some other line of reasoning.

What about the reports of higher transition temperatures? They are too numerous and too well documented to be simply dismissed. However, all the reports share several features: The transition that is observed refers almost always to a sudden drop in resistance, but because the measuring currents are small (otherwise the phenomena disappear), the resistivity could still be quite large. No laboratory has reported observation of a true Meissner effect (see 6.2), which is the acid test of superconductivity, at any temperature above about 95 K. The effects tend to be transient, lasting only for a few hours or days, and are difficult to reproduce even within a batch of samples. In general, the samples that show these effects are of rather poor quality, perhaps deviating from the intended composition or containing contaminant phases. Thus, there is no evidence so far of true, bulk, superconductivity at any higher temperature than about 95 K. Perhaps what has been observed is associated with grain boundaries or with other phases, with a transition in that material from a resistive state to one of much lower resistivity, but which is not necessarily superconducting.

Because we do not yet have any microscopic theory of superconductivity in the new materials that is totally convincing, there are no clear signposts of the avenues that should be explored. We can be almost sure that in 1986 Bednorz and Müller did indeed discover an example of a new mechanism of superconductivity; within a matter of weeks only, and without any substantial clues to the mechanism involved, T_c had been raised to 92 K. It would indeed be unkind of Nature, but not impossible, if this were to be the highest transition temperature that will ever be.

Of course, we cannot preclude the possibility that yet another new class of superconductors will be discovered with even higher T_cs; but unless that happens, almost all the scientific effort will be devoted toward understanding the materials we now have, and to the slow, unglamorous, process of learning how to make them into useful conductors and devices.

8. Conclusions

The new oxide superconductors $YBa_2Cu_3O_7$ and (La-Sr)CuO_4 do represent a major leap forward for the science of superconductivity. It is one that is not well understood microscopically, and that lack of understanding perhaps inhibits the development of superconductors with transition temperatures significantly above 90 K.

The scope for applications of the newly discovered materials is constrained by the difficulties of making them in suitable form. Certainly, the earliest applications will be to relatively simple devices that do not need to carry large currents. Whether the oxide superconductors will ever be used to replace conventional conductors or superconductors in electrical machines, magnets and so on, is a question that awaits the solution of major problems in materials preparation

Bibliography

The background to superconductivity and elementary accounts of conventional superconductors are given in the standard introductory textbooks on solid state physics, for example, any of the recent editions of:

C. Kittel — *Introduction to Solid State Physics*, John Wiley; New York.

More detailed discussions are provided in a number of graduate-level texts, including:

M. Tinkham — *Introduction to Superconductivity*, McGraw-Hill; New York (1975).

D.R. Tilley & J. Tilley — *Superfluidity and Superconductivity*, Adam Hilger; Bristol (1986).

A highly readable and concise survey of superconductivity in relation to the new materials is:

P. Campbell — *A superconductivity primer*, *Nature*, 330, 21-24 (1987).

The British journal *Nature* and the US journal *Science* have both followed developments closely, and because they are published weekly, they provide up-to-date and informed news in their editorial pages. They publish also some reports of research conferences, and a number of technical papers of more general interest.

More than a thousand scientific papers have already been published on the new superconductors, in journals such as *Physical Review Letters*, *Physical Review B*, *Japanese Journal of Physics*, *Zeitschrift für Physik*, *Journal de Physique*, *Journal of Physics C & F*, *Solid State Communications*.

Recent conference proceedings that contain large numbers of relevant papers include:

Proceedings of the 18th International Conference on Low Temperature Physics, published as a supplement to *Japanese Journal of Applied Physics* 26 (1987).

Novel Superconductors, ed. S.A. Wolf & V.Z. Kresin. Plenum Press: New York, 1987.

As far as applications are concerned, a number of reports have been written in recent months, primarily directed at power engineering aspects. Naturally, as the available materials improve, or difficulties emerge, their conclusions will need to be reconsidered.

F. Schauer, F.P. Jüngst, P. Komarek and W. Maurer — *Assessment of Potential Advantages of High T_c-Superconductors for Technical Application of Superconductivity*. Kernförschungs Karlsrühe (W. Germany) Report No. KfK 4308 (September 1987).

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Table I

Common cryogenic gases

Gas	Boiling point (at 1 atmosphere) C	K
Helium	-269	4.2
Hydrogen	-253	20
Nitrogen	-196	77
Oxygen	-183	90

Table II

Typical superconductors

	T_c K	B_c Tesla
Metallic elements		
W	0.012	1×10^{-4}
Zn	0.88	5.3×10^{-3}
Al	1.18	1.0×10^{-2}
Sn	3.72	3.1×10^{-2}
Hg	4.15	4.1×10^{-2}
Pb	7.2	8.0×10^{-2}
Nb	9.2	2.0×10^{-1}
Alloys and intermetallic compounds		
Nb-Ti	9	14
Nb_3Sn	18	24
Nb_3Ge	23	38
Metal oxides		
$Ba(Pb-Bi)O_3$	13	5
$(La-Sr)CuO_4$	35	50?
$YBa_2Cu_3O_7$	92	100?

The listed critical field is the maximum field, for $T \ll T_c$, at which superconductivity is sustained. In Type II superconductors, it is the upper critical field B_{c2}.

Figure captions

Figure 1. The electrical resistivity of copper below room temperature (300 K). Note that at liquid nitrogen temperatures (77 K), the resistivity has fallen by a factor of about 8. At the lowest temperatures, the residual resistivity ρ_{resid} is controlled by the level of impurities; in commercial high-purity copper it is less than the room temperature value by a factor of typically 100. Other pure metals such as aluminium, zinc, silver, etc. behave similarly.

Figure 2. The superconducting transition in lead. Notice that the difference between a relatively pure sample (a) and an impure one (b) is in the magnitude of ρ_{resid}; the impurities do not contribute any resistivity in the superconducting state, although they may affect the transition temperature.

Figure 3. The crystal structure of the oxide superconductor $YBa_2Cu_3O_7$. The material loses oxygen preferentially from the arrowed sites when heated above about 400 C. Material that has less than about 6.5 atoms of oxygen per formula unit never becomes superconducting.

Figure 4. The oxygen stoichiometry x of $YBa_2Cu_3O_x$ as a function of temperature; the data presented are for 1 atmosphere oxygen pressure. Notice that at typical sintering temperatures of 800° C or more, the material is in its tetragonal form, and is highly deficient in oxygen.

Figure 5. (a) A superconductor (shaded) excludes flux when a magnetic field is applied, as would a perfect conductor, but also (b) a material that is cooled in a magnetic field and then becomes superconducting, expels flux, which a perfect conductor would not do. This flux expulsion from a superconductor is known as the Meissner effect, and is a key test of true superconductivity.

Figure 6. Type II superconductors show a more complicated behaviour in a magnetic field. At low fields, they exclude flux, as do the Type I superconductors of figure 5. However, above the lower critical field B_{c1}, flux starts to penetrate; this mixed state persists to the upper critical field B_{c2}, where superconductivity is destroyed. In the commercially useful conventional superconductors, such as Nb-Ti and Nb_3Sn, B_{c2} is about 100 times greater than B_{c1}.

Figure 7. Current J flowing through a Type II superconductor in a magnetic field B. There is a Lorentz force F on the flux lines, and if they move, energy is dissipated.

Figure 8. Critical current densities J_c in $YBa_2Cu_3O_7$ in different forms. At 4 K, J_c is extremely high in single crystals and thin films, but at 77 K J_c in bulk material is much smaller, and drops rapidly with applied field. The best materials reported so far are those from Bell and Hitachi. For comparison, the performance of the conventional superconductors Nb-Ti and Nb_3Sn at 4 K is shown, and also that of ordinary copper conductor at room temperature.

Figure 9. Magnetic flux inside a Type II superconductor carrying an AC current. Flux motion again leads to dissipation.

Figure 10. Schematic superconducting flux transformer. Changes in field in the primary induce a persistent current which alters the field in the secondary. The primary and secondary can be well separated, and their areas and number of turns optimized to suit the specific application.

Figure 11. Superconducting magnets are often equipped with superconducting switches. To energize the magnet, the short-circuit is heated above its superconducting transition temperature, so that current from the power supply passes through the magnet winding. When the required current has been reached, which may be 100 Amps or more, the short circuit is allowed to cool and become superconducting. The current then circulates through an entirely superconducting circuit, and the power supply can be disconnected; furthermore, the copper leads (which conduct a lot of heat into the cryogen) can be physically removed, so as to cut cryogenic losses.

Figure 12. (a) The current-voltage characteristic of a junction between two pieces of superconductor, separated by a thin layer of insulating oxide. At zero voltage, a small supercurrent can flow. (b) When the junction is irradiated with microwaves, steps appear at regular and very precisely known voltage intervals δV; this phenomenon is now used as the basis of national voltage standards.

Figure 13. Principle of a SQUID. The niobium ring with its junction responds in a periodic fashion to the magnetic flux coupled to it by the signal coil. The flux period is only 2.07×10^{-15} Webers, making the

device extremely sensitive. The magnetic shield protects the SQUID from extraneous magnetic disturbances.

Figure 14. The magnitudes of physiological magnetic fields. Notice that they are much smaller than typical ambient fluctuations, and cannot be seen by even the most sensitive non-superconducting device, which is a flux-gate magnetometer.

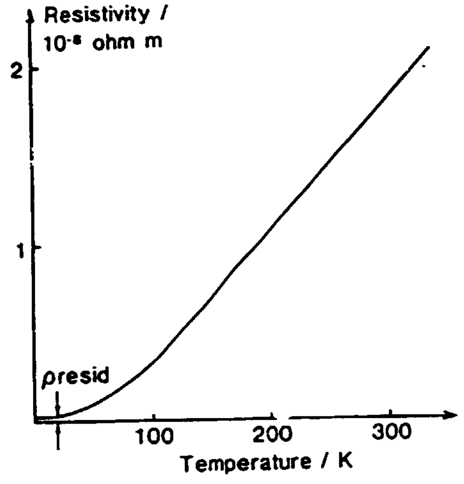


FIGURE 1

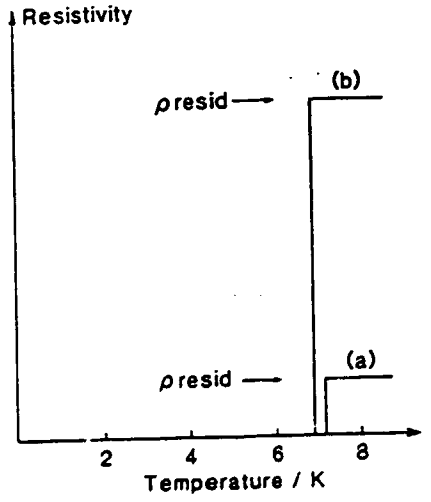


FIGURE 2

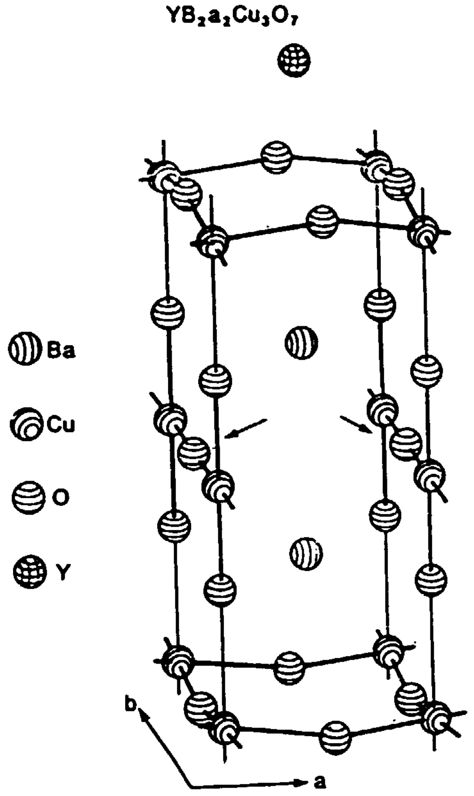


FIGURE 3

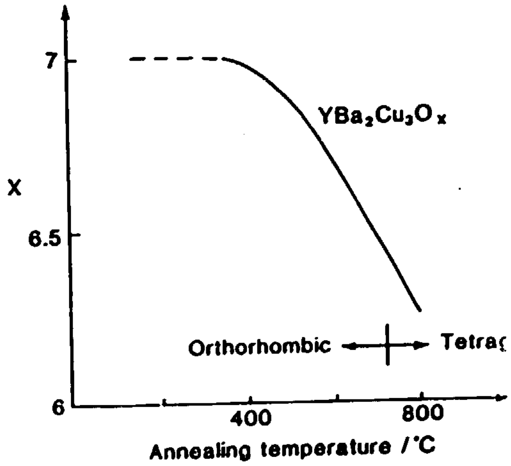


FIGURE 4

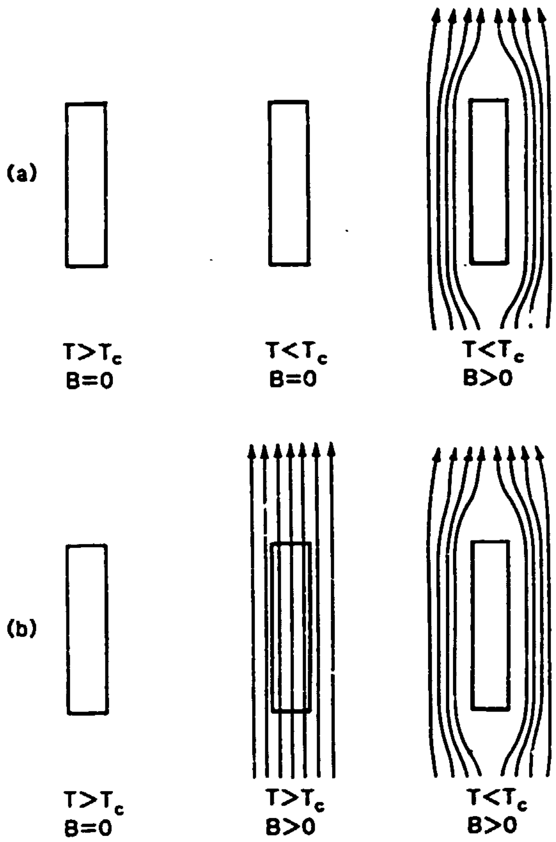


FIGURE 5

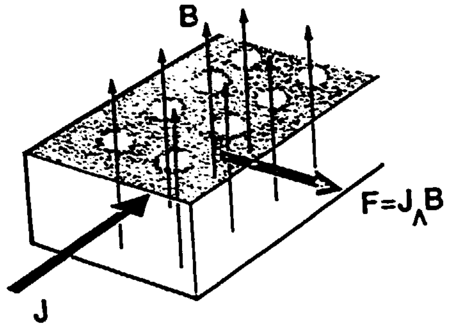
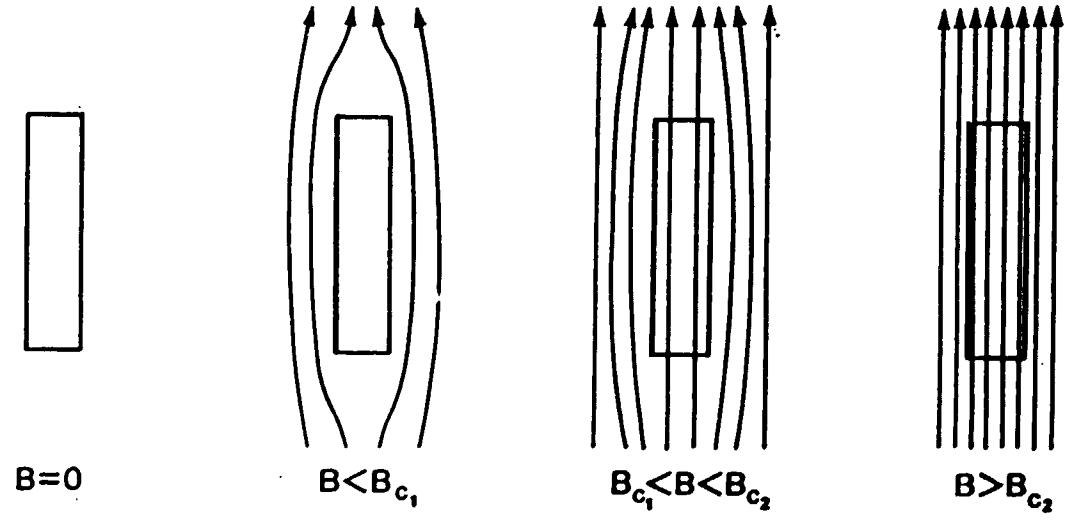


FIGURE 7



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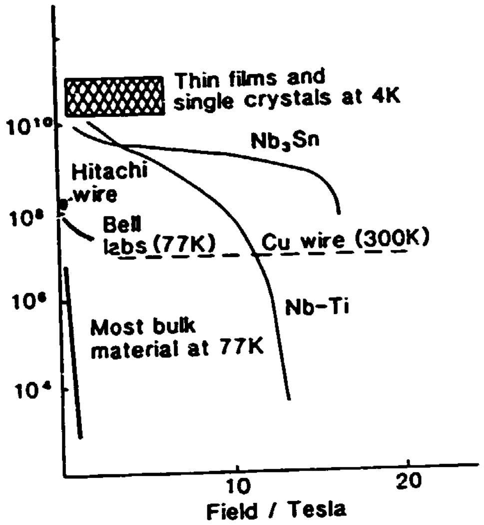

FIGURE 8

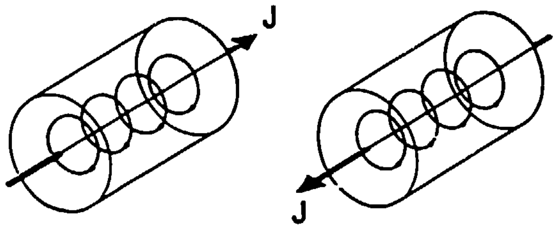

FIGURE 9

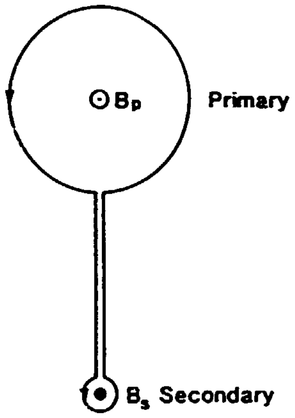

FIGURE 10

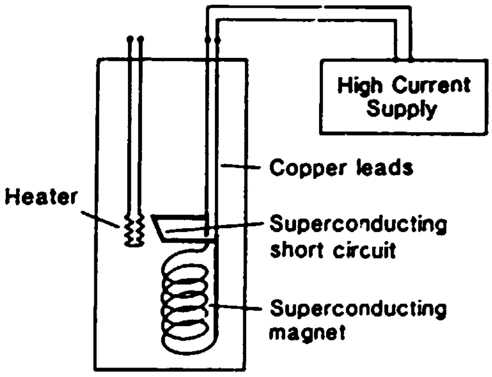

FIGURE 11

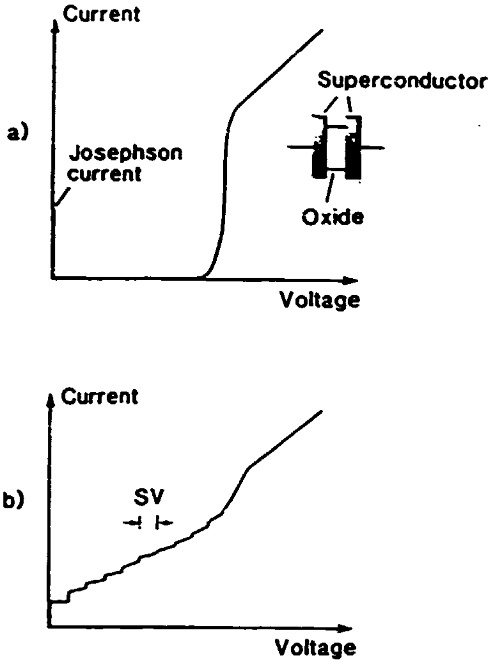

FIGURE 12

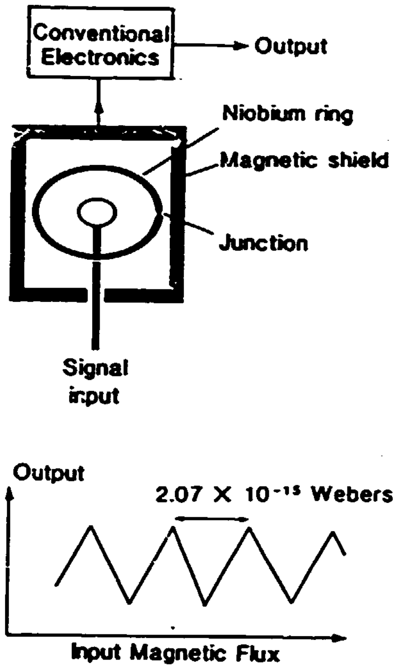

FIGURE 13

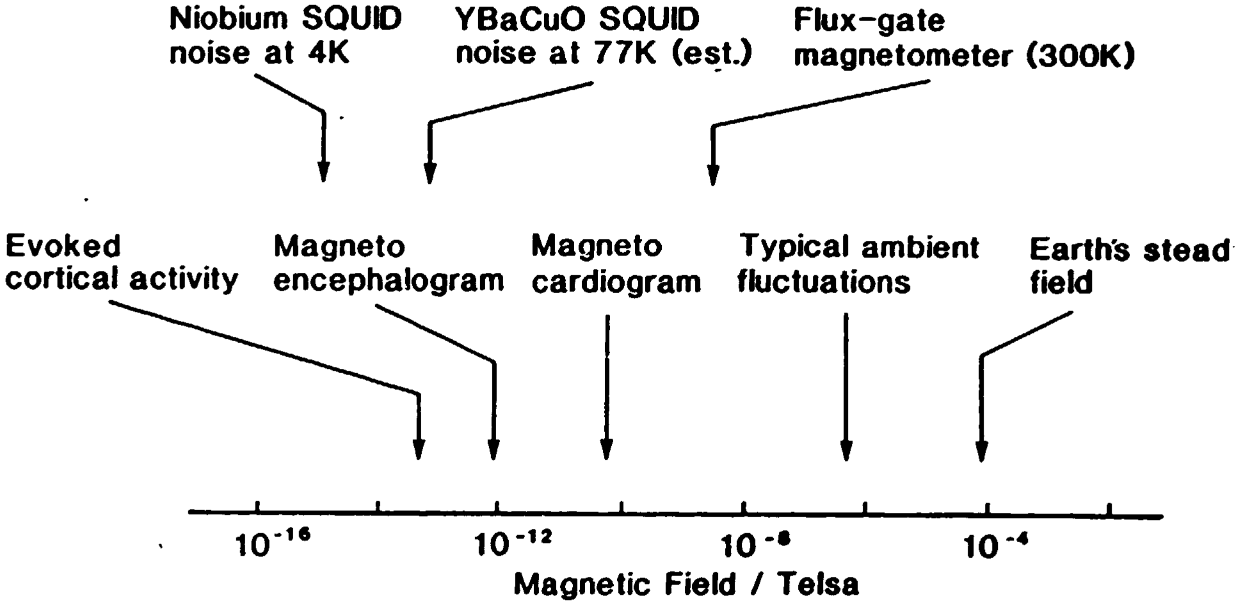

FIGURE 14

* * * * *

2. THE DISCOVERY OF A CLASS OF HIGH-TEMPERATURE SUPERCONDUCTORS

K. Alex Müller and J. Georg Bednorz*

The exceptional interest in the new class of oxide superconductors and the importance of these materials are discussed together with the concepts that led to their discovery. The discovery itself and its early confirmation are summarized, including the work until the beginning of 1987. The observation of a superconductive glass state in percolative samples is also discussed.

High transition temperature superconductivity in the Ba-La-Cu oxide system (1) was discovered by Bednorz and Müller at the IBM Zurich Research Laboratory and confirmed in early fall of 1986 (2). For this reason we were asked to review the progress for this special issue on "Science in Europe." Since this invitation, the work and interest in the field have been exceptional. Figure 1 shows the progression of the superconducting transition temperatures (T_c) from the discovery of the phenomenon in mercury by H. K. Onnes in 1911 (3) until February 1987. One notices a more or less linear increase in maximal T_cs until the 75th anniversary of the discovery. This led to the expectation of T_cs near 30 K in 1990. However, in the year of the anniversary this trend changed. By the beginning of 1987, T_cs had risen to 48 K for the original compound and its isomorphs (4). At the beginning of February 1987, the confirmed T_cs were over 90 K in a Ba-Y-Cu oxide found by Chu and collaborators (5) and nearly, but not simultaneously at Bellcore and the Academy in Beijing (6). Looking at figure 1, one notices the following: practically all of the high-T_c materials discovered until 1986 are cubic niobium compounds, and the new superconductors are layer-like copper oxides (2, 7), which form a new class per se. The exceptional interest is due to four factors: (i) these oxides are easy to fabricate, in contrast to the highly refractory niobates, and thus can be investigated at smaller laboratories and universities; (ii) their T_cs are very high, and so are their critical magnetic fields, H_{c2}, with estimates in the megagauss (8) range; (iii) they represent a considerable challenge to theoreticians, and various models have already been proposed; and (iv) they are of considerable technological importance, because in addition to the known applications (9) summarized in figure 2, they may allow cheap energy transport.

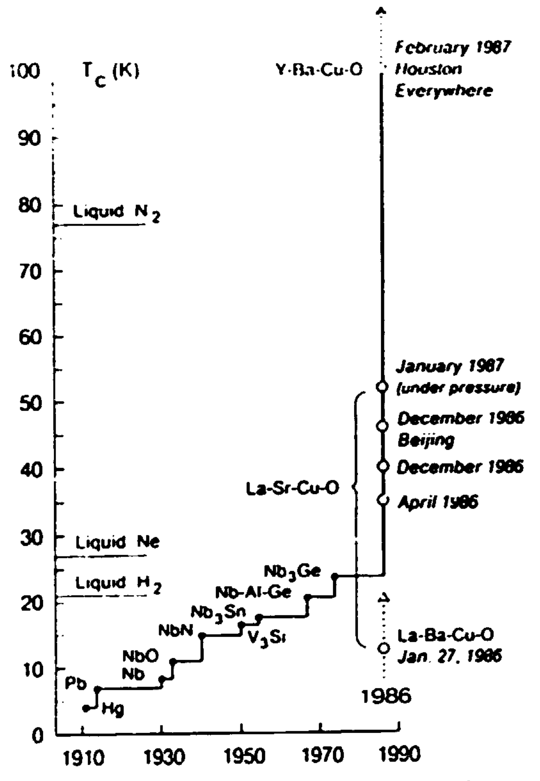

Fig. 1. Evolution of the superconductive transition temperature subsequent to the discovery of the phenomenon

Owing to the large number of papers already submitted, nearing 100, it is not possible to review all of these efforts. Also, many of them have now been undertaken outside Europe. Rather, it was thought appropriate to summarize the achievements up to early 1987, including the original concept, which led to the discovery and which was followed by the early confirmations in Japan, the United States, and China.

The concept

There has been a substantial effort to increase the transition temperature by alloying intermetallic compounds in many laboratories. However, for more than a dozen years, all efforts to enhance T_c over

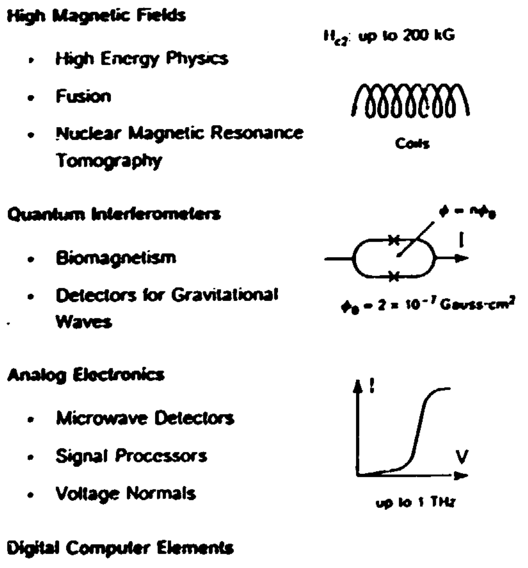

Fig. 2. Applications in superconductivity [see also (9)]

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the 23.3 K reached by Gavaler (10) and Testardi et al. (11) in thin films of nearly stoichiometric Nb_3Ge failed. This situation and a study of representative reviews (12) led us in Rüschlikon to the conviction that the efforts in intermetallic compounds should not be pursued further.

The first superconducting metallic oxide was $SrTiO_3$, with a T_c of 0.3 K (13). Later studies in niobium-doped $SrTiO_3$ at Rüschlikon increased T_c to 0.7 K (14). For this T_c, the carrier concentration was only $n_c = 2 \times 10^{20}$ cm^{-3}, two orders of magnitude lower than in a metal, suggesting an extremely large electron-phonon coupling. The reason a large coupling is obtained at this small concentration is that the plasma edge lies below the highest optical phonon, which is important for Cooper-pair formation. Therefore, this phonon is unshielded. Upon increasing $n > n_c$, the plasma edge moves above the phonon and shields it, and the superconductivity disappears (15). However, in 1973, high-temperature superconductivity in the Li-Ti-O system with onsets as high as 13.7 K was reported by Johnston et al. (16). Their X-ray analysis revealed the presence of three different crystallographic phases, one of them with a spinel structure showing the high T_c (17). Two years later, superconductivity in the mixed-valence compound $BaPb_{1-x}Bi_xO_3$, a perovskite, was discovered by Sleight et al. (18). The highest T_c in homogeneous oxygen-deficient mixed crystals occurs at 13 K, with a comparatively low concentration of carriers, $n \approx 2 \times 10^{21}$ to 4×10^{21} cm^{-3} (19). Therefore, according to the Bardeen-Cooper-Schrieffer (BCS) theory (20), a large electron-phonon coupling was present. Thus one could expect to find still higher T_cs in other metallic oxides if the electron-phonon interactions and the carrier densities, $n(E_F)$, at the Fermi level could be further enhanced. We were not aware that $n(E_F)$ is enhanced by going from three- to quasi-two-dimensional lattices, owing to the presence of a Kohn anomaly at E_F as calculated by Hirsch and Scalapino last year (21).

Strong electron-phonon interactions can occur in oxides, owing to polaron formation as well as mixed-valence states. This can go beyond the standard BCS theory. A phase diagram with a superconducting to bipolaronic insulator transition was proposed early by Chakraverty (22) and has since been modified (23). A mechanism for polaron formation is the Jahn-Teller (JT) effect as studied by Höck et al. in a linear chain model (24). From it, one expects heavy polaron masses if the JT stabilization energy becomes comparable to the bandwidth of the degenerate orbitals. Isolated Fe^{4+}, Ni^{3+}, and Cu^{2+} in an octahedral oxygen environment show strong JT effects because their incompletely occupied e_g orbitals, transforming as $3z^2-r^2$ and x^2-y^2, point towards the negatively charged oxygen ligands (25) (figure 3). Although $SrFe^{4+}O_3$ is a distorted perovskite insulator, $LaNiO_3$ is a JT undistorted metal in which the transfer energy b_{π} of the e_g electrons of the Ni^{3+} is large enough to quench the JT distortion (26). On the other hand, $LaCuO_3$ is a metal containing only the non-JT Cu^{3+}. Therefore, it was decided to investigate and "engineer" nickel and copper-containing oxides, with reduced bandwidth $\sim\hbar\omega$, partially containing Ni^{3+} and Cu^{2+} states. Furthermore, in Rüschlikon, there was a tradition of more than two decades of research in insulating oxides that undergo structural and ferroelectric transitions, which was a strong motivation to pursue the program. (27).

The discovery of superconductivity in Ba-La-Cu oxide ceramics

In our laboratory, the search for superconductivity was initiated in mid-summer of 1983. Our effort first concentrated on Ni^{3+}-containing perovskites, such as mixed crystals of $LaNiO_3$ and $LaAlO_3$. In these unpublished efforts, the metallic behaviour of the various synthesized double or triple oxides was measured, and at low temperatures they exhibited localization upon cooling. This indicated the possible existence of JT polarons, however, without any signs of superconductivity (28). In late summer of 1985, the efforts were shifted to copper-containing compounds, such as $LaCuO_3$. Because Cu^{3+} has two electrons in the e_g subshell, the latter is half-filled. Thus, its grounds state is not degenerate. It was clear that an oxide with mixed Cu^{2+}/Cu^{3+} or Cu^{3+}/Cu^{4+} valence had to be tried.

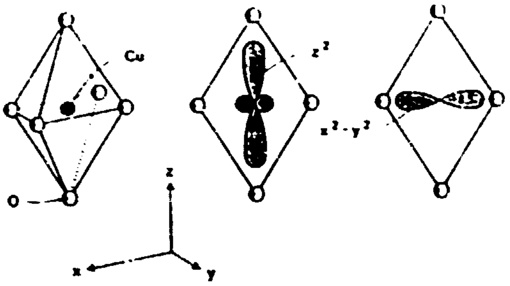

Fig. 3. The partially filled 3d wave functions of the Cu^{3+}/Cu^{2+} mixed-valence states. Positions of copper and oxygen atoms are shown at left.

At this stage, we became aware of a paper by Michel, Er-Rakho, and Raveau (29) on the mixed perovskite $BaLa_4Cu_5O_{13.4}$, exactly meeting the requirements of mixed valency. The French authors had shown that this mixed oxide, a metal at room temperature and above, contained Cu^{2+} and Cu^{3+}. Thus, we tried to reproduce it, at the same time continuously varying the Cu^{2+}/Cu^{3+} ratio by changing the Ba concentration in $Ba_xLa_{5-x}Cu_5O_{5(3-y)}$, and we looked for superconductivity. At Rüschlikon, the samples were prepared by the coprecipitation method from aqueous solutions of Ba-La and Cu nitrates. When added to an aqueous solution of oxalic acid as precipitant (30), an intimate mixture of the corresponding oxalates was formed. Decomposition of the precipitate and solid-state reaction were carried out by heating at 900°C for 5 hours. The product was ground and pressed into pellets at 4 kbar, then reheated to 900°C for sintering. We performed dc measurements of the resistivity $\rho(T)$ by the four-point method with current densities around 0.5 A/cm^2. A typical set of data is reproduced in figure 4. In general, a high-temperature metallic behaviour was observed, with an increase in resistivity at lower temperatures. Then upon further cooling, a sharp drop in $\rho(t)$ occurred that for higher currents was partially suppressed (figure 4, upper curves, left scale). The sharp drop was studied as a function of annealing conditions and barium content. The onset could be shifted by these means to 35 K (1).

At lower temperatures, the resistivity of some samples became three orders of magnitude smaller than the sensitivity of the apparatus, evidence for bulk superconductivity. Therefore, the onset of the drop in $\rho(T)$ was interpreted as possible high-T_c superconductivity of a percolative nature. The shift of the onset to lower temperatures with higher probing currents also supported this interpretation, as well as the comparison of the Ba-La-Cu-O data with those known for polycrystalline $BaPb_{1-x}Bi_xO_3$ (31). X-ray analysis revealed that the system consisted of three phases: CuO, the $Ba_xCu_{5-x}O_{5(3-y)}$ originally wanted, and a K_2NiF_4 phase containing

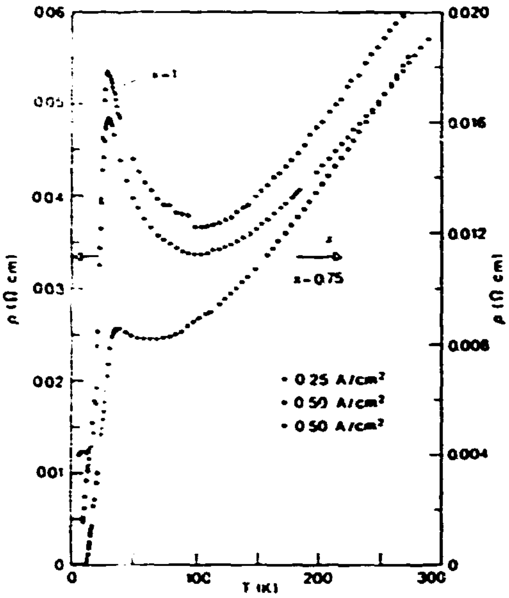

Fig. 4. Temperature dependence of resistivity in $Ba_xLa_{5-x}Cu_5O_{5(3-y)}$ for samples with x = 1 (upper curves, left scale) and x = 0.75 (lower curve, right scale) (x nominal). The first two cases also show the influence of current density. [Reprinted from (1) with permission, copyright Springer-Verlag.]

perovskite layers (2). Owing to the presence of the latter, the possibility of two-dimensional superconducting correlations was also mentioned.

The way the sample were prepared was of real importance for the discovery. Michel et al. (29) obtained a single-phase perovskite by mixing the oxides of lanthanum and copper and $BaCO_3$ in an appropriate ratio and subsequent annealing at 1000°C in air. By applying this annealing condition to our samples, which were obtained by the decomposition of the corresponding oxalates, no superconductivity was found. Thus, preparation from the oxalates and annealing below 950°C for a La/Cu ratio of 1 were necessary to obtain a layer-like, perovskite-related phase with a limited temperature range of stability. Because one of the three phases, CuO, is an insulator, only the K_2NiF_4 phase remained as a possible candidate for superconductivity, namely, the La_2CuO_4 double oxide. A detailed powder X-ray analysis combined with susceptibility measurements, discussed below, showed that the phase becoming superconducting was indeed the layer-like oxide La_2CuO_4. At this point, it should be mentioned that Michel and Raveau had investigated the structural and electrical properties of this phase shown in figure 5, and summarized their findings in their 1984 review (32). True, taking into account the determined search for superconductivity in Rüschlikon, this phase with its La/Cu ratio of 2 would, even without the lucky preparation conditions, have been found sooner or later. Of historical interest is the first synthesis of $LaSrCuO_4$ in 1973, a case in which the copper is fully trivalent (33), whereas a mixed Cu^{2+}/Cu^{3+} valence state is crucial for the occurrence of superconductivity.

To corroborate the existence of superconductivity, the susceptibility of Ba-La-Cu-O samples with various compositions and preparation histories was measured. It was expected that below T_c, grains coupled by Josephson junctions or the proximity effect might yield diamagnetic shielding currents and thus cause a change from Pauli-paramagnetic to diamagnetic susceptibility. The experiments carried out in late summer and fall of 1986 did indeed bear out this property in a systematic way (2), as shown in figures 6 and 7. Figure 6 shows experiments with a sample containing only 1 per cent barium substituted for lanthanum. The resistivity exhibits a clear transition to localization when cooled, whereas its susceptibility is nearly temperature independent, metallic, and Pauli-like, except for a Curie-Weiss enhancement starting at 20 K. Such behaviour has been termed a "Fermi glass" by Anderson (34), because for weakly correlated particles during localization (that is, mobility reduction) the Fermi-Dirac statistics still holds. In figure 7, the resistivity and susceptibilities of samples labelled 2 and 3 are shown. For sample 2, the onset in resistivity drop occurs near 26 K, and for 3 at 35 K (figure 7, upper part). For sample 2, a crossover from Pauli paramagnetic to a diamagnetic susceptibility at 20 K is seen on cooling, and for the latter at 32 K (figure 7, lower part). Owing to the absence of diamagnetism for sample 1 (figure 6) with no drop in resistivity and the existence of diamagnetism in samples 2 and 3 with conjoint increases of the onset in ρ(T) and a diamagnetic crossover, evidence for high-T_c superconductivity was present. The diamagnetism measured was rather low, of the order of 1 per cent, relative to a $-1/4\pi$ full-Meissner effect. As discussed then, the small diamagnetism reflects the percolative character of the early samples. Its suppression by external magnetic fields also led to a new aspect in superconductors: the existence of a superconducting glass state.

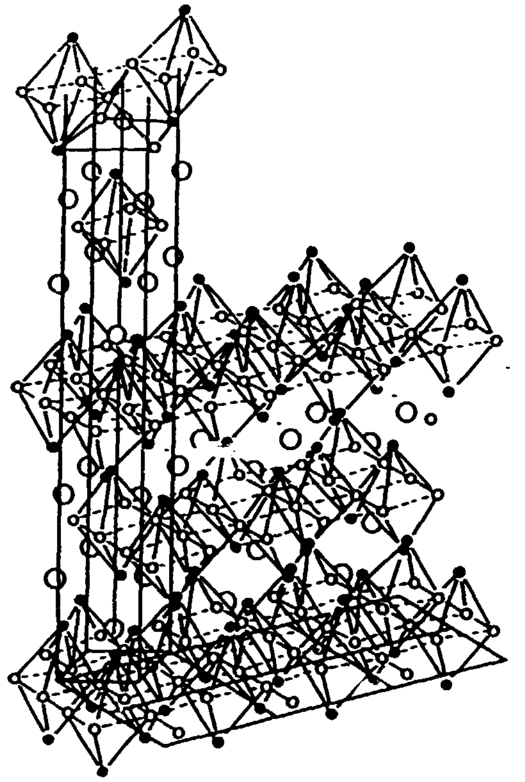

Fig. 5. Structure of the orthorhombic La_2CuO_4. Large open circles represent the lanthanum atoms, small open and filled circles represent the oxygen atoms. The copper atoms (not shown) are centered in the oxygen octahedra.

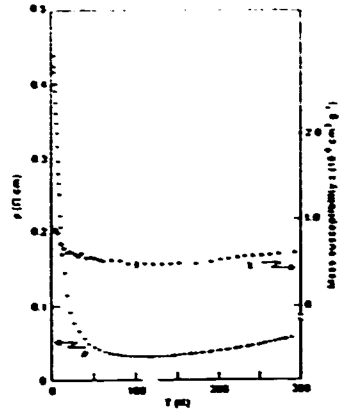

Fig. 6. Temperature dependence of resistivity ρ (x) and mass susceptibility χ (•) of sample 1 with 1% barium. [Reprinted from (2) with permission, copyright Editions de Physique.]

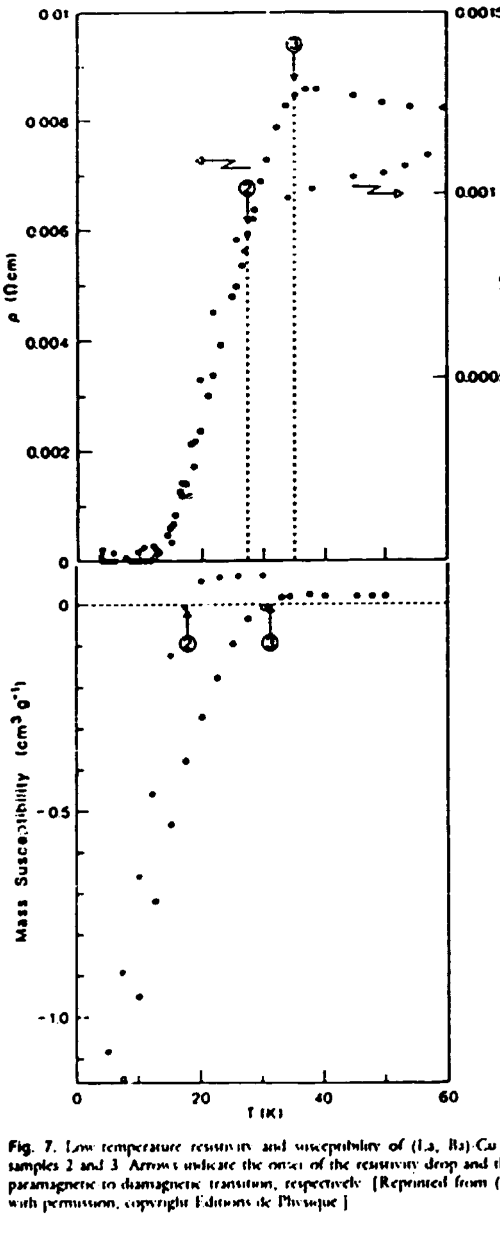

Fig. 7. Low temperature resistivity and susceptibility of (La, Ba)-Cu-O samples 2 and 3. Arrows indicate the onset of the resistivity drop and the paramagnetic to diamagnetic transition, respectively. [Reprinted from (2) with permission, copyright Editions de Physique.]

Early confirmation and progress

For more than a decade, the highest superconducting transition temperature had remained constant. Therefore, we expected that confirmation and acceptance of the Rüschlikon discovery could take as much as 2 to 3 years. In fact, subsequent events occurred very rapidly. We had not thought of the vigorous groups who had investigated the oxide superconductor $BaPb_xBi_{1-x}O_3$, such as the ones of Tanaka in Tokyo, Chu in Houston, and Batlogg at AT&T. These groups were reducing their efforts in 1986. This meant that their expertise in oxide superconductivity and equipment were still in place but rather idle. The new oxide ceramic was as easy to prepare as the earlier ones had been.

The first group to confirm the existence of high-T_c superconductivity in the Ba-La-Cu-O system was at Tokyo University. Rather than argue whether our findings were true or "irreproducible," they decided to try to reproduce our results after the appearance of our first paper (1). They observed diamagnetism in their samples (35), prepared by reacting the oxides with a La/Cu ratio of 2. The onsets in ρ(T) and diamagnetic crossovers were in the same temperature range as in our samples. Also, their independent structure analysis agreed with our X-ray study (36).

In fall of 1986, we conducted an X-ray study as a function of barium content at 300 K and found that the La_2CuO_4 underwent an orthorhombic-to-tetragonal structural phase transition (SPT) for higher barium concentrations. It could be that this orthorhombic-to-tetragonal SPT is related to the high-T_c superconductivity because it occurs near the barium concentration where the highest onsets are observed. This view is supported because, in doping our La_2CuO_4 also with Sr^{2+} and Ca^{2+}, we found the same relation between T_c and SPT on alkaline-earth substitution (37). The Sr^{2+}-containing samples yielded the sharpest onsets of superconductivity and largest diamagnetism (38). Our results on alkaline-earth doping proved the electronic origin of the superconductive enhancement, because the ionic radius r of Sr^{2+} is nearly the same as that of La^{3+}, with r = 1.14 Å, for which it presumably substitutes. The radius of Ba^{2+} is 0.22 Å larger, and the one of Ca^{2+} is 0.15 Å smaller than that of La^{3+}. Thus, these two ions produce local stresses. The alkaline-earth doping creates Cu^{3+} ions, which is essential for superconductivity to occur.

The Japanese confirmation "fanned the fire" in the United States. Both Chu's and Batlogg's groups, as well as that at Bellcore, not only confirmed, but had by the end of the year surpassed the Rüschlikon results in two ways. At AT&T, they started directly with Sr^{2+} substitution for lanthanum (39). Their expertise in oxide ceramics allowed AT&T to obtain sharper onsets, with full superconductivity reached a few degrees below onset, and up to 30 per cent Meissner effect at low temperatures, thus proving the presence of three-dimensional superconductivity. Tarascon et al. at Bellcore achieved a transition width of only 2 K with T_c very near 40 K (40). At Houston, first the Rüschlikon results (41) were confirmed, and then resistivity measurements under hydrostatic pressure revealed onsets up to 52 K (42). Therefore, Chu et al. foresaw still higher T_cs for the future (42), which they did indeed find (5, 6). At the Academy of Science in China, a long tradition of research in oxide ceramics exists. The scientists there also optimized the barium-strontium replacement of lanthanum and had reached a T_c of 48 K by the end of 1986 (4).

Thus, after our first results became public, independent results were obtained at various research institutes all over the world, which in general agree with one another experimentally. The known structure of La_2CuO_4 allowed Mattheiss (43) to perform electronic structure calculations for the tetragonal La_2CuO_4 lattice. A half-filled Cu(3d)-O(2p) band of $3d, x^2-y^2$, two-dimensional character with nearly square Fermi surfaces was found, as expected (21). This electronic structure is of help in understanding the occurrence of superconductivity in the material.

The superconductive glass state

The early samples with their percolative nature and small diamagnetism qualitatively resembled the behaviour in the layer compounds $TaSe_3$ and $NbSe_3$. However, in the latter compound, the T_c and the magnetic fields suppressing the diamagnetism are substantially lower (44). This was attributed to Josephson or proximity junctions becoming normal. The existence of frustration was pointed out theoretically for such a situation (45). A large cluster can support many supercurrent-carrying states of nearly equal energy. It has been said that "the presence of a hierarchy of loops is crucial in defining its behaviour in high magnetic fields" (46, p.1542). Recently, Stroud and collaborators presented calculations of diamagnetic response of coupled superconducting clusters in the presence of high magnetic fields (47). In their model, superconducting grains, each small compared to the London penetration depth, are weakly coupled into closed loops. The picture they arrived at, in agreement with earlier calculations by themselves and others (47), corresponds to a spin glass, hereafter called a superconductive glass state.

Some essential features of the glass state are (i) the difference in field-cooled and zero-field-cooled responses, (ii) the existence of a de Almeida-Thouless line separating metastable from stable regions, and (iii) nonexponential time dependences (48). Figure 8 shows typical sequences on the early ceramics supporting statement (i). After zero-field cooling the sample and then switching on of a 0.03-T field, the susceptibility χ is measured at point A. On heating the sample, point B on curve 1 is reached. On cooling, a nearly temperature-independent susceptibility is measured. With further heating, point B is passed until point C is reached. On cooling from C, a temperature-dependent slope smaller than that of curve 1 is followed. On continued heating, curve 1 becomes reversible past point D. The same value D is reached by field cooling from 35 K. In field cooling past D, curve 2 is followed reversibly on a time scale of 2 hours.

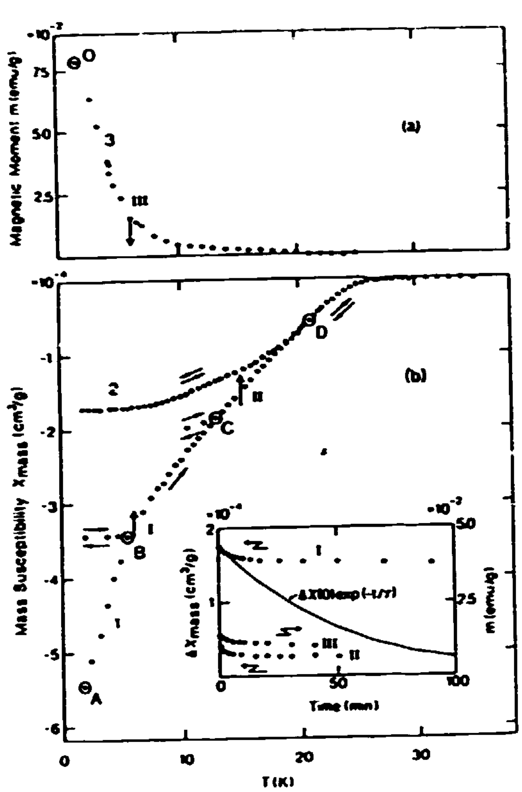

Fig. 8. (a) Flux trapping curve (3) and (b) nonergodic values versus ergodic behavior of the susceptibility after zero-field and field cooling, respectively, as discussed in the text. Inset: Decay of metastable states, τ = 39 min [Reprinted from (48) with permission, copyright American Physical Society.]

Figure 8b shows that on this time scale a reversible and an irreversible trajectory of the system are present. Point D at temperature $T^* = 21 \pm 1$ K and magnetic field $H = 0.03$ T marks the ergodic limit. From measurements with different fields H, a quasi-de Almeida-Thouless line in the H-T plane is obtained, corresponding well to a curve $H = 1.17[1-T^*(H)/T(0)]^{3/2}$, for $T(0) = 23$ K (figure 9). Theoretically, de Almeida and Thouless (49) derived the line separating ergodic and nonergodic regions, from the Sherrington-Kirkpatrick model with infinite-range spin interaction, to be $H = H_0[1-T_g(H)/T_g(0)]^{\gamma}$, $\gamma = 3/2$ where T_g is the glass temperatures. That $H(T^*)$ for the superconductive glass fits the exponent $\gamma = 1.5$ so well may be related to the longer range of forces present in a superconductor as compared to a magnetic system. Figure 9 is evidence for statement (ii).

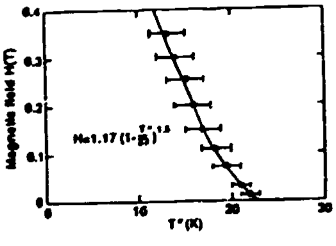

Fig. 9. Experimentally determined $H(T^*)$ line that separates ergodic from nonergodic areas, together with an analytic expression for the quasi-de Almeida-Thouless line. [Reprinted from (48) with permission, copyright American Physical Society.]

When the sample was field-cooled, following curve 2 to low temperature and then switching off the field, a positive remnant magnetization was observed, shown at point O in figure 8a. This remnant magnetization results from the flux trapping and was a proof of superconductivity in its own right. On heating the sample at a rate of 0.3 K/min, the magnetism follows curve 3. After a monotonic decrease, the magnet movement m(t) disappears around T*, that is, where the irreversibility of the susceptibility also disappears and curves 1 and 2 merge at point D. This shows the consistency of all the data in figure 8, since above T* reversibility exists and no flux trapping can occur.

When the superconductor is in a nonequilibrium state, as for χ on curve 1 below T* or for m on curve 3 (figure 8), it is metastable. Therefore, it tends to relax toward the stable state. The system can do that through a hierarchy of relaxational paths via phase slips (45-47, 49). The measured decay of χ at points I and II of curve 1 and III of curve 3 is shown in the inset. The long time decay is slow, proportional to log t, and arises from the fact that after a certain time larger clusters with superconductive phase coherence have fewer relaxation paths.

An important aspect is whether this phase coherence has to occur between the La_2CuO_{4-y}:Ba grains or within them. In the experiments, grain sizes reached a volume $V = 50\ \mu m^3$. According to earlier calculations (47), the low-field limit to maintain complete field exclusion is $H^*_{c1} = \Phi_0/2S$, where Φ_0 is the flux quantum and S is the homogeneous superconducting area. The probing field H of 300 G did not reach the valve of H^*_{c1}, and thus $S \approx \Phi_0/2H = 0.03\ \mu m^2$. This means that the single-phase areas were smaller than that of a single grain with $S = V^{2/3} = 14\ \mu m^2$. Therefore, the superconductive glass state was present in the La_2CuO_{4-y}:Ba grains. However, it should be noted that samples prepared differently show no tendency to carrier localization on cooling; a sharp onset of superconductivity and a much higher diamagnetism below T_c are seen in figures 7 and 8. Therefore, in those samples S is still larger and the superconductive glass features are considerably reduced.

Conclusions

The young "tree" of layer-oxide superconductors already appears to have grown a side branch: the existence of a superconductive glass state. This new class of materials found at the IBM Zurich Research Laboratory are hole rather than electron superconductors. The finding of the layered copper oxide superconductors can already now be foreseen to prompt many investigations in the sectors detailed in the introduction. The authors hope to contribute to some of them and keep informed of the others.

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3. SUPERCONDUCTIVITY

A threat or a promise?

Not a day goes by without a report from somewhere in the world claiming yet another "latest development in superconductivity". Hailed as the greatest discovery since electricity, the transistor, or floodlit football, high-temperature superconductors operating above the temperature of 77°K, have the potential to change the face of industry. But at the moment, high-temperature superconductors are still only in their embryonic state and have a long way to go before they can emerge from the laboratory to make a significant technological impact.

When IBM's Mueller and Bednorz baked the first batch of a new breed of ceramic superconductors, made from an unlikely mix of lanthanum, barium, and copper oxides, such an idea was initially treated with scorn by the scientific world - such ceramics would surely act as insulators? But their remarkable results, which have gained them this year's Nobel Prize for Physics, have provided a fillip for a frenetic pace of scientific activity. Such ceramic superconductors are relatively easy and cheap to make. It is also proving to be a productive field of research, as a number of groups have been quickly able to mirror, or better, the original IBM discovery of almost a year ago. Some of these claims have been confirmed at a number of laboratories, but there are a number that appear to be dubious - reports of brief superconductivity up to a room temperature of 293°K which cannot be repeated.

Superconductivity was originally discovered in mercury at 4°K in 1911. The phenomenon exhibits the Meissner effect, whereby a superconductor excludes any magnetic field that comes near it. With other non-magnetic conductors, a magnetic field can penetrate the material, but superconductors have the ability to shrug off such an intrusion and the magnet is repelled by the superconductor. However, above the superconductor's transition temperature, the same material behaves like any other non-magnetic conductor.

Although an interesting concept, the commercialization of superconductors was put on the back burner until the development and improvement of niobium alloys in a copper matrix in 1961 and 1973. Even so, the superconductors like those used in body scanners, transmission lines, and mineral processors, still had to be cooled by liquid helium at temperatures of 4°K to enable them to work.

Until Mueller's and Bednorz's discovery early in 1986 of a ceramic compound that became superconductive at 35°K, the thought that another higher-temperature coolant (to slow down the atomic activity within a material and allow superconductivity to take place) could be used had not been conceived. The race was on, then, to find a superconductor which could operate without using a difficult to handle, store, and expensive coolant such as helium. Paul Chu's discovery at the beginning of 1987 at the University of Houston, of a compound comprising yttrium, barium, and copper oxides which became superconductive at 98°K meant that superconductors operating at the boiling point of liquid nitrogen (77°K) were at last feasible. This would mean that liquid nitrogen, costing about 20 pence per litre could be used instead of liquid helium, at around £8 per litre.

To manufacturers of the now "conventional" superconducting wires incorporated in the large volume electromagnetic superconducting markets, which have seen tremendous developments within the last 15 years, the new breed of ceramic superconductors could pose a threat. Apart from requiring cheaper coolants, they theoretically can carry electrical currents without losing power through resistance - here everyone immediately focuses on the potential energy savings. So the more exotic uses of superconducting wires such as the coils of powerful magnets used in nuclear physics and the wires in electricity transmission systems could become more commonplace.

In principle, the higher-temperature superconductors could be used to make resistanceless connections, solenoids generating high magnetic fields without dissipating large amounts of power, and to form the basis of systems for magnetic levitation, particularly in transport systems. Further, superconducting circuits containing weak link junctions could lead to their use in very sensitive magnetometers and as fast computer elements such as semiconductors.

The business world appears to be waking up to the implications of these high-temperature superconductors - hardly surprising, owing to the immense publicity being given to the subject. Major companies throughout the world are sensing the great potential for such developments, hence the juxtapositioning for patent rights, even though it could be 20 years or so before large-scale substitutions could be put into effect. Teams of researchers are working to improve both current density and superconducting transition temperature levels, develop viable manufacturing and fabrication techniques, and commercialize systems and devices such as thin films, fibres, flexible tapes, and bulk superconducting ceramics. And all this, before the reason why they work can be explained. According to one Plessey scientist "these low dimensional structured ceramics will be a 'nightmare' analytically, even if the theory of how they work was 'understood'". But if it would be gauged why this phenomenon happens, then perhaps their processing, and manufacturing problems could be solved, and their properties improved.

The large-scale implications of superconductor production, once the initial euphoria has died down, are still largely an unknown entity, particularly as the practical technicalities and economics for converting to these new materials have still to be resolved. A number of fundamental problems have still yet to be overcome relating to manufacture, stability, current density and how much electrical current they can cope with. Some of these problems may be unsurmountable, but the number of scientists working in the area and the vast amounts of cash injected into their research and commercialization will ensure that these materials will take the place of conventional ones in a number of applications.

Basic ingredients

Compounds of rare earths, alkaline earths and copper oxides are the fundamental ingredients for high-temperature superconductor developments. Most researchers start working with Chu's original formula, $YBa_2Cu_3O_7$ (or "123" compound) which broke the "liquid nitrogen" barrier, in which he substituted yttrium for the lanthanum in Mueller and Bednorz's recipe.

Although the starting materials can be produced by the traditional powder processing route, chemical precipitation is being favoured to manufacture purer materials, thus enabling greater control of impurity levels. For example, Sandia National Laboratories has indicated that it co-precipitates all of the cations for the 123 compound through metal salt solutions precursors in a mixing cell reactor at a pH of 13.5.

It has been reported that researchers are getting sharper transitions in resistivity drop-off and higher T_c values by using purer materials. As a general rule, workers on superconductivity in bulk devices are using material at three-nines purity, whereas those carrying out research in electronic applications tend to use five-nines material. Higher purity materials are being used to aid the process of elimination, in trying to determine the factors which cause superconductivity. But, who knows, the impurities themselves may be linked with the phenomenon?

Suppliers of rare earths, including the Western world's two major producers - Molycorp of the USA and France's Rhône-Poulenc, as well as Chinese traders, appear to be anticipating increased levels of demand as research continues. For example, Rhône-Poulenc said that by July it had launched a major development programme at its Monmouth Junction, New Jersey operations, to produce "ready-to-use" powders of alkaline- and rare-earths, and copper oxides.

Although there are claims that manufacturing companies have been stockpiling some of the more expensive materials which could lead to disruption and shortages in supply, companies such as the UK's Johnson Matthey maintains it has been strengthening its stock levels and extending its range of superconducting materials and is making every effort to maintain stock levels for immediate delivery. Johnson Matthey, which has been closely involved with superconductivity research efforts ever since IBM used its materials for the initial breakthrough in Switzerland, supplies an extensive range of superconducting materials from its Materials Technology Division at Royston in Hertfordshire. Further, Kali-Chemie AG of the Federal Republic of Germany, which claims to be the world's largest producer of strontium and barium carbonates, said it had expanded its Italian subsidiary's production facilities in January to include the manufacture of high purity barium-carbonate for superconductors.

Variation on a theme

In attempting to push T_c levels of the new superconductors towards room temperature levels there have been a number of variations on the 123 compound, including swapping yttrium with other rare earths, substituting strontium for barium, and varying the proportions. Some researchers have also been adding nickel or fluorine.

In Hungary, Istavan Kirschner's team at the Roland Eotovos University in Budapest, have been experimenting with changing the 123's ratios. By using twice as much copper as the total amount of combined yttrium and barium, they reported that the resistance became zero at temperatures just over 100-105°K in the first sample and 101°K in the second. Kirschner said that this compared favourably with the 77°K temperature for zero resistivity reported for compounds where the combined yttrium and barium proportions were twice as much the level of copper, where the onset of superconductivity started from 90°K. Encouraging results - apart from the fact that the second sample lost its superconducting properties after three weeks.

Concerning the rare earth constituent, many other rare earths have been substituted for yttrium, such as Yb, Eu, Tm, Dy, Lu, and Sc. As long as they are trivalent they have been found to be as superconductive as the material which uses yttrium, with all of them having a T_c within a few degrees of each other. According to Merwyn Brodsky, the associate director of the USA's Argonne's Materials Science Division, the one-part yttrium in the 123 compound does not have a direct effect on the superconductivity, as the yttrium sits apart from the other atoms in the material. Chu, from the University of Houston, has also shown that the rare earth ion has no influence on the onset of superconductivity in these materials. But he found that by substituting the barium ions the T_c value was affected. When he used strontium ions the structure of the material collapsed, reducing the transition temperature from 97°K to 77°K. The T_c level also dropped when he substituted calcium ions. But a combination of both strontium and calcium substitution produced high-temperature superconductivity.

In Japan, the Electro Technical Laboratory has a recipe which includes the addition of strontium to the basic copper, oxygen, yttrium, and barium mix. Although superconductivity only lasted a day, the company put forward the theory that because strontium has a different size compared with barium, the copper atoms are pushed further apart, consequently opening up the lattice framework and enabling it to hold more oxygen.

In July, Stanford Ovshinsky's team at Energy Conversion Devices Inc. in Michigan, tried adding fluorine (next to oxygen in the periodic table) to their mixture. They said that one compound, $YbBa_2Cu_3F_2O_y$, attained zero resistivity at up to 155°K. Further, another sample's resistance declined rapidly starting at room temperature, possibly indicating that the sample contained phases of material that are superconducting above room temperature. But other laboratories have been unable to confirm Energy Conversion's results, particularly as the company itself seems to be having difficulty in reproducing them.

Baking a batch

Most researchers into superconductivity are using a standard method of manufacturing the compound of metallic oxides into the ceramic superconductor, which falls into a class known as perovskites (orthorhombic $(Ca,Na,Fe^{2+},Ce)(Ti,Nb)O_3$). Some argue that by using the conventional manufacturing technology or equipment it would mean no great technological leap forward for their mass production.

The basic method involves placing the oxides or rare earths, barium and copper in a mortar and grinding them with a pestle. The mixture is heated for around nine hours at between 900°C and 1,100°C. It is then removed from the furnace but must be cooled slowly, otherwise a green super resistor phase can form. Although the material is a superconductor the powder is processed again by being pressed into a pellet and annealed for another eight hours. The pressed pellets and discs are generally produced by hot pressing up to 349 MPa. During sintering flowing air or oxygen is used to preserve the oxygen content of the material. There are obviously variations to this method by altering a number of the parameters, such as annealing time, and the general rule is that both oxygen and temperature can alter the basic structure of the superconductor.

Another way to manufacture the new materials is by vapour deposition, whereby they are deposited onto a substrate. Such a method is used by IBM to manufacture superconducting films. Briefly, it involves placing the powdered ingredients into a vacuum chamber, where electron beams heat and evaporate the powders to form three separate vapours. As the oxides react the superconducting perovskite is formed and condenses on a thin sheet of aluminium oxide.

Problems facing stability and fabrication

With T_c levels for superconductors becoming more commonplace at 120°K, liquid nitrogen can be used to cool them, instead of the more expensive helium. As scientists strive to push this temperature still further, they are beset with a number of difficulties. Once they have made a high-temperature superconductor, how do they get it to retain its powers, and will the new family provide more than a source of interesting research?

Work on keeping the superconductor stable is taking place in conjunction with improving temperature levels. Some researchers claim that by using compounds containing yttrium, barium, copper and oxygen, with additional strontium and higher proportions of yttrium, the stability of the superconductor could be improved if it is kept in its powder form, as opposed to the more typical pellet or disc. Better stability could be accounted for, they say, because the changeable nature of superconductors near room temperature may be due to unstable boundaries between small grains of materials, and such boundaries become important when the grains are pressed together.

The ultimate goal for all the work being carried out is to transfer laboratory knowledge to the factory floor. Researchers are fervently trying to resolve problems in fabricating the ceramic superconductors into viable commercial products. Once the compound has been baked for a day in a platinum plan in a kiln and then slowly cooled, the new superconductors emerge as a brittle, crumbly, and difficult to work with black lump. Besides shattering when hit, some also dissolve in water.

In June, the Massachusetts Institute of Technology claimed to have produced a novel process which could result in a more ductile and usable material. It manufactured a more malleable superconductor by oxidizing an alloy of europium, barium, and copper, and claimed that it would be manufacturing wire on an experimental basis in less than a year. The superconductor here works at around 90°K. The following month, Applitech of Indianapolis in Indiana, announced that it had achieved a manufacturing process by applying advanced metallurgical techniques, flexible enough to work with a wide range of customer requirements.

The Oregon Graduate Center, in conjunction with the Northwest Technical Industries Inc., claimed a major breakthrough promising to "give superconductivity a giant leap forward" last month. This "leap" concerns the mechanical strength problem which has hindered practical applications. The team claims to have manufactured machinable, joinable, mainly metallic copper high-temperature superconducting parts. The privately-funded research is led by Lawrence Murr and Alan Hare, who have patented the techniques.

Researchers are collaborating to specialize in new superconductor processing. One such company is Ceramics Process Systems Corp., which was set up by a group of scientists to commercialize high-technology ceramics, one of the founders being a ceramics expert, H. Kent Bowen, at the Massachusetts Institute of Technology. It is attempting to organize a superconductivity research consortium to pull in companies involved in the medical, semiconductor and transportation industries.

Like the "old" idea of the ceramic engine, it could be that these new materials call or new design concepts - perhaps ceramic tubes instead of wires in solenoids? Although there seems an endless list of problems associated with the new superconductors, research is being carried out at an extraordinary pace. And industry is being continually reminded that when the conventional superconducting alloys of niobium/tin/titanium first came on the scene, the idea of winding them into wires for magnets also looked futuristic.

Current densities - there's the rub

Current density limitations is the other fly in the ointment which has stymied the commercialization of superconductors operating at liquid nitrogen temperatures. It's all very well producing high-temperature ones on the laboratory and then working out how to mass-produce shapes, but if the electric current that they carry is not even equivalent to that carried by the flex of a domestic kettle, then what is the point in substituting them in practical applications?

Researchers are faced with an arduous engineering challenge. Until recently, the new materials were not dense enough to transmit practical current levels. Many still only carry about one-hundredth as much electrical current per unit of area as the older generation superconductors (which attain values of 100,000 amps per sq. cm).

The cause of the problem hinges on atom alignments, crystal voids, and jagged boundaries. During the formation of the superconductor, on cooling, the superconductor crystals grow in an askew fashion. The resulting boundaries and voids interrupt the flow of the electrons, inhibiting the material's overall ability to transmit current. Scientists are working on ways of improving critical current density levels, like lowering the void level, and controlling the errant oxygen atoms. Such work has been going on at Cambridge University.

James Smith, at Los Alamos National Laboratory, thinks that by changing the way the materials are made may improve current density. Although the oxide grains are annealed by heat and pressure, they remain porous. This could mean that the grain surfaces and links between them can affect the oxide's ability to carry current. Hence, Los Alamos is trying to produce superconductors with smaller, more closely packed grains. Oak Ridge Laboratory has been working on developing a process to precipitate the oxides out of molten urea.

Although over the last few months there has been a spate of improved current density levels, a number of spurious results has led research teams to depend more on magnetic susceptibility measurements instead of bulk resistivity measurements to determine superconductivity. Until May 1987, the best current levels achieved in the USA were superconductors which could carry 1,200 amps per sq. cm - obviously useless for computer devices, magnets, and power transmission wires which need levels at around 100,000 amps per sq. cm. Brodsky, at Argonne National Laboratories, has stated that superconductors will require a critical current of 10^4 to 10^6 amps per sq. cm, and must have a critical field of between two and eight tesla to be commercially viable.

The early stage of investigations of the 123 compound showed that critical current densities were at the 1,100 amp per sq. cm level - equal to that of copper wire at room temperature. However, they were thought to have a much greater potential than this. In May, researchers at IBM, Yorktown Heights, New York State, claimed to have bettered these levels by producing bulk single crystals of the material (single crystals, which give much better current densities than polycrystalline varieties, are typically used in eletronic superconductivity applications). IBM's crystals were produced by a thin-film fabrication method and measured 1 micrometre in thickness and 2.54 cm, and attained a critical current of 100,000 amps per sq. cm at 77°K - apparently adequate for most foreseeable applications (presumably in the field of electronics). From this research more has been learnt about the crystal structure. It was shown that electricity flowed 30 times better in one direction through the crystal than another, and this in itself may complicate fabrication of the superconductors. Also, in July, the University of Illinois announced that it had developed a new procedure to manufacture a much denser material.

Future implications

It is too early to say what technological developments will emerge from the use of the new breed of superconductors, although on the face of it the possibilities seem endless. Producers of conventional metal alloy superconductors may be cynical, but you can be sure that they are keeping a close watch on developments and even dabbling with the new materials themselves. Even the new superconductors operating at above liquid nitrogen temperatures have the potential to transform technology, so the mind boggles at the thought of what could be done when they can operate at room temperature without the need of any coolants.

Scientists are in two minds. The cautious pessimists say there is too much still to be learnt about these new materials that can transmit electricity without resistance - it is all very well making amazing breakthroughs in the laboratory (many of them by accident), but it is another matter transforming these into practical, large-scale applications. At best it normally takes about 10 years of laboratory research to move into large-scale commercialization, but in the case of the new superconductors it could be more like 20 years. Others say that the race of commercialization is on - there is no time to wait for a better understanding and modification of the new materials. Quite an understandable attitude when you consider that the sales volume alone for conventional superconducting materials is over $200 million per annum (National Bureau of Standards, USA).

Numerous forecasts on the impact of new materials are being made. One gives a growth performance to $1,500 million by the year 2005 from a current superconductor and end use products size of $450 million. But a lot could (or could not) happen over the next 20 years. Look at the fate of the ceramic engine, now considered by many as a white elephant.

But there are too many people working on the new superconducting oxides for commercial products not to emerge from the laboratory. Another thought is that as the new materials are different, why shouldn't the applications be different as well - not just old ones at higher temperatures. Strategic Analysis Inc. in Pennsylvania says that the new superconducting markets will grow because of the end use cost benefit to the manufacturers, and the first large-scale application will be "retroffitting into existing design for products such as medical imaging equipment and selected test sections of high-energy accelerators". In the longer term, reasons for growth include the "acceptance and development of application-specific alloys, improved fabrication techniques, including composites; increase in the number of suppliers actively developing and promoting superconductors; engineer and end product designer awareness; the creation of an entirely new family of products such as equipment for diagnostics, thin-film magnetics for electrical and electronics, and ultra-energy-efficient conductors for selective military uses".

One topic which researchers, industrialists, and consultants appear to agree on is that the first important practical applications will happen in the electronic field - where developments are creating a flurry of excitement. Some say that commercial applications could be on the market in a year's time.

Experimental applications have been making the headlines for the past six months. For example, by July, Toshiba had produced a silver-clad wire and tape that was fabricated into 2 cm diameter coils. IBM had produced functional microelectron thin-film devices, and CVC Products Inc. in Rochester, New York State, had produced sputtered films. Japan's top superconductivity researcher, Shoji Tanaka, of the University of Tokyo, has said that it could be five to six years before any practical aplications of superconductivity become available. Tanaka is leading a 30-strong superconductivity research team, 10 of whose scientists have been seconded from companies like Toshiba, Hitachi, Matsushita and Tokyo Electric Co. He expects to see the first fruits of his research in about four years, with the advent of laboratory systems based on the new superconductors, and a fully commercialized system such as those to be used in medical diagnostics in about 10 years.

Such sentiments are agreed by the USA's Defense Advanced Research Projects Agency (DARPA). Craig Fields, DARPA's deputy research director, said the agency is giving superconducting ceramics a high priority and is concentrating its efforts to develop an industrial technology base for processing, fabricating and manufacturing the new ceramics. Once DARPA has selected defence applications "We expect to develop small-scale pilot production lines or boutique factories, as we did with gallium arsenide, and hope to see some concept demonstrations aimed at defense applications within the next three or four years," Fields said. Major application areas will include magnets, motors and thin-films for high-speed microelectronic components.

The thrust of the research concerns ways to replace traditional superconductors with the new family of superconducting ceramics. Potential producers are eyeing applications in power and computer transmission. A prime candidate for replacement concerns long-distance power-transmission mediums, with the consequent replacement of some of the aluminium and copper traditionally used. Conventional aluminium or copper superconductors typically lose about 10 per cent of the electrical energy they are transmitting, but one of the ideas put forward is to use aluminium or copper tubing with a thin layer of the superconductive phase deposited on the surface, with liquid nitrogen running along the tubing.

Market sectors earmarked for scrutiny as potential new superconductor uses (even cooled by liquid nitrogen) are:

- Microelectronics and computers - the new materials could lead to the increased use of Josephson Junctions, zero resistivity interconnects, and high-powered integrated devices.

- Energy - power generation via superconducting magnets, generators and electromotors in conventional and nuclear fusion industries.

- Medical - improved diagnosis through lower cost, less cumbersome nuclear magnetic resonance imaging and neurological research. Most body scanners use NMR techniques, and the only way to make magnets powerful enough for use in hospitals is to use niobium/tin/titanium alloys in a copper matrix as electromagnetics. They have a transition temperature of 17°K and must be cooled by a combined liquid helium and liquid nitrogen system. If the new superconductors can be used, the cooling costs could plummet.

- Mineral processing - using magnetic separators made with the new materials and replacing those that use "conventional" superconductors.

- Transportation - using electromagnetically levitated trains and battery-powered cars with highly efficient superconductor electromotors.

- Satellites - using improved remote sensing for agricultural and defence applications.

Electronics - looking good

The promise of the new superconductors in electronics is that they could revolutionize electrical devices including smaller and faster electronic components. The beauty of electronic circuits with no resistance is that the time constants depend on the resistance and the capacitance of those circuits. If there is no resistance you therefore eliminate the time constants, accelerating the transfer of signals within a circuit. Electronic researchers are continually looking at ways to improve performance and reduce electronic noise.

Conventional techniques such as vapour deposition in the manufacture of semiconductors are being applied to the new ceramic superconductors for use in electronic circuits. Superconducting electronic circuits could then reduce the power requirements to operate the circuits and enable them to handle very fast pulses, which becomes increasingly important in transmitting data over long distances. Alloys of niobium and tin have produced electronic pulses lasting only 0.5 picoseconds, a speed apparently only bettered by optical systems. Theoretically, higher temperature superconducting materials could better even these pulse speeds, particularly in the form of films. IBM is one company which is focusing strongly on the electronic applications of these materials.

Much time and effort has gone into the development of processes for the manufacture of thin films for potential electronic uses such as integrated circuits. Last June a new method was introduced that used rapid laser pulses to vaporize small amounts of superconducting materials. The process was developed by researchers at Bell Communications Research Inc. (Bellcore) at Piscataway, New Jersey. The superconducting vapours were deposited as a thin layer on a foundation substance and then baked at high temperatures. The films exhibited zero electrical resistance at 83°K. North Carolina State University also announced a laser method in June. Here scientists used a high-energy laser to irradiate and vaporize a sample of superconductor (yttrium, barium, and copper oxides). The substrates used were silicon dioxide and sapphire, as well as strontium titanate and magnesium oxide. They also found that by using this method the superconducting properties were retained for a longer period. Stanford University also used a method where electron beams were used to vaporize the superconducting materials.

Barium and strontium titanates are becoming increasingly popular substrates for thin film spraying and vaporization of superconductors. They are grown as single crystals which are then cut into wafers, and which aid the order of the thin film. Such single crystals play an important role in influencing the current densities. The better-ordered the thin film, the better the current densities. For electronic uses, a current density of 10^6 amps per sq. cm is generally required, and to date, more and more researchers are coming up with levels of at least 10^3 or 10^4 amps per sq. cm

In May, IBM had perfected superconducting materials to carry 100 times the amount of current it could carry previously. The company produced a single crystal of yttrium/barium/copper oxide which could carry currents of over 100,000 amps per sq. cm. when the critical current was measured at 77°K. The crystals were grown on a barium titanate substrate.

AT&T in the USA has also been working on commercializing electronic applications. By May, the company had manufactured a superconducting tape, small doughnut-shaped magnets, and wires. The tape had a limited flexibility (50-200 microns thick), and at the time could only achieve critical current densities of 200 amps per sq. cm.

So much for all the research on thin films, tapes, and Josephson Junctions - but what about the practical applications? One of the first devices to hatch from the superconducting laboratories is a "superconducting quantum interference device" (squid), an extremely sensitive magnetic field detector, with a thickness one-hundredth that of a human hair.

IBM produced its first squid in May, although it then only worked at 68°K, by using its fabricated thin films needed for computer devices. In the UK, the first squid was developed by Birmingham University in July, and worked at 45 degrees above absolute zero. Just a day after the Birmingham announcement, a team from Strathclyde University revealed that they had produced a similar device that was effective at liquid nitrogen temperatures.

Squids operating at liquid helium temperatures have recently been introduced to the market by a handful of companies, the two most important ones being Hypres of the USA and Cryogenic Consultants of London, UK. Cryogenics started work on Josephson Junctions and squids six years ago in a joint venture project with Cambridge University and began deliveries of squids, made using the whole wafer technology, over two years ago. The squid, which acts as an electronic amplifier measuring 1-28 watts, is made up of a layer of aluminium oxide (40 angstroms thick) sandwiched between niobium (100 nanometres thick top layer and a 10 nanometre thick bottom layer). Cryogenics has found that its superconducting squid gives the lowest possible noise - those cooled in liquid nitrogen are 10 times noisier. Like other companies researching into squid technology, Cryogenics is looking into squids made from new superconducting materials, but maintains that they would still need to be cooled at liquid helium temperatures to be noise free.

But why the interest in squids? Because they have a wide range of potential applications. They are so sensitive that they can measure magnetism down to one ten-millionth of a gauss (the Earth's magnetic field). Potential uses can include measuring magnetic signals emitted by electronic components, in medical applications in brain scanners or detecting foetal heartbeats, in inertial navigation systems for submarines, and submarine detection (hence the Ministry of Defence's keen interest).

Wires - full of wind?

Conventional superconductors, those such as copper which work at room temperatures, or the niobium/tin/titanium ones which need to be cooled by liquid helium are obvious targets for substitution by the higher-temperature superconductors. Most traditional superconductors are used in wire form, so it is hardly surprising that research work is centring on the fabrication of ceramic superconducting wires.

Again, scientists are hampered with the age-old ceramic problem of brittleness, formability, and difficulties in mass manufacturing techniques, in conjunction with poor current densities. As Carl Rosner, President of Intermagnetics General Corp. - a manufacturer of conventional superconducting wire, pointed out "There are significant limitations to the material, and it is not clear that we can solve them all". But researchers are trying hard to solve the problems as they think there will be a bit pot of gold at the end of the rainbow.

At Cambridge University in the UK, Jan Evetts and his team are working on the problem of fragility and brittleness. Most industrial applications will require either a flexible wire that can be wound around a core such as that used in magnet manufacture, or thin films adaptable to semiconductor manufacture. In its powdered form the superconducting material can be packed into a narrow tube of silver to form a flexible superconducting wire. Because silver does not oxidize, the oxygen (vital for high-temperature superconductivity to work) can pass through to the material inside. Such a method is favoured by AT&T in the USA, which involves placing the superconductor into a silver tube and then cold drawing it to fine wire thickness. But as the silver is too soft for a number of potential applications, Evetts has designed a stainless steel tube with a hole in the centre, and surrounded it by a thin silver membrane. The Cambridge team has already filed for five patents, ranging from the basic physics of the materials to superconducting wire.

Another wire manufacturing approach has been taken by several laboratories in the US, which could prove practical for some rigid windings on magnets and motors. Oak Ridge National Laboratory, Argonne, and AT&T Bell Laboratories extrude a combination of oxide and plastic or other binder. To prevent the brittleness after heating, the wire is shaped before it is fired.

Plasma spraying is another technique which has fired the imaginations of the wire manufacturing scientists. Here, the ceramic superconductor is sprayed onto the surface of a substrate after it is drawn into a wire. IBM pioneered the technique for wires which had the potential to be used to connect logic and memory chips in computers.

There has been a steady flow of announcements on superconducting wires this past year as scientists attempt to solve the problems of introducing such a strange and new phenomenon into industry. The first one of significance which hit the headlines was made by Toshiba Corp. in March. It had developed an yttrium/barium/copper oxide compound that functioned at 93.7°K. The company then processed the material into wire rods, measuring 0.6 mm in diameter and tapes 5 mm wide and 0.1 mm thick. As a wire rod the material started its transition at 93.5°K and had no resistance at 87°K. At the same time, the USA's Argonne National Laboratory came up with an extruded wire measuring 0.2 mm in diameter with critical current densities of 190 amps per sq. cm.

Work in China in April, at the Institute of Chemistry, produced a superconducting wire working at liquid nitrogen temperatures. The wire measured 0.5 mm in diameter and offered no resistance to electric current and diamagnetism when cooled to 83°K. Later that month, IBM introduced its spray-paint technique, involving the plasma coating of superconducting ceramics, which led engineers to believe that there was a chance of making superconducting flexible cables for transmission lines. IBM coated preformed wires, contoured surfaces and tubes, and the coating became completely superconductive between 60-82°K.

By May, Argonne National Laboratory was showing off its thread-thin wire, which it claimed could be wound. It was planning with the University of Chicago to start up a company to develop the wire for commercial applications. During the same month, Nippon Steel Corp. had developed a superconducting wire rod which became completely superconductive at 92°K. The rod was registering current densities of 350 amps per sq. cm in liquid nitrogen, and was being reproduced consistently.

The following month, another Japanese steel major, Kawasaki Steel, claimed to have produced a wire rod which could carry current of 410 amps per sq. cm. The material began losing its electrical resistance at 95°K and became superconductive at 93°K. The company said that its single crystal formation enabled production of 10 kg wire rods, measuring 1 mm by 10 metres. Other developments in Japan occurring at the same time involved Sumitomo Electric Industries Ltd., which had developed thin films with current densities of 32,000 amps per sq. cm, exceeding those in the wire rods developed by Toshiba Corp. and Hitachi Ltd. of 510 and 1,000 amps per sq. cm respectively.

With so many developments on superconductivity coming out of Japan, some of the UK power supply and electrical engineering companies expressed concern that "Japan may steal a lead in applying the new generation of superconductors". At a meeting held by the Department of Trade and Industry in July, George Moore, the Technical Director of major cable manufacturer BICC, said that the Japanese were well placed to exploit the breakthrough in high-temperature superconductors within the power transmission industries. Other electrical engineering and power supply companies admit that the new materials could offer a number of advantages (e.g. in energy storage systems for AC generators at levels of 1,000 MVA or higher), but so much of the work is still at the R&D level it would be years before all the problems would be resolved.

The transformer industry highlights some of these problems. For the industry to take up the new superconductors, providing they could work at room temperature and the technique for fabricating transformer winding had been sorted out, they would need to demonstrate the ability to work under AC conditions (where magnetic fields can offset current densities) with high current densities. The upper critical current level would depend on the surface effects of the conductor, temperature, and current densities. Magnetic field strengths would have to be around two tesla. The new materials would need to have good mechanical handling properties owing to the short circuit strengths. Conductivity would also have to occur over a broad temperature range.

Once all these parameters have been met, then the new materials would give much lower load losses in transformers. They would also mean smaller core sizes which would ultimately lead to cheaper transformers. But because of the high operating voltages, the system would need to be insulated, and moisture extracted which could otherwise lead to electrical breakdown. But one compromise could be to use systems which require cooling by liquid nitrogen, which in itself could act as an insulator. Work is already under way at looking at the replacement of conventional copper wire transformers which operate at room temperatures by niobium/tin wire which would be cooled with liquid helium. Alsthom, the French transformer manufacturer, has been developing such systems, and has said that core size savings and load losses would be reduced by around 70-80 per cent compared with current conventional copper systems.

Electromags - how practical?

One important property of superconductors in commercial applications is their upper critical magnetic field. Superconducting magnets are finding increasing application in nuclear magnetic resonance medical diagnostic equipment, and particle accelerators. Such equipment has magnetic fields of 10 tesla, but more typically two tesla. Theoretically, the La-Sr-Cu-O superconductors have upper critical field levels of 45 tesla at 0°K. But the extrapolated fields for the 123 superconducting compounds are nearer 360 tesla at 0°K. All very impressive, but hardly viable at today's level of practice.

Mineral processing is one of the "hot topics" being discussed as a suitable market to introduce the new superconductors into. Between $200 million to $250 million worth of equipment is sold every year to the mining industry for the separation of minerals by the process of magnetic separation. On the surface this would appear a lucrative market, and one that is earmarked for substitution by the new breed. But on closer inspection, the potential reward may not be as great as it seems.

Typically, the new superconductors are poised to infiltrate markets where conventional superconductors such as copper and niobium/titanium/tin alloys in a copper matrix are used in electromagnetic applications. A large range of magnetic separators are on offer to the magnetic separation industry. Separators using superconducting magnets have been introduced which can generate very high magnetic fields in large volumes but only using low levels of power. Their fields are much higher than those attained by using electromagnets and permanent magnets and they ultimately would give improved levels of mineral beneficiation with lower operating costs.

There are two types of separators using superconducting magnets currently considered commercially viable, the open gradient magnetic separator and the high gradient magnetic separator (HGMS) - both types of which are manufactured by London-based Cryogenic Consultants Ltd. But, of the 40 or so HGMSs, which sell for around $1-1.5 million each, only one to date uses a superconducting magnet (using niobium/titanium wires) cooled by liquid helium, and that is supplied by Eriez of the USA in the beneficiation of Huber's kaolin. The potential market for substituting helium cooled HGMSs with the new breed of superconducting ceramics is not, then, as big as it initially seemed.

But could the higher-temperature superconductors realistically be used for magnetic separation, particularly as current densities would need to be at the 100,000 amps per sq. cm level? For this application you need two basic requirements - a field strength of at least two tesla 20,000 gauss (although if one could be produced with strengths of one tesla it would generate a great deal of interest) to compete with conventional magnets, and a suitable field gradient. According to Dr. Adam Stadtmuller of Cryogenic Consultants, "there is no indication that the new materials can operate at these fields". A statement mirrored at the Magnet Technology 10 meeting in Boston by Dr. Larbalestier of the University of Wisconsin, and an eminent expert in the field of superconducting magnet technology. His sentiments were that now the euphoria with new superconductors has died down, there is "nothing" for magnetic uses in the short term. Larbalestier said that the new materials were completely unsuitable for magnet manufacture, mainly because they could not carry sufficient critical currents. The highest current densities have been achieved in the field of single crystals for electronic uses, and such crystals are not exactly practical for large-scale magnetic applications. The existing magnets in separators are vastly more popular with end-users.

A basic volume problem

Most work on new materials in electromagnetics has looked at developing the wires that form the solenoid. But, a more novel approach from London-based Basic Volume (also involved in supplying exotic metal oxides) has been to manufacture superconducting tubes, or solenoids manufactured in one piece. Since April, Basic Volume has been making lanthanide-transition metal oxide superconductor tubes up to 38 mm in diameter, dishes, rings, bars, and sputtering targets, as well as trying to improve both the material's uniformity and density.

The first tube was manufactured from a 123 superconducting compound and measured 90 mm in length, 14 mm outer diameter and with an 11 mm inner diameter, and was stable in water. Also in the pipeline is the development of superconducting ceramic solenoids up to 150 mm in diameter and lengths of up to two metres, although this has not been achieved to date. Targeted commercial applications are superconducting magnets for medical scanners and magnetic separators, along with magnetic bearings, high torque DC motors, spin resonances, spectroscopy, and electron imaging. But the inventor, Dr. C.P. Tavares, has said that although results were encouraging it is still early days as far as possible applications are concerned, and more financial assistance would be needed before he could refine his techniques. James Watson of Southampton University has been testing the materials, and has said that there are a lot more opportunities using macroscopic tubes rather than wires. One application which has sustained his interest is the use of such tubes in magnetic separation. Although inadequate current densities are proving a problem for such a machine, he has said that Basic Volume's claims of current density are sufficient for certain types of magnetic separators.

But industry experts are sceptical about the use of superconducting ceramic tubes. It is generally difficult to form ceramics into practical shapes because of their brittle and crumbly nature. And although there is plenty of expertise in mixing and binding agents to improve formability, such additions can have a detrimental effect on the superconductor's properties.

For ceramic superconducting solenoids to become viable in magnetic separators, and compete with HGMSs, they would have to attain field strengths of the two tesla level. This would require 20,000 ampere turns, i.e. one turn of wire (1 cm high) would require 20,000 amperes to be passed through it. For a typical magnetic separator magnet (industry standards are 50 cm high and 2 metres in diameter), irrespective of the diameter, there would be a requirement of 1 million ampere turns. Resistive electromagnets, such as those used for kaolin separation, normally have around 320 turns and carry 3,000 amps, but to achieve the same capacities the superconducting ceramic varieties would have to be considerably larger. That these ceramic solenoids could have applications in magnetic separators may be possible, but it is likely that they could only have field strengths suitable for low field separators used in the separation of iron ores.

Patently obvious

With prospects of a multibillion dollar market, companies involved in superconductivity developments are keen to make sure they do not miss out on the financial rewards, and one way of doing this is to lodge patents. Once the IBM patents have been granted then the wave of patent applications may subside. But even so, there should still be plenty of room for new breakthroughs by simply changing the basic recipe, under the pretext that that extra ingredient is vital to the superconductor's performance (by no means a new game).

Another indication that the superconductor market is worth chasing is the vast amounts being spent by private companies and Governments of the principal players - the USA and Japan. The Japanese have given the subject top priority, with the Government pledging over £100 million, and the private sector is expected to match that figure several times over. One recent estimate is that the Japanese Government has provided 3,000 million yen to superconductivity research since 1981. As a countermeasure, $150 million has recently been added to the Pentagon's research and development purse for superconductors, and it is also providing numerous grants for researchers and venture-capitalist companies in an attempt to commercialize devices and manufacturing techniques. Last year IBM poured $3,900 million into research and development and AT&T spent over $2,200 million in the same area - both are seriously committed to superconductivity development.

One thing is obvious, no-one would spend all this money on a wild goose chase. High-temperature superconductivity may pose a threat to traditional suppliers and manufacturers now, but there is time, and the field is broad enough, to fulfil some of the new material's promise.

Supplement 1

Claiming temperature points

The excitement generated by the new breed of superconductors hinges on the fact that these materials can operate at temperatures higher than the boiling point of cheap liquid nitrogen (77°K). Superconducting systems in use today require expensive, and sometimes cumbersome cooling systems which involve the use of helium operating at temperatures of just over 4°K. The spate of superconducting discoveries within the last year or so have fired the imagination of both scientists and industrialists alike - and have brought "high-temperature" superconductivity (superconductors which become operational above the temperature of liquid nitrogen) to the realms of the practical. Not content with reaching this point, scientists are racing to raise superconductivity levels to as high as room temperature levels (293°K), which in itself would negate the use of even liquid nitrogen, and could lead to dramatic advances and cost savings in transporrtation, electronics, power transmission, and diagnostic medical applications.

Over the last few months there have been spectacular advances in superconducting ceramics, with transition temperature rising to above 95°K. There are reports that some superconductors have been produced which can operate at or above room temperature - one Japanese laboratory has claimed superconductivity in a ceramic oxide at 325°K. Even though the scientific world treats, not unnaturally, such claims with a degree of scepticism, particularly as many claims cannot be verified or repeated or are only short-lived phenomena, levels of superconductivity at 120°K are now well established. But the definitive room temperature superconductivity still has not been established, and will not happen until many laboratories reproduce a room temperature finding.

The following highlights some of the major temperature breakthroughs reported in the Press, but even this short list only touches the tip of the iceberg concerning the phenomenal number of university and company laboratories which are working on a variety of aspects of superconductive ceramics.

- In 1983: Karl Mueller and Johannes Bednorz of IBM in Zurich start researching metal oxides.

- In February 1986: Japanese scientists Tetsuya Ogushi and Yoshihisa Osono claim superconductivity at 44°K in niobium/germanium/aluminium/oxygen thin films.

- In December 1986: Mueller and Bednorz obtain a promising mixed oxide of lanthanum, barium, and copper whose critical superconducting temperature reaches 35°K, improving previous results by 12°K.

- In January 1987: Paul Chu of the University of Houston varies the pressure of the barium, lanthanum, copper oxide compound which gives superconductivity at 52.2°K. He then substitutes yttrium for the lanthanum atom, and comes up with a superconductor which is superconductive at 98°K (-284°F).

- In March 1987: IBM's Almaden team unravels Chu's superconductor, and find it to be a mixture of three phases of the same compound, including a black variety and a green version, the "super resistor". At the same time, Chu makes the comment that he "foresees a balmy 120°K within a few months" and does not rule out superconductors that can operate at 300°K.

- In March 1987: Marvin Cohen's team at the Lawrence Berkeley Laboratory reports a new yttrium/barium/copper/oxygen compound which becomes superconductive at 100°K.

- In May 1987: Energy Conversion Devices Inc. claims that it has produced a superconducting material with zero resistivity at 155°K, but keeps the composition confidential until it can publicize its findings.

- In June 1987: Five laboratories claim to have tested ceramic oxides that lose all resistance to electrical current at close to room temperature. Energy Conversion Devices Inc. in Troy, Michigan, reports superconductivity in a ceramic oxide at 280.2°K (45°F) containing fluorine. Scientists at the National Physical Laboratory in New Delhi, India, claim partial superconductivity at 299.1°K (79°F). In the Soviet Union, Yoshihiko Otsuki of Waseda University in Tokyo witnesses superconductivity at 308°K (95°F) in a ceramic oxide at the Institute of Low Temperature Physics, Moscow.

- In June 1987: A research collective of Kim Ilsung University succeeds in producing a high-temperature superconductive material, sintered from well-mixed oxides of yttrium/barium/copper at high temperature and the material gives an electrical resistance which drops to zero at 80°K (-193°C).

- In June 1987: Northwestern University researchers confirm Chu's 96°K superconductive material, but cannot confirm Energy Conversion Device's achievement of superconductivity at 155°K.

- In July 1987: Japanese Sumitomo Electric Industries Ltd. develops a superconductor material which has parts of it which exhibit no electric resistance at 300°K (27° Celsius). One of five samples shows the Meissner effect, and remains superconducting for a week. The material is based on yttrium, barium, copper and oxygen, plus "a certain material". Samples measure 7 mm in diameter by 3 mm in thickness and show superconductivity anywhere from 77°K to 300°K.

- In August 1987: Colorado State University says it has isolated microscopic superconducting particles that work at near room temperature.

- In August 1987: University of Maryland scientists claim to have produced a stable compound showing signs of superconductivity at 240°K. The teams say they have fabricated a compound which shows consistently superconductivity near 240°K for over five weeks, with around 2 per cent of the sample exhibiting the Meissner effect.

- In September 1987: At the annual American Chemical Society's meeting, researchers cast serious doubts on claims by investigators of room temperature superconductivity, as the findings have not been able to be reproduced.

- The last word should probably be left with the man that broke the "liquid nitrogen" barrier, Paul Chu. He says that he has identified local surface superconductivity in multiphase ceramics with a temperature of 225°K, and although this second phase seems to come and go, it appears to have a different structure to those which conduct at 90°K.

(Source: <u>Materials Edge</u>, November 1987, article written by Jacqui Robbins) (To obtain a free sample copy of <u>Materials Edge</u>, contact Diana Little by Telex 21383 metbul g, or fax (01) 3378943.)

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4. NATIONAL AND REGIONAL EFFORTS AND PROGRAMMES

(a) <u>USA</u>

<u>Superconductivity bills introduced in Congress</u>

A bill entitled "The National Superconductivity and Competitiveness Act of 1987" has just been introduced by Congressman McCurdy. Its purpose is to create a national programme in superconductivity that draws on the strength of the various agencies and departments. This bill would establish a five-year R&D programme, beginning with FY 1989, to be carried out through consortia for enabling superconductivity technologies composed of industry, university, and research institutions, and operated through designated DOE laboratories. The suggested funding is $150 million a year. This takes into consideration the $50 million for DoD in the President's initiative and provides similar amounts for DOE ($48 million), NSF ($40 million), and NBS ($10 million). The remaining $2 million is for responsibilities designated in the bill to be assumed by the National Critical Materials Council and a Presidential Advisory Commission. Congressman McCurdy's bill also calls for the President to establish "a programme of international co-operation in the conduct of fundamental and basic research on superconducting materials ... [which] shall include the exchange of basic information and data as well as the development of international standards for the use and application of superconducting materials".

Another bill, entitled "The National Superconductor Manufacturing and Processing Technology Act of 1987", has recently been introduced by Congressman Ritter. This bill would establish a manufacturing and processing technology initiative to be implemented mainly by the Defense Advanced Research Projects Agency (DARPA) along with DOE, NSF, and NBS with a co-ordinating council to co-ordinate their activities. The total funding recommended in the Ritter bill is $400 million over five years, with the bulk of the funding ($50 million per year) going to DARPA, with NSF and DOE each receiving $12.5 million per year, and NBS $5 million. This bill also calls for the establishment of a Presidential Commission. (Source: Materials and Processing Report, September 1987)

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Superconductivity drive sparks new policy debates

The key need is co-ordinated federal government programme involving universities and business, together with a policy that integrates government/industrial research relations with Japan.

Superconductivity by now is a term familiar to anyone who reads the daily newspapers or watches the evening news. The discovery of ceramic copper oxide materials that can conduct electricity without resistance at temperatures within or above that of liquid nitrogen has touched off unprecedented excitement in the scientific and technological communities, and an extraordinary amount of "hype" in the Reagan Administration.

What has also been touched off is an apparently new focus for debate about US technology policy. The debate consists of two related parts. One is an attempted harnessing of government, industry and universities into a single big effort to exploit a major breakthrough. The other is to throw a challenge to the country's top technological and economic competitor, Japan. Superconductivity is the symbol around which the US aims to prove it can "compete" in global high technology. Naturally, not everyone sees the picture in the same way.

In late July, the White House Office of Science & Technology Policy with the Department of Energy sponsored a two-day meeting on commercial applications in the field. President Reagan spoke and announced an 11-point federal initiative. About 1,100 attended.

At the meeting, organized by Reagan's science adviser William R. Graham, Energy Secretary John S. Herrington sounded the tone of urgency. "The race to commercialize superconductivity is on," he said. "And the economic prizes await the nation that first discovers a viable, marketable technology. We will face unprecedented international competition. Although we have the jump on our competitors in basic research, we must marshall all our resources and tap our ingenuity to the fullest to compete effectively in the marketplace."

Herrington was aiming his rhetoric mostly at Japan.

A later speech by US Trade Representative Clayton Yeutter also was directed at Japanese competition. Even National Academy of Sciences president Frank Press, known for his measured prose, was drawn into the all-or-nothing rhetoric. Herrington quoted Press as saying, "Superconductivity has become the test case of whether the US has a technological future."

Individual voices are counselling a balanced view. Says Donna Fitzpatrick, assistant secretary of Energy for conservation and renewable energy, "Some people [might be led to believe] we have a near monopoly [in superconductivity] but I do not think it's the way the world works anymore". Adds Roland Schmitt, General Electric's corporate vice president for science and technology, "I would not like to see this superconductivity situation characterized as a life or death situation. I would suspect there will be lots of deals struck between US and Japanese companies."

Meanwhile, government agencies, heeding President Reagan's mandate, are gearing up for expanded work. About $55 million is currently being spent, much of it in funds redeployed from other programmes. More is expected to be asked for in Congress next year. The Pentagon alone is slated to receive $150 million over the next three years.

The immediate goal of superconductivity research is disarmingly straightforward. What is involved is nothing more than developing a piece of ceramic copper oxide wire and a strip of film based on something nature, not any scientist, has produced. In a sense, it is up to science to improve on nature's provision. The wire would be used for coil in magnets, the film for electronic circuits. DOE is taking the lead in funding the former, the Department of Defense the latter. The National Science Foundation and the National Bureau of Standards will be working on the fundamental science and the basic engineering.

There are many, however, especially in DOD, who feel that the time to push applications is right away, anticipating the emergence of test materials a few months hence.

Much of DOD's work will be concentrated in the Defense Advanced Research Projects Agency (DARPA). "We have decided to concentrate our efforts to develop as quickly as possible an industrial technology base for the processing, fabrication, and manufacturing of these new superconducting ceramics," says Craig I. Fields, deputy director for research at DARPA. "We expect to develop small-scale pilot production lines, or 'boutique' factories, as we did with gallium arsenide. We hope to see some concept demonstrations in three or four years. We are relying on other organizations to do the work to establish a solid intellectual basis for understanding the properties of the new materials. We feel this is a situation where engineering must parallel or even precede science."

There are those, however, who believe the Administration should have used the conference to make a case for strengthening the country's scientific base.

William O. Baker, former president of Bell Laboratories and a long time insider in national science policy issues, is one who believes so. "The way the government has gone about establishing a superconductivity policy has been backward," he says. "We don't need commercial razzle dazzle when the fundamentals are a mystery. It was naive to assume that science would automatically be pulled along or that it already existed. We have a severe knowledge deficiency in this country. The lack of scientific and technological literacy is going to hurt us. The universities need additional wisdom. We need to have more scientists. That's what the emphasis should have been on."

Baker also believes the conference should have tweaked chemistry for its lack of imagination and its failure to be more interdisciplinary. "The chemistry departments have been reluctant to do much work in solid state science," he says. "Chemistry, metallurgy, and physics are still backward with regard to collaborative research. It's a challenge to theoretical chemistry and the universities are just not with it."

The Baker argument forms the hub of the technical debate. It is US science that is in crisis, he argues, and the superconductivity campaign diverts the country from a more fundamental science policy agenda - building a more solid foundation by attracting young people to science in the volume Japan and the Federal Republic of Germany do. Yet, even a Baker ally in criticizing Administration hype over superconductivity thinks applications should be given strong emphasis. He is Rustum Roy, materials scientist at Pennsylvania State University.

"The science will happen in any case," Roy contends. "Remember, we are talking about materials nature already has made. I would fund the people with ideas on bringing the product to applications. They will adapt as the ideas come along."

The Government is hoping that many ideas will come out of the federal laboratories, mainly DOE's big national laboratories, such as Argonne, Lawrence Berkeley, and Brookhaven. The national laboratories at present have a total superconductivity budget of around $11 million. But the keys to their potential are their resources and equipment, and some provisions of the Technology Transfer Act passed last year. That act allows the laboratories to collaborate with private industry and involves transfer of patent rights to companies provided they try to commercialize the developments. DOE has great hope that the facilities will pay off for industry.

One sceptic, however, is GE's Schmitt. He believes the national laboratories serve small entrepreneurial firms better than large corporations like GE.

"To work in corporate régimes," says Schmitt, "requires big investments in linkages and communications. We have 600 PhDs in our laboratories and 1,200 technical people at the bench. And those people get 12,000 to 15,000 visits a year from the corporate marketing side. When I look outside General Electric, I see adequate linkage opportunities not with the national laboratories but with universities. Right now I don't have anything in place with the national laboratories. But I think the laboratories working in a mode of spinning off technology and licensing would be the way to go."

But universities need a revival, too. Says D. Bruce Merrifield, Assistant Secretary of Commerce for Productivity, Technology, and Innovation, "We're doing $15 billion a year in basic research in universities, 10 times more than any other nation does or can do. I'd like to see the amount doubled. No one else has [such a basic research structure] in place or can replicate it. And we're largely wasting it.

"The trouble with the universities," he adds, "is that they don't know that there is a marketplace. They have a gold mine in the research they do and they are only beginning to build the patenting and licensing structures to take advantage of the knowledge they are producing."

Merrifield has one initiative he is trying to promote. "We're taking some of our most experienced industrial people - retired executives, vice presidents and technical managers of various corporations - and offering them to colleges and universities to help the institutions identify the potential of their research. These are people on the leading edge of technology who know what the score is." About $1 million is available for that activity through the Technology Transfer Act. In charge of that programme is consultant Lee Rivers, formerly of Allied-Signal Corp., and a recent visiting fellow at OSTP.

To Penn State's Roy, collaboration is necessary but he doubts whether NSF in its programmes is equipped to force such collaboration. NSF, he says, is still too wedded to the disciplines, despite the emergence of its engineering research centres in the universities. "It must force recipients to form interdisciplinary teams within the university itself and with industry," he points out.

"Also," he says, "there should be no peer review because peer review discourages a scientist from revealing his best work. He's afraid it will be stolen by the 'peers'." Roy says the lack of outside peer review by such DOD agencies as the Office of Naval Research makes these agencies models of research support in the field of materials science.

A further belief among senior policy figures in Washington is that Graham's OSTP should be given the power to manage the superconductivity effort. That Graham was able to convince the White House to approve of a conference and even have President Reagan attend speaks for Graham's influence with the President's inner circle of advisers. Where Graham needs to improve, observers say, is in relations with peers and with other agencies.

"Graham didn't even clear the idea of the conference with his own White House Science Council," says one critic. "Nor did Graham consult with the President's own Critical Materials Council." The latter council, chaired by Interior Secretary Donald P. Hodel, was established to assess policy problems around critical material needs for a high-technology era. Nor was NSF director Erich Bloch brought into the planning. "Many are concerned that Bloch's role was too small in discussing the scientific and manpower issues," one critic says. "What will go on are turf wars," he says, "and OSTP must fight against these."

Perhaps the major element missing from the Administration's war-drum rhetoric on superconductivity appears to be recognition of the importance of collaboration with Japan in the field, a development that is more a sign of hope than of despair.

Joint ventures between US and Japanese companies are increasing. In the past year and a half, the Commerce Department's Merrifield points out, 400 joint ventures were set up between US and Japanese companies. The number the year before was half that. Next year, he says, the figure could be 800. "The only way the Japanese can access our technology," says Merrifield, "is going to be through joint ventures - something that expands the economy rather than carving it up into small pieces."

Du Pont, reports Pariser, already has several joint ventures with Japanese companies. It has ventures in fluoropolymers, Kevlar, and Capton, and last year opened up an electrochemical development laboratory in Tokyo. "We've made no joint venture decisions yet on superconductivity," says Pariser. "On our list of things to consider right now is exploring some type of synergism with our colleagues in US companies. Our strength is in materials, less so in forward integrated applications."

Du Pont, he says, established early this year a business development group for superconductivity, much as several other companies have done. "They're looking at various market segments and trying to assess opportunities," he says. "For example, they're asking what the market opportunities would be for a material with superconducting properties at 95 K. We have not been in touch yet with the Japanese, but we have exchanged scientific information with them at open meetings. I certainly don't want to see a big wall built between us and the Japanese, or else we'll both go down the drain."

GE's Schmitt says GE already has a joint venture going in a small area of the superconductivity field through a partnership with Yokagawa Medical Systems involving manufacture of a computer tomography scanner. "This case was interesting in that they started out as our distributor and decided they wanted to license the technology," he recounts. "We said no dice. We wanted a joint venture instead. So we own 51 per cent of the company. It's a good example where American and Japanese skills can match. In this case, we provide the technology, Japan provides the design. One of the nice aspects of teaming up with the Japanese is that we get a nice percentage of the Japanese market."

Revamped government-to-government science and technology relations with Japan are a top item at Graham's OSTP. The action centres around renewal of the Presidential-level science and technology agreement between the US and Japan. Signed originally by President Carter and Prime Minister Masayoshi Ohira in 1980, the agreement is up for renewal now and Graham hopes to make this the official policy framework between the countries in science and technology.

Graham travelled to Japan last February in an effort to lay the groundwork for his position. In one speech he told a group of Japanese science and technology leaders that the US wanted to see "American graduate students, post-doctoral fellows, and senior researchers working in such centres of excellence [in Japan] as the Institute of High Energy Physics in Tsukuba, Institute of Molecular Sciences in Okazaki, Institute for Physical & Chemical Research in Wako, and the Electrotechnical Laboratory in Tsukuba."

A Graham aide put it in blunter terms, "It's time for the US and Japan to work together in sharing risks, costs, and benefits of science and technology. The US and its partners have shared responsibilities. And no one nation should bear a disproportionate burden in maintaining the science and technology enterprise we all need. At any one time we have 100 people in Japan. There are 14,000 Japanese students in the US."

The aide says OSTP is pressing Japan to come up with more in the way of sharing their knowledge. The science and technology goals recently announced by Japan involving a more international thrust in their R&D - such as their Human Frontiers Programme - are considered at OSTP "a cheap way of buying future access to centres of excellence in the West.

"It looked like they were just intending to drop their people off here and there. So we proposed to them that they set up a world class institute for third world scientists. They wouldn't hear of it. So they lost credibility by not doing something totally selfless. Japan is awash with capital. Industry could have given millions of dollars to set up this facility.

"And the complaint that more Americans would be invited if they knew Japanese is a smoke screen. The Japanese have no problem functioning in both languages. The issues that are more important involve how people are received."

The OSTP attitude, shared by the Department of Commerce, is not popular in the State Department, however. State is important because it actually drafts all scientific and technological agreements between countries and sees to it that the language has the appropriate diplomatic nuances.

A State Department official with long experience in Japan criticizes Graham's use of the word "reciprocity" in dealing with Japan because he feels the term implies barriers between the two countries. He says Japanese government laboratories are as open as those in America. "It's true that more Japanese visit the US than we visit there," he says. "But the Japanese Government invests heavily in teaching people English. Very few American companies make the same kind of investment."

The official claims that the debate has been "poorly managed" and claims that OSTP is taking an "amateurish" approach toward foreign policy. "Trying to educate people who don't know the situation is a painful process," he says. "The living standards in Japan are not the same as in America. Very few Americans would want to go to Japan and live like the Japanese do. OSTP is misunderstanding realities when they want to include in the agreement that visiting Americans must live in Japan without any reduction in their standard of living. Western-style houses or apartments run up to $8,000 a month in Japan.

"Another myth is that Japanese are awash with money. OSTP wanted Japan to put more money into the Superconducting Super Collider and the space station. They didn't know the Japanese Government has a more serious deficit problem than we have. Their trade surplus does not go into the coffers of government. Their percentage of total outstanding debt as a percentage of gross national product is higher than ours. And their fiscal policy over the past six years under Prime Minister Yasuhiro Nakasone has been zero growth. We in the State Department don't want to go to foreign countries and rattle the tin cup. We are not going to have an agreement that involves the Japanese spending more money here."

And so it goes. With superconductivity, both the US and Japan seem to have arrived at a new playing turf in their science and technology policies. Remnants of the "America must be first" mentality still persist in the US, whereas many Japanese still believe that theirs is a poor island nation. Neither myth truly sustains either society.

Superconductivity brings national and international science and technology into one context. By focusing on one thing, all things must be considered, from understanding why GE's 1,200 bench scientists can no longer do long-range research in this era of corporate bottom line frenzy, to solving the modest but crucial energy needs of a South Asian village. The dissonance of the dialogue only demonstrates how few really seek to understand its scope.

Superconductivity initiatives feature $150 million for Defense Department

During July's federal conference on superconductivity, President Reagan outlined several government programmes to spur developments in superconductivity and other technologies. He spelled out a total of 11 initiatives to:

- Expand antitrust laws to allow corporations to enter joint manufacturing ventures.
- Amend patent laws so that US owners of process patents can sue foreign manufacturers when they export to the US a technology that infringes the US patent.
- Tighten Freedom of Information Act rules to prevent commercially valuable technical information generated in government laboratories from being disclosed to foreigners.
- Establish expert Superconductivity Advisory Group to advise the Administration on research and commercialization policies.
- Establish Superconductivity Research Centres at Argonne, Lawrence Berkeley, and Ames national laboratories, and at the National Bureau of Standards' Boulder, Colo., laboratory. Allocate $150 million to the Department of Defense for a three-year programme of superconductivity research for military systems. Expand National Science Foundation superconductivity research and engineering by transfer of funds from other programmes.
- Accelerate federal, university, and industry co-operation in research.
- Accelerate patent procedures for superconductivity uses and court suits.
- Accelerate standards work for superconductors and related devices and materials.
- Expand reallocation of agency funds into superconductivity research.
- Speed up sensor and electronic work at NBS and DOD.
- Seek more US involvement in Japanese superconductivity research.

Argonne gets major role in national superconductivity effort

Argonne National Laboratory near Chicago has been tabbed by the Administration to take the federal lead in catalyzing the transfer of commercial uses of superconductivity from the public sector to business. The laboratory has been doing research on superconductivity and on ceramic materials for 20 years and has established under Gregory Beslo a superconductivity applications office within its Technology Transfer Centre. In June it held a meeting outlining Argonne's capabilities to almost 200 representatives of industry.

The centre itself was set up some years ago to seek out promising Argonne research for licensing to the private sector. Proprietary aspects will be handled through a non-profit entity known as ARCH Development Corp. ARCH is an acronym combining Argonne and the University of Chicago, which manages Argonne under a Department of Energy contract. As manager, the university is the automatic owner of Argonne inventions and, through ARCH, licenses inventions to interested corporations. Half the royalties, however, will be contributed to Argonne's research budget.

The centerpiece of the superconductivity outreach effort at Argonne will be an industrial affiliates programme modeled after many that already exist in the country's major technical universities. Beslo says the programme, costing companies with fewer than 500 employees $15,000 a year and larger companies $25,000 annually, will organize yearly meetings that will review progress in the field, publish a newsletter for members, and provide preprints and reprints of research plus market analyses of new commercial ventures. In addition, Beslo says the centre will provide affiliates - who will be from R&D, manufacturing and financial fields - one consulting day per year at Argonne and it will send out experts to provide seminars at affiliate sites.

To protect proprietary information, affiliates will have to sign nondisclosure agreements to ensure that important findings are kept within ARCH. In addition, Beslo says Japanese firms will not be eligible for affiliate membership. Whether US companies that engage in joint ventures with Japanese firms will be allowed membership has not been determined.

Through its economic development activities, the state of Illinois is also hoping to cash in on the enthusiasm for superconductivity. So an equally significant move at Argonne is a planned Illinois Superconductivity Institute that would draw upon superconductivity work at Illinois Institute of Technology, Northwestern University, University of Chicago, University of Illinois, Argonne, and Fermilab. Illinois believes it has the best concentration of superconductivity research and applications talent in the Western world and is hoping to build a "Superconductivity Valley" on the plains of northern Illinois.

Looking down at it all with considerable pride is Argonne director Alan Schriesheim. "In superconductivity," he says, "Argonne has the largest nonindustrial basic programme in the country. And with our work in basic ceramics, too, we can easily mesh a basic and applied programme. We also have the facilities to examine structure. If there is a game to be played here, Argonne will certainly always be a player."

Science adviser Graham boosts Keyworth's new venture

As a direct result of the current superconductivity hoopla, various consulting groups are forming to advise industry of trends and opportunities in the fast-moving field. But during July's federal conference on superconductivity, science adviser William R. Graham singled out only one for a plug - that formed by his predecessor, George A. Keyworth II.

Graham announced before his largely industrial audience that Keyworth, now a Washington consultant, was setting up a non-profit "Council on Superconductivity for American Competitiveness". Keyworth will be chairman; Roland Schmitt, vice president for corporate science and technology for General Electric and chairman of the National Science Board, will be vice chairman.

Members of the council board are yet to be announced, but, according to Keyworth assistant Bruce Abell, the new organisation will "bring together knowledgeable people to share insight with members and get first-hand information on things that are going on and where they are heading". Keyworth was working on the idea before the conference began, Abell says, and the council will try especially hard to attract members who are not "first line" companies in the field.

The big distinguishing feature of Keyworth's council, says Abell, is that it "focuses on a technology that cuts across a whole range of industries and government areas." Japanese corporations will be excluded from purchasing membership.

* * * * *

Superconductivity: key research areas targeted

A National Academy of Sciences report commissioned by the federal government calls for an eight-point programme of research in the field of high-temperature superconductivity plus, as a beginning, about $100 million a year in federally sponsored research in this booming field.

The report was prepared by a 26-member panel headed by John K. Hulm, director of corporate research and R&D planning for Westinghouse Corp. It was issued as part of a continuing series of research briefings on various fields by the Committee on Science, Engineering and Public Policy.

Superconductivity is all the rage these days because of the discovery of copper oxide ceramic materials that conduct electricity at or above the temperature range of liquid nitrogen. The panel is excited along with everyone else in materials science and technology. Although acknowledging that a lot of theory needs to be done to understand the phenomenon, it says "enough is already known to encourage commercial development efforts with the newly discovered materials". The commercial market for superconducting devices currently is around $400 million.

The report says the "precommercial exploration period" will last about a decade. But near-term prospects for applications of high-temperature superconducting materials include magnetic shielding, the voltage standard, superconducting quantum interference devices (SQUIDS), infrared sensors, microwave devices, and analogue signal processing.

Long-term prospects, it says, include large-scale applications such as microwave cavities, power transmission lines, and superconducting magnets in generators, energy storage devices, particle accelerators, rotating machinery, medical imaging machines, levitated vehicles, and magnetic separators. In electronics, prospects include computer applications with semiconducting-superconducting hybrids, Josephson devices, or novel transistorlike superconducting devices.

Hulm's group picks out eight major areas of research that it believes need emphasis in exploring the new materials:

- Improved understanding of such properties as transition temperatures, critical magnetic fields, critical currents, and alternating current losses in superconductance.

- Understanding of the basic molecular mechanisms responsible for superconductance.

- Synthesis of new compositions, structures, and phases as part of an intensified effort to develop further promising materials.

- Preparation of thin films of controllable and reproducible quality, and establishment of improved techniques for growing films suitable for fabricating electronic devices.

- Development of bulk conductors from current materials with special emphasis on enhanced current-carrying capacity.

- Advanced understanding of synthesis, processing, stability, and large-scale production of the materials.

- Fabrication of prototype circuits and electronic devices based on superconducting microcircuits or hybrid superconductor/semiconductor circuits.

- Fabrication, as bulk conductors are developed, of a range of prototype high-field magnets, ac and dc power devices, rotating machines, transmission circuits, and energy storage devices.

The panel recommends that the Government appropriate $100 million for fiscal 1988 to accelerate the effort. About $30 million is being spent now in reappropriated federal funds. And the panel estimates that at least that much is being spent by industry on the science and technology of the new materials.

It says a mechanism should be established to monitor the potential demand for manpower to prepare for the time when technologically appropriate materials are developed.

The panel also calls on the Government to review progress in the field 12 months hence as a guide to establishing further levels of support. It wants the Government to assure that industry remains internationally competitive in the field by linking up with university-based engineering centres supported by the National Science Foundation and by sundry cost-sharing projects between Government and industry on proof-of-concept projects.

* * * * *

The President's superconductivity initiative announced

On 28 and 29 July close to 2,000 US businessmen, engineers, scientists, plus numerous members of the Press, both US and foreign, gathered in Washington, D.C., at the Federal Conference on Commercial Applications of Superconductors to hear about the status and commercial potential of the recent breakthrough in high-temperature superconductivity and the Government's plans to foster US leadership in realizing its commercial promise. The impressive display of government unity with the presence of President Reagan, Secretaries Herrington, Schultz, and Weinberger, plus many agency heads bespoke the administration's commitment to bring government and industry together.

In his address, President Reagan announced his 11-point "Superconductivity Initiative". It includes "a 'Wise Men's' advisory group on Federal policies and regulations that affect superconductivity research and commercialization; 'quick start' grants for good ideas on processing superconducting materials into useful forms; the establishment of a number of superconductivity research centres; and a nearly $150-million R&D effort by the Department of Defense (DoD) over three years".

With the exception of DoD, no other specific agency funding was mentioned. Rather the federal agencies are encouraged "to continue to reallocate

FY 1987 funds into superconductivity basic research, applied research in enabling technologies, and prototype development". They are also "directed to place a high priority for this area in FY 1988 funding and in FY 1989 planning". At present the total government spending on the new superconductor activities is around $50 million, all of which is reprogrammed money. While this may not have a detrimental effect on existing programmes in the short run, if new money is not allocated, ongoing productive programmes would most certainly suffer.

In the area of legislation, the President announced that he would soon send a legislative initiative to Congress addressing the issues of antitrust, patents, and the Freedom of Information Act. The first issue addresses amending the National Co-operative Research Act to expand the concept of a permissible joint venture in order to reduce the perceived risk of businesses that certain joint production ventures could expose them to antitrust legislation. The second issue addresses the protection of intellectual property rights by amending the US patent laws to increase the protection for process patents. And the third issue would authorize federal agencies to withhold from release, under the Freedom of Information Act, certain commercially valuable scientific and technical information.

This last appears to be somewhat at odds with the 11th point of the President's Superconductivity Initiative, which states a desire to take "advantage of the opportunity presented by the current negotiations for renewing the US-Japan Agreement on Science and Technology to seek reciprocal US opportunities to participate in Japanese government supported research and development, including superconductivity". This agreement - which became effective in 1980, was extended for two years in 1985, and then for an additional six months last April - it comes up for renewal in October.

A key point in the initiative that is already being implemented is the establishment of a number of Superconductivity Research Centres at the Department of Energy (DOE) National Laboratories to conduct basic research and serve as repositories of information to be disseminated throughout the scientific community. The Centre for Superconductivity Applications will be at Argonne, The Centre for Thin Film Applications at Lawrence Berkeley, and the Centre for Basic Scientific Information at Ames. To supplement these activities, Secretary Herrington has designated Los Alamos to "explore private sector interest in the establishment of co-operative research programmes to develop enabling technologies for commercial applications of superconductivity".

The DOE's Office of Scientific and Technical Information at Oak Ridge is developing a superconductivity information system with the ultimate goal of making it available to business and academia. On 6 July an electronic mail system and bulletin board for sharing current information went on line, and on 3 August a data base of searchable work in progress with initial input from DOE contractor researchers became available. Scheduled for completion by 14 September is a fully searchable preprints data base. To date, the scope of system users has been limited to DOE researchers and contractors but will soon be expanded to include business users, within the limitations of the present equipment (200 password holders).

The National Bureau of Standards (NBS) Laboratory in Boulder is designated as a Centre for Electronic Applications. Since the early 1960s when intermetallic superconductors with magnetic fields of 10 tesla were discovered, this laboratory has been at the forefront of superconductivity technology. The NBS Laboratory in Gaithersberg has been directed to "accelerate its efforts to develop and co-ordinate common standards". However, here again no additional funds have been suggested.

The National Science Foundation (NSF) has also been requested to support additional superconductivity research programmes in three of its materials research laboratories, and to initiate the "quick start" grants for processing research mentioned above. (Source: Materials and Processing Report, September 1987)

(b) Japan

AIST airs superconductivity-related development policy

In March 1987, the Agency for Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI), announced a "Policy for Development of Superconductivity Related Technology". The policy will promote the elucidation of theories on superconductivity and efforts to find new materials by doing the following: (1) establish a round-table committee on the development of superconductivity-related industrial technology; (2) further emphasize the research on superconductivity being carried out in national research institutes; and (3) conduct feasibility studies and research on equipment and materials related to the application of superconductivity to power generation.

A. Background

1. In connection with raising the temperature at which superconductivity occurs, revolutionary progress has been made in research by foreign and domestic laboratories since last year. It was announced that superconductivity was realized at a temperature above the nitrogen liquidation temperature (77K) and this was followed by new observations concerning new materials. It has reached a point where the possibility of superconduction at normal temperatures is being discussed.

2. Last autumn, upon receiving scientific information from the Zurich laboratory of IBM that high-temperature superconductivity was possible in oxides, Tokyo University immediately proved that this could be done. This, along with basic research on superconductive substances by the electronic technology research institute and other Japanese research organizations, are greatly contributing to research on superconductivity.

Furthermore, MITI has always been aware of the great potential of superconductivity by heavily promoting the elucidation of the basic structure of superconductivity and R&D on high-temperature superconductive materials, the Josephson device, superconductive wire, and superconductive electric power equipment by laboratories under the sponsorship of AIST or through co-operation with private firms.

3. Although there are a lot of problems with superconductive materials that have to be resolved, such as increasing the electrical current the materials can support and improving processability, if these can be established as industrial materials in the future, it will simplify handling and drastically reduce the cost of media for cooling. Therefore, it can become a broad-based industry which can be used for low-currency products such as devices and their circuitry for superfast computers and strong currency products such as highly efficient electromagnets for medical equipment, energy generation, transport equipment and precision measuring equipment. It has great potential for contributing to human progress and the potentials of the technology itself are boundless.

4. Based on this important breakthrough in basic technology concerning superconductive matter, we will continue to make contr [illegible] ions globally to the technological revolut [illegible] the area of basic technology, with a vi [illegible] rd realizing superconduction at norm [illegible] mperatures, by moving forward with a broad range of efforts to elucidate theories on superconductivity and find new materials. Along with this, we will seek to enhance properties of superconductive features and processability of materials that already have been developed in order to establish and apply them as industrial materials. To do the above, it will be necessary to further strengthen our R&D system.

Toward this end, MITI will take the following measures:

(Note: Superconduction is the phenomenon wherein electrical resistance is zero when certain substances are cooled to extremely low temperatures.)

B. Content of the policy

1. Establishment of a "roundtable committee on the development of superconductivity related industrial technology" (an advisory committee to the director-general of AIST)

(a) The roundtable committee will convene its first meeting in mid-April 1987 and will compile a report within the year. (It will compile an interim report around June 1987.)

(b) Items to be studied:

(i) Recent technological breakthroughs and future prospects concerning superconductive materials.

(ii) Impact of the breakthroughs on future industries.

(iii) Selection of topics that should be taken up at the national level as topics in future policy on industrial technology.

(c) Others:

(i) General affairs for the committee will be handled by AIST.

(ii) Specific content of technology and areas of application to be covered by the roundtable committee will be considered at the expert level.

2. Strengthening research on superconductivity in national research institutes

Regarding research on matter that is superconductive at high temperatures and the development and application of high critical temperature superconductive materials, R&D is being conducted in the electronic technological research institute as a special research project entitled "research concerning extremely low temperature electronics". We will raise the priority on accelerating this project and build a system for research co-operation in this field which will be headed by this institute and will include such organizations as the chemical technological research centre, the Nagoya industrial technological laboratory and the textile and high polymer materials research centre.

Additionally, research on organic superconductors, which is being carried out in the electronic technological research institute under R&D on conductive high polymer materials as a part of R&D on next-generation industrial key technology, will be continued in FY87. (Allocation from the budget will be ¥327,946,000.)

3. Feasibility survey and research on superconductive power generation equipment and material technology

Additionally, as part of the "Moonlight Project" (project to develop energy-saving technology), in FY85 and 86, a broad-ranging feasibility survey was conducted on the technological and economic possibilities of a highly efficient power generator that applies the phenomenon of superconductivity. Continuing with this, experimental production and assessment of superconductive wire and conceptual design of the power generator are scheduled to be implemented in FY87. (Total budget will be ¥100 million.)

(See annex 1 for the results of the FY85-86 feasibility survey.)

Annex 1

Summary of feasibility survey on superconductive power generation related equipment and material technology

A. As part of the "Moonlight Project" (development of energy-saving technology), AIST conducted a two-year feasibility survey in FY85-86 on equipment and materials technology applying the phenomenon of superconductivity.

AIST commissioned a company, "Technova", with the survey and research. It was headed by Akira Yamamura (Professor emeritus of Tokyo University and a director of the electric power central research institute) and conducted with the participation of over a hundred experts from academic and industrial circles and the national laboratories.

B. Main results of the survey

1. A superconductive power generator would be more efficient than a conventional generator because rotors made of superconductive material would create strong magnetic fields. It would have the following advantages over existing generators:

(a) The size and weight of the generator would be reduced (reduce axis length by 40 per cent and weight by 50 per cent).

(b) The stability of the electric power system would be increased (increase transmittable power by 50 per cent).

(c) The generator's efficiency would be raised 0.5-0.7 per cent.

(d) A superconductive generator is more economical than a conventional generator beginning with 300,000 kilowatt (KW) class generators, and the larger the generator, the greater the economic benefits. (Annual cost benefit in the 1 million KW class would be ¥700 million.)

2. Technological development topics

(a) Armature (stator) structure and materials: development of air gap coil structure (completely new topic).

(b) Rotor structure and materials: development of multi-cylindrical structure that could withstand high-speed rotation and that could be cooled easily (completely new topic).

(c) Cooling system: generally speaking, the lower the temperature of superconducting materials, the more possible it becomes to create strong magnetic fields.

3. Technological effects

Wire used in generators and power equipment must be able to withstand the most rigorous conditions Consequently, development in this field will contribute to the development of high-performance wire for use in superconductive transmission cable, transformers and magnets.

4. Proposed development programme

Phase 1 (about eight years) will be for the development of technology to make wires from superconducting materials such as oxides. Using a 70,000 KW model generator, data on reliability and basic data for bigger generators will be collected. It will be possible to complete the model generator in the fifth year of this phase, and it will take two years for test operation.

Phase 2 (four-six years) will be to introduce a 200,000 KW pilot generator into an electric power system and assess its performance.

Phase 3 will be for the production of demonstration equipment.

C. Relationship with high-temperature superconductive materials

Research aimed at making wires from superconductive materials is important. The development of usable wires with high critical temperatures and with the ability to support high currency will contribute to reduction of cost and increase in reliability. (Source: TSUSANSHO KOHO, 30 March 1987)

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Superconductors in Japan

The state of play

If the business at hand were not so deadly serious, the superconductor "bumu" (boom) now sweeping Japan would be glorious black comedy - the International Trade and Industry Ministry (MITI) slipping into its most comfortable role of encouraging Japan's private sector to unite and conquer, while nervously guarding its rear from attacks by other ministries; university professors and research staff scrambling back to their laboratories before sun-up, to catch what the first newspaper editions are saying their competitors achieved overnight; publishers madly commissioning books on "superconductivity" to fill already well-stocked bookshop shelves on the subject; an Osaka rare earth importer fending off 30 inquiries a day for his "Superconductivity Kit" with weekly sales topping about 100 ... at up to $US 4,450 each; while researchers at a government laboratory in Hokkaido expound the virtues of rice husks for commercial superconductor applications.

"In March and April, everybody was trying to find out about the new oxide superconductors," recalled Ienari Iguchi, an associate professor in Materials Science at Tsukuba University outside Tokyo. "Then in May there were new discoveries about higher temperatures being reached and it was not until September that the fever calmed down. But there are several symposiums planned in Nagoya and near Nikko in the next few weeks and so now we have to see what's going to happen next."

Last spring, Iguchi was among the napless hundreds in research institutions and private companies across Japan who staggered home at around 3 am "for a nap" before rushing back to scan the Electronics Section in morning papers like the Nihon Keizai Shimbun - with a circulation of 3.5 million. But such demonstrations of devotion to the cause should be viewed in context.

Spiteful mutterings - coming mostly from across the Pacific - about the cunning Japanese capitalising on yet another Western scientific advance are based more on a highly aroused state of paranoia than any genuine view of developments in Japan. Like everyone else, the Japanese have their eyes firmly fixed on a high-temperature, stable and large-capacity grail of superconductors - and part of a market prize some say will be worth $US 70,000 million by the turn of the century. But apart from excited press statements, new books and other shiny trappings, Japan's knights are largely a dishevelled lot and they have not progressed much further in the quest than their Western counterparts.

Surprising discoveries

The superconductor fever that gripped Japan last spring arose more out of stunned surprise than anything else. When the research papers of the Bednorz and Mueller discovery were published in April 1986, the Japanese joined the flurry of international research though not with the same zeal they would show 12 months later. For one thing, IBM's scientists still used liquid helium which, in their eyes, did not amount to much of a breakthrough.

By the time of the Zurich discovery, several Japanese university research laboratories were well into their second decade of superconductor development. In fact, several months before that first "higher temperature" discovery was made in December 1985, Japan had unveiled its first electromagnetically-propelled train. This was the so-called HSST of High Speed Surface Transport train that Japan Airlines and Sumitomo Electric began building as early as 1974 - and one the CIA allocated $55,000 for bribes in an attempt to get the blue-prints. The train is propelled by a linear motor using helium-cooled superconductor electromagnets and gave pleasure rides to visitors at the 1985 Tsukuba Expo. Companies like Hitachi and NEC are no strangers to "conventional" niobium-titanium alloy superconductors.

Japanese lead in applications

Industry observers suggest that while researchers in other countries - notably the US - are more likely to beat the Japanese at being the first to define high-temperature superconductivity and "further the process of understanding", it is the Japanese who will lead in applications.

Still back in 1985 and long before Houston University's Paul Chu revealed his magical green-coloured oxide - which sent Japanese laboratories plugging electrodes into almost every green substance they could think of - Japan was already toying with superconductor applications.

The playgrounds were laboratories belonging to MITI's Agency of Industrial Science and Technology (AIST), in many universities across Japan and at research centres in scores of private companies including Hitachi, Sumitomo Electric, Mitsubishi Electric and Toshiba. The government-sponsored work dove-tailed with existing programmes like AIST's multi-billion yen "Moonlight Project" research programme begun in 1976 concentrating on advanced technology in energy conservation.

On the corporate side, Toshiba had been making laboratory-scale superconducting niobium-tin magnets and coils since the mid-1960s in conjunction with bodies like the Japan Atomic Energy Research Institute and the Electric Power Industry Central Research Institute; Mitsubishi Electric superconducting wires were used in rotary condensors, resulting from work begun in 1963; and Hitachi has been making niobium-titanium multifilamentary cables for superconducting magnets for over a decade.

However, Professor Chu's announcement on 15 February that he had achieved superconductivity at -180° C rocked Japan's scientific world. Apart from the obvious - that Chu had confirmed what Bednorz and Mueller had only suggested was possible - there were two other reasons for Japan's excitement, epitomised by Shoji Tanaka's "I can sense a new age coming".

New age dawning

Arguably of lesser import was the fact that Chu had monitored a superconductive reaction at above -196° C, the temperature of liquid nitrogen. This was of significance because Japan cannot make liquid helium locally and had been importing almost all of its requirements from the US. In October, the liquid helium price in Japan ranged between 3,000 and 4,000 yen per litre, while that of liquid nitrogen - which can be manufactured domestically - was only 45 yen per litre. Suddenly, superconductors became a lot more commercially attractive for Japanese companies.

The second reason was that the Japanese had been so close. Assistant professor of engineering at Tokyo University, Koichi Kitazawa, recalls that when Chu made his announcement, his students jokingly suggested he should resign. Kitazawa, working under Japan's superconductor pioneer, Shoji Tanaka, had been experimenting with green-coloured ceramics through much of 1986 when Kitazawa told his students to drop the green stuff since he thought "superconducting materials cannot be green-coloured". But as an embarassed Kitazawa observed, "If I had not made this misjudgement, our group might have hit upon the substance ahead of Doctor Chu".

Pipped at the post but not out of the competition, Chu's discovery ignited an explosion of Japanese research that produced results almost immediately. In early March, AIST's National Research Institute for Metals (NRIM) announced it had achieved Chu's critical temperature; on 17 March a research group at Kagoshima University in Kyushu claimed it discovered a ceramic that superconducted at "room temperature" or 14° C. On 3 April, a team at Tohoku University announced superconductivity at -178° C and another government laboratory -173° C, a day after Toshiba announced it had made the world's first "higher temperature" superconductive wire. Hokkaido University would soon announce it had pushed the critical temperature up to -98° C, followed over the next few weeks by numerous other "record-breaking discoveries" that were all signs that Japan's infectious superconductor fever was spreading.

The speed with which laboratories scattered the length and breadth of Japan, announced similar discoveries clearly shows the high level of superconductor research activity existing long before Chu's revelation. But, as Chuck Goto, a securities analyst with S.G. Warburg Securities in Tokyo suggests, quantity does not mean quality.

"Most of the statements being made are garbage," he told ME. "Nobody has defined exactly what 'superconductivity' is and so the criteria each uses to judge when a material superconducts is different."

Goto was among the hundreds who packed a Tokyo auditorium recently at Japan's first international symposium on superconductivity. "I was very disappointed because even there, scientists were contradicting each other over what makes a material superconduct," he said. Tsukuba University's Iguchi agreed saying, "there is still lots of controversy about the mechanics of this new oxide superconductor and nobody really knows what is going on."

But there are still problems

And while Tokyo University's Tanaka and others are excited by the prospect that room temperature superconductors will inevitably become a reality, Iguchi for one is far more cautious. "If I assume they exist - that physics and their atomic structure permit them to be made - then probably they will be developed in a few years. But before saying that, I must be convinced that it is physically possible to make a room-temperature superconductor," he said, adding "I am not convinced yet."

The question of stability is one plaguing superconductor researchers the world over. In August, MITI's Electrotechnical Laboratory, also at Tsukuba, made two samples using a yttrium-barium-strontium-copper oxide compound which has a critical temperature of 65° C or 338° K. But observers say the two were among over a hundred samples the ETL made, were extremely difficult to reproduce - let alone in the millions for commercial applications - and their superconductive state disappeared after 10 days at room temperature. Sumitomo Electric Industries announced in late June it had made a "room temperature" superconductor where all electric resistance was lost at 27° C or 300° K.

Most work proceeding now in Japan involves the use of that yttrium-barium-copper compound whose characteristics - that it superconducts at between 90 and 95° K or above liquid nitrogen - are at least known and fairly predictable if not completely understood.

The next barrier Japan is trying to overcome is applying the technology of carefully-mothered laboratory samples to the harsh world of product fabrication - either in the form of superconductive wires or thin films less than a micron thick.

In laboratory experiments, yttrium oxide, barium carbonate, and copper oxide are mixed with other ingredients in powdered form, pressed then sintered at about 900° C to make a superconducting ceramic pellet. MITI's NRIM has made similar pellets which boast critical temperatures of up to 123° K or well above liquid nitrogen. However, when the NRIM tried pressing the ceramic into a thin copper-nickel alloy tube to make a superconducting wire, the properties deteriorated and the wire had to be cooled to 30° K or -243°C (liquid helium temperature) before it superconducted. Hitachi, IBM and others have also been faced with the same problems when trying to make thin films.

Making the ceramics is not the problem. Apart from the major electronics manufacturers like Sumitomo Electric and NEC, non-ferrous metal smelter Mitsui Mining and Smelting, and steelmakers Nippon Steel and Kawasaki Steel have announced they too have made Ba-Y-Cu-O based ceramics which superconduct at about 90° K.

But few, however, have successfully made stable superconducting products. Hitachi Cable, with many years' experience in niobium-titanium superconducting wires (it developed cables for the magnets used in another linear train built by Japan Railways), has only managed 93° K for its oxide wires. Another cable maker, Fujikara Ltd., has only managed 89° K with its wire while Japan's telecommunications giant, Nippon Telegraph and Telephone (NTT) has pushed this to 84° K (-189° C) with a thin film made at its Optoelectronics Laboratory in Tokaimura, north of Tokyo.

Advances in densities

What is significant about NTT's advance, revealed last August, is that when the temperature was lowered to liquid nitrogen's— -196° C, NTT could pass boost current density to 1,800,000 amps per sq. cm. This is important because to make a superconducting magnet, the density of the electric current passed through the wire coil must be at least 100,000 amps or 1,000,000 amps per sq. cm or the magnetic field created will not be strong enough. Moreover, NTT claimed that the capacity of its film to carry large amounts of electric only deteriorated after 75 days. "The development of this film will greatly enlarge the scope of superconductivity applications", said Toshiaki Murakami who heads NTT's research group.

Perhaps it will, but then producing one film between 0.6 and 0.7 microns thick and churning out millions to the same rigid specifications for commercial applications is quite different. As Yoichi Kimura of MITI's Electrotechnical Laboratory observed, "There is still a wide gap between possibility and reality and finding a breakthrough in the existing technology is our chief concern".

One thing is certain, however. When that breakthrough is made - whether inside or outside Japan - MITI's years of work in building a structure where advances in fields like superconductors can have immediate import, will quickly pay off. (Excerpts from Materials Edge, March 1987 article, written by Russ McCulloch in Tokyo) (To obtain a free sample copy of Materials Edge, contact Diana Little by tlx 21383 metbul g, or fax (01)3378943)

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(c) Europe

UK establishes joint committee to support developments in superconductivity

The UK's Department of Trade and Industry (DTI) and the Science and Engineering Research Council (SERC), formed a joint committee in October 1987 to co-ordinate support for developments in superconductivity.

Chaired by Sir Martin Wood (Oxford Instruments), the committee will include representatives from industry, academia, and government, and will have responsibility for advising both SERC and DTI on national research and development priorities in an effort to boost the UK effort.

Both DTI and SERC have supported research and development in conventional superconducting technology for many years, although recent developments have led to a re-examination of needs in this area. The potential advantages of superconducting materials at room temperature are, of course, enormous, and one of the first tasks, therefore, will be to help select the location of the University Research Centre for Superconductivity. The committee will also assess national education and training needs.

In order to further encourage industrial/academic collaboration and keep in close touch with developments abroad, the DTI and SERC have appointed Dr. Ian Corbett as the UK's Joint Co-ordinator for Superconductivity. He is Head of the Applied Science Division at the SERC Rutherford Appleton Laboratory, and part of his role will be to ensure that industry and academia are well informed about the policies of the national committee for superconductivity. (Source: European Science Notes, 23 October 1987)

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Superconductors - a technological revolution

Multiple applications

Superconductors have many different technological applications and if, as current research indicates, we can reach higher temperatures, if possible close to the ambient temperature, this will signify a real industrial revolution, especially for:

- The carrying of electrical power in high tension lines where some 10 per cent of the terawatts produced are now lost;
- Superconductor magnetic levitation trains, which could travel at 400 or 500 Kph without wheels, as extremely powerful magnetic fields keep the train gliding above the track. Only superconducting magnets can produce magnetic fields of sufficient strength. At present the Japanese (HSST) and German (Transrapid) prototypes would necessitate the cooling of superconductors to the temperature of liquid helium, which makes this type of transport excessively expensive;
- Electric cars where energy would be stored in superconducting coils;
- High-power motors, generators, etc.;
- Very compact computers.

As we can see, there are numerous applications covering wide sectors of our economy. That is why the international scientific community has moved very fast to take up this challenge. This is particularly true in Europe, especially as that is where new materials were initially discovered.

Two European meetings have been held under the aegis of the Council of Europe and the European Community to take stock of research and applications in the field of new materials: superconductors.

The first was held in Strasbourg at the Council of Europe under the aegis of the European Materials Research Society (EMRS) which gathers every year to take stock of progress in research into and the applications of new materials. As a very great deal is at stake, discussions this year were substantially devoted to these questions.

A second meeting at Genoa made it possible to continue discussions and compare the most recent findings.

The European research community thereby intends to play a full role in meeting this challenge in order to place European industry in a favourable position and ensure that we maintain a presence as far as future applications are concerned. (Excerpted from Forum Council of Europe, 2/1987, article written by Jean-Pierre Massué, Head of the Higher Education and Research Division, Council of Europe and Paul Siffert, President, EMRS, Centre de Recherches Nucléaires, Strasbourg.)

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First European workshop on high T_c superconductors and potential applications

The first European Workshop on High T_c Superconductors and Potential Applications was held in Genoa, Italy, from 1 through 3 July 1987. Its goals were to review European progress in this field and to formulate strategy and policy for the direction and support of future work, both in basic research and technological development. There was sharp awareness of the competitive nature of work in this field, and the need to at least keep pace with advances in the US and Japan. The outlook was intended to be European, rather than national, with the EEC fostering and to some extent supporting strong intra-European co-operation. Presentations on materials preparation and characterization occupied slightly more than one day of the workshop, and applications the second day and evening. The last day's activities included two invited talks describing the status of American and Japanese work, and panel discussions on European policy and initiatives.

The general response in most European countries to the challenge presented by the new high T_c superconductors has been to organize interdisciplinary groups to provide a large range of sample preparation and characterization techniques. Many members of these groups have little previous experience in superconductivity, their expertise being in metal oxides, perovskites, and other relevant fields. Most of the presentations of research results at the workshop were in the form of posters, there being about 100 of these out of a total of about 150 contributions. In many cases virtually identical work was presented independently by several groups, with mutually consistent results. There was no representation from the USSR, and almost none from Eastern Europe.

Ideal structures

There is now general agreement on the structures of the two classes of superconducting compounds exemplified by $Ba_xLa_{2-x}CuO_{4-y}$ and $YBa_2Cu_3O_{9-y}$, having transition temperatures T_c near 40 and 92 K respectively. The essential roles of O content and Cu valency were demonstrated by many groups, which described changes in particular properties as samples underwent compositional and structural transitions between superconducting and normal phases. These transitions could be achieved reversibly by annealing and cooling in O or inert gas atmospheres. Details of temperature, pressure, cooling schedule, etc. all affected the outcome. In the case of Y-Ba-Cu-O, for example, appropriate annealing in O yields the black, slightly O-deficient, orthorhombic, mixed Cu valency superconducting phase.

Several presentations dealt with the location of the O vacancies essential to the superconductivity. For example, F. Baudelet and co-workers (LURE, France), used extended X-ray absorption fine structure (EXAFS) to determine the average distance and number of nearest O neighbours for Y and Cu atoms in Y-Ba-Cu-O. Measurements at the Y K-edge showed no change with deoxidation by annealing in inert gas atmosphere. However, the Cu K-edge results indicated a decrease in the number of surrounding O atoms. This demonstrates that the superconductivity is associated with the appearance of O vacancies in the basal planes of the structure, which contain square planar-co-ordinated CU^{2+} atoms. In these planes the Cu and O atoms form chains along the b-axis. Complementary results concerning the location and ordering of O vacancies were obtained by electron microscopy by M. Alario-Franco (Faculty of Chemical Sciences, Spain) and others. In general, the structures of the ideal high T_c superconductors seem to be reasonably well understood.

Structure defects

A general theme permeating discussion of nearly all measured properties was the role of grain boundaries, and the related problem of twinning. Put another way, one wonders whether measurements are indicative of bulk or surface/intergrain effects. That the composition, and therefore the structure of the surface and interior of the grains differed strongly, was demonstrated for Y-Ba-Cu-O by scanning Auger electron spectroscopy (AES) by R.O. Toivanen et al. (Helsinki University, Finland). Clean surfaces were obtained by ion sputtering, scraping, or breaking in vacuum. Compositional maps for the four constituents mimicked some features of the granular topography, and showed great irregularity. The altered "surface" compositions seem to extend hundreds of Angstroms into the grains.

No one seems to have observed single crystals of Y-Ba-Cu-O free of twinning. The twins appear upon transition to the orthorhombic structure. Measurements in an electron microscope by M. Marezio and his group at France's National Centre for Scientific Research indicated a twin size and resultant domains of order 500-1000 A. Heating in vacuum by means of the electron beam used for imaging caused reduction of the sample and domain wall changes, indicating the relation between O content and twinning. The orthogonal orientations of square planar Cu-O units in neighbouring domains could be observed in the scanning electron microscopy (SEM) photos. A suggestion was later made by S. Amelinckx (SCK/CEN, Belgium) that growth under stress might yield untwinned single crystals. This is important since with twinned samples, investigation of the a/b anisotropy in the basal plane is difficult.

Many other classes of structural defect have been observed in otherwise "good" crystalline regions of samples. Some examples by B. Raveau (University of Caen, France) are: regions of order 100 A with larger or smaller O content causing altered structure inclusion; sections of extra planar units which cause bending of the surrounding planes; shifts of registry of the La and Ba, or Y and Ba planes. These show up clearly in SEM photos.

Finally, there were many references to aging of the materials, even at 300 K, due probably to changes in O content and metal ion migration. This seemed particularly serious in the case of thin films.

$T_c > 92$ K

This subject was of major interest and concern, but the workshop produced no unambiguous evidence for higher superconducting transition temperatures than those already known. A number of participants described observations of T_cs in the range 100-120 K, all in materials based on the Y-Ba-Cu-O system, but the results were erratic, usually appeared in multiphase samples, and could not be ascribed to an identifiable phase. Among these results, $Y_{1.2}Ba_{0.8}CuO_{4-y}$ was reported by A. Aresti et al. (University Dip. Scienze Fisiche, Italy) to lose its resistance around 110 K with a relatively narrow transition width (for these materials) of 1 K. Samples showed a Meissner effect, specific heat anomaly, and X-ray diffraction peaks which indexed to a superposition of two different orthorhombic phases. In a study which attracted considerable interest, D. Djurek (University of Zagreb, Yugoslavia) found that use of a pulsed electric field in sample preparation altered the resistance vs. temperature curve, shifting the onset of resistance loss to higher temperature, and yielding structure in the curve at around 240 K. This work was still in a preliminary stage and details were sketchy. During heat treatment, 10 msec, 1-10 watt electric field pulses were applied with a 10^{-3} duty cycle, to plates pressing on a Y-Ba-Cu-O charge in a capacitorlike configuration. The field strength was adjusted for changes in sample resistivity in order to keep the power approximately constant. Djurek suggested that the effect of the field might be to cause local heating at grain contact, or to enhance ionic diffusion.

On the subject of fluorine-substituted material there were several presentations and comments, but much skepticism was expressed. The latter was based on several unsuccessful attempts to reproduce the results reported earlier, on suspicion of contact effects, and on the facts that the role of the F, its location in the unit cell, and apparently even its very presence in the material after processing, have yet to be established. Nevertheless, reports of increased T_c after processing of Y-Ba-Cu-O with BaF_2 as a starting material, were presented. In what appears to be the most thorough study (though still incomplete), four samples with T_c in the range 110-120 K were obtained (J. Als-Nielsen, Haldor-Tapsoe Research Laboratory, Denmark). The samples had narrow superconducting transitions and were clearly multiphase; no Meissner effect work had yet been done. It is still probably too early to form definite conclusions regarding the effects of processing with BaF_2. Finally on this subject, reviews of work in the US (R.J. Cava, Bell Laboratories) and Japan (H. Takagi, Tokyo University) provided no grounds for expecting T_cs substantially above those provided by the Y-Ba-Cu-O family in the immediate future. However, rumours persisted. In Japan, where apparently over 100 separate groups are engaged in research on high T_c materials, the latter are referred to as USOs, or "unidentified superconducting objects".

Theory and superconductivity mechanisms

The workshop included very little theoretical discussion and no new results in this area. Most theory thus far seems concerned with $LaBaCuO_4$ and related materials. According to T.M. Rice (IBM Zurich) this may in fact be the more difficult material to deal with, since its ground state appears delicately balanced between a large number of possibilities - for example, metallic, charge density wave, and charge ordered, dimerized, ferroelectric and antiferromagnetic insulator. However the theory for the Y-Ba-Cu-O compounds is said to be more complicated. The relatively high value and temperature dependence of the resistivity and non-Drude optical behaviour in the normal state of La-Ba-Cu-O materials are not typical of metals, hence the conclusion that a strong coupling interaction is responsible for both the superconducting and normal properties. The model presented was essentially that of Anderson, but several other possibilities were considered; there is no resolution yet. Experimentally the situation is confused by the contradictory nature of the results so far, some implying the need for strong phonon coupling and others its unimportance. For example, the well-documented absence of an isotope effect in $LaBaCuO_4$ (shown by R.J. Cava) leads either to the conclusion that electron-phonon coupling is not responsible for the superconductivity, or to ingenious arguments for avoiding this conclusion. But preliminary work from Bell now shows a 25 per cent isotope effect for Y-Ba-Cu-O. Are the mechanisms for superconductivity in the two known classes of high T_c materials different?

In a rather curious talk laced with references to the designs of Mother Nature, C.F. Van Bruggen (Groningen, Netherlands) suggested that the classes of materials under consideration are in fact metastable. Indeed, the question of long-term stability is crucial to applications but has received little attention as yet. Present samples are sensitive to moisture and modest temperature rise and appear to age even under controlled conditions.

Applications

About one third of the papers presented orally, and a smaller proportion of the posters, were concerned with potential applications. Major emphasis was placed on heavy industrial applications, perhaps reflecting one of the major sources of support for the workshop. As it turned out, concern for large-scale mechanical and electrical applications appears to be quite premature. In the short term, the new high-T_c materials probably will have most impact on electronics and, perhaps, magnets. The following comments apply to superconductors having T_c around 100 K, thus requiring liquid nitrogen cooling. Clearly the advent of room temperature superconductors would alter all of the views summarized here.

In his paper, F. Schauer (Institute for Technical Physics, Federal Republic of Germany) said that large-scale applications divide into three general categories. First are systems requiring superconductivity, such as fusion reactors. For these, the cryogenic portion of the cost is a small fraction of the total, and a switch to liquid nitrogen cooling would not offer very significant rewards. Second are applications in which the cost of cryogenics is a large fraction of the total cost (as, for example, scientific instruments, magnets for nuclear magnetic resonance (NMR) scanning, and accelerator magnets. In this case the new materials might effect a significant cost reduction, but the results would not be revolutionary. Third are cases where superconducting competes with nonsuperconducting technology, as for electrical power installations, power transmission lines, transformers, and levitated transportation systems. In many cases, elaborate studies have already been made for applications involving liquid helium cooling, and some prototypes have been constructed. In general it seems that replacement of liquid helium with nitrogen is not remarkably advantageous. Gains from use of the latter might include, in addition to reduced construction and operating costs, greater reliability and simpler design.

C. Benvenuti of the European Organization for Nuclear Research (CERN) and H. Desportes, Saclay, provided instructive examples by applications to high-energy accelerators. In its upgrading to 90 GeV the CERN electron-positron collider will use 256 superconducting rf cavities for particle acceleration. These will provide about five times greater efficiency than the normal Cu cavities. The superconducting lining of the cavities must have a defect-free surface, without granular structure, and its properties must be stable against thermal cycling and radiation damage. Similar considerations, and, in addition, the question of critical current, I_c, are relevant to the superconducting magnets used by accelerators; the SSC would use more than 10^4 magnets.

Discussion of applications elicited a list of required properties as, for example, those cited by G. Gobner (Siemens, Federal Republic of Germany). These included: I_c in the range 10^3-10^6, A/cm^{-2}, structural rigidity, small bending radius (for wire), environmental stability (thermal, atmospheric, radiation), good surfaces, and simple fabrication. Clearly, present materials do not approach these requirements; the crucial question is whether they can do so with further development.

The repetition of industrial interests prompted an unscheduled contribution by G. Donaldson (Strathclyde University, UK) suggesting a rich field of "small scale" electronics applications. These included circuit interconnects which could be fast, lossless, and dispersion-free, antenna structures of length much smaller than the wavelength for which resistive losses usually predominate, microwave cavities for high power and high Q operation, magnetically screened spaces from small equipment enclosures to rooms and buildings, Giaever and Josephson tunnel junction devices, SQUIDS, and perhaps computers. SQUID fabrication and operation was in fact described in several contributions C.E. Gough (University of Birmingham, UK) and G. Donaldson, (Strathclyde University). Results on mm wave tunneling devices up to 550 GHz were presented by T. Claeson (Chalmers University, Sweden). These used E band waveguide, 1.5×3-mm cross section, in which an area in the broad side was replaced with Gd-Ba-Cu-O. This was contacted internally by a Nb wire or another high- temperature superconductor ground and etched in HF to a point approximately 20 microns in diameter. Operation was at 4.2 K. Tunneling characteristics were obtained but results were preliminary; upon thermal cycling it was found necessary to remake contacts.

A general view was expressed that, as the materials improved with further research, many new applications would appear.

Wires

A number of presentations (for example, those by R. Flukiger [Institute for Technical Physics, Federal Republic of Germany] and P. Dubots [Laboratoire de Marcoussis CRCGE, France]) dealt with superconducting "wires", both single strand and multifilament. The only successful method thus far entails compaction of superconducting powder inside Ag tubes followed by drawing out and annealing in O atmosphere. The latter can be provided by inclusion of a substance which releases O upon heating, or by using a tube which is both O-permeable and O-resistant and heating in an external O atmosphere. Results seem scattered; nevertheless, a wire which yields I_c of about 10^3 A/cm^{-2} at 77 K was described. Problems include O-loss, formation of amorphous material, lowered density of superconducting phase, and thick nonsuperconducting outer layers on the grains. Since the properties of the materials are strongly anisotropic, a method for aligning the grains to yield a common crystalline orientation would be useful.

Summary

A panel discussion following the technical presentations was concerned with summarizing progress to date, and considered short- and long-range goals, and the role of the EEC in nurturing the European effort. It was generally agreed that research in the following areas was essential: true single crystal preparation and analysis, microstructure and texture characterization, role of grain boundaries, mechanical properties, stability and aging, understanding superconductivity mechanisms, chemistry, and phase diagrams with a view towards finding other families of materials with possibly more attractive properties. Progress is needed in the growth of films, which so far seem to exhibit inferior properties (e.g., lower T_cs, broader superconducting transitions, and instability). Interface reactions will be critical, in view of the intimate contact between film and substrate, wire filaments and sheath, and superconducting and insulating or metallic layers. Interfaces may be troublesome, in view of the high O and metal atom mobilities and reactivity. In particular, the nature of superconductor/normal-metal contacts has not received attention; experiments rely exclusively on conducting paint and epoxy or In solder for contacts, which display high resistance and age badly. Obtaining high values for I_c and the upper critical field H_{c2}, good mechanical properties and stability are clearly essential for successful applications.

Regarding EEC policy, among the actions suggested were aid to intercommunication, data banks, unfettered support for basic research, increased accessibility of major test and research facilities, and training programmes. (Source: European Science Notes, 21 July 1987)

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(d) India

India plans top-level spending on superconductor research

India's prime minister, Rajiv Gandhi, has set up a Cabinet-level committee under his own chairmanship to promote research related to ceramic superconductivity. This development is a measure of India's confidence that its researchers have much to contribute to (and that India stands to gain something from) the international excitement over the new phenomenon.

The members of the new panel include the ministers of science, finance and human resource development, the cabinet and finance secretaries and the heads of the science agencies supporting research on superconductivity. The committee's members also include Professor M.G.K. Menon, Gandhi's science adviser, Professor Yash Pal, chairman of the University Grants Commission, and four prominent industrialists.

Dr. Vasant Govariker, secretary of the Department of Science and Technology (DST), a member of the panel, says that the formation of the panel under the prime minister is a sign of the government's commitment to research in superconductivity. Gandhi has also set up a Programme Management body under Professor C.N.I. Rao, the director of the Indian Institute of Science and Technology at Bangalore and chairman of the government's science advisory committee, to co-ordinate research at government and industrial laboratories. This body will have the executive power and financial muscle to pursue the project to its ultimate goal. Govariker says that the equivalent of several million dollars has been allocated to the co-ordinated programme.

Seven Indian research groups are engaged in superconductivity research: the Indian Institute of Science (Bangalore), the Tata Institute of Fundamental Research (Bombay), the Bhabha Atomic Research Centre (Trombay), the Madras Indian Institute of Technology, the Indira Gandhi Centre for Atomic Research (also at Madras), the National Physical Laboratory (New Delhi) and the National Chemical Laboratory (Pune). Each of these laboratories claims to have produced ceramic material superconducting up to 120 K, and the National Physical Laboratory claimed room-termperature superconductivity just a week ago.

Despite excitement about the potential of the field, Gandhi's panel will have to talk tough to make the groups work together. The DST, referring to the "varying levels of accomplishment" at the different laboratories, says that these efforts "will come to nothing" unless there is a purposeful direction and a pooling of talent. (Reprinted by permission from Nature, Vol. 327, Copyright (c) 1987, Macmillan Journals Limited)

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High temperature superconductors - Can they affect India's energy sector?

The Nobel Prize for physics for this year is awarded for observing superconductivity in oxides at the comparatively high temperature of -238° C. This began the race for synthesis of new ceramic materials that show superconductivity (SC) at still higher temperatures reaching up to -175° C. A spate of articles have appeared in the media containing nearly the same scanty facts (some distorted ones), the same pictures and the same diagrams. The combination of two unusual properties, namely zero electrical resistance and the possibility to sustain strong magnetic fields which are several times larger than those produced by conventional materials is what makes the superconductors promising to open up entirely new possibilities. Zero electrical resistance has the obvious meaning of flow of electricity without losses. Strong magnetic fields provide applications in research for high energy physics, for magnetic levitation as also for reducing size of power generators, etc. Together, these two provide scope for storage of electricity.

No wonder, since 1913, there have been five Nobel Prizes awarded in this area of research - the earlier four involving the low-temperature superconductors (LTSCs) at around -269° C.

The revival of interest in the SCs is because the high-temperature superconductors (HTSCs) could work with liquid nitrogen as coolant which is 30 times cheaper than liquid helium used earlier, considering the differences in price and cooling efficiencies. Very recently, room temperature superconductors (RTSCs) have also been reported to exist, but they are not yet stable enough and serious doubts persist about the reliability of these results. While some of the micro-level applications in medicine, defence, computer chips and so on may be relatively easier to introduce due to comparatively fewer technological hurdles and the secondary importance of cost constraints, it is possible that these applications may remain only specialized applications and may not penetrate society on a large scale. If, however, some of the envisaged applications in the energy and transport sector are successful, it could result in rewards of megabucks and bring revolutionary changes in society.

In India, Rs.35,000 crores are expected to be invested in the power sector during the seventh plan period alone. Due to the long gestation periods and heavy investments involved in the power sector, indicative (not definitive) plans are already available till 2005. These periods are long enough to realize some of the potential of the HTSC applications. Our electricity production increases by 8 per cent every year and yet there are persisting shortages. This growth, compounded by the cost-escalations in the power sector, consumes 20 per cent of five-year plan resources. Although the impacts of the HTSCs may be only marginal by the year 2000, they could signal a major change that may come to stay.

It is not generally realized that work on the applications of the LTSCs dates as far back as the mid-sixties. Conceptual designs, feasibility studies and details of prototypes of magnets, electricity storage devices, power generators, transmission cables, motors, etc., were developed in nearly 50 laboratories and industries around the world. Thus, it is not really premature to think about the importance of these applications for India, now that the HTSCs are feasible. Due to higher temperature, refrigeration requirements are reduced. In some cases, capital costs of insulation, etc., could be reduced by 50 per cent and the operating costs of refrigeration systems could be reduced nearly tenfold. Therefore, all the early developments of the LTSCs may require a fresh look. But here, we shall restrict ourselves to four major applications in the energy sector for the HTSCs.

Power generation: Since superconducting materials can sustain magnetic fields several times larger than conventional materials, a possible application in power generators would be to increase the capacity of generation of a given size or to reduce the size for a given capacity. Analysis based on LTSCs suggest that the break-even unit size required is 500 megawatts (MW). In India, in conventional power plants, we have the capacity to make only 220 MW generating units. Generators of 500 MW unit size have just made an entry in India whereas unit sizes of 1,000 MW and more have been in existence abroad for nearly two decades. The emphasis of the development efforts for power generators using SCs until present is on getting more power from the same size generator, say 1,200 MW from a 500 MW size rather than on reducing the size of a 500 MW generator. The advantage in generating efficiency due to SCs is not reported to be significant but due to a nearly 50 per cent reduction in size, there are a number of cost advantages such as reduction in foundation costs, in transport costs, in crane size for handling, and in costs of facility for on-site repairs and maintenance as also in the casting and fabrication equipment in the generator manufacturing plants.

One of the Planning Commission reports on power sector in India till year 2005, expects nearly 30 per cent of capacity from 500 MW units and 6 units of 800 MW size. If one could get higher, say 500 MW power using all the existing infrastructure of manufacturing 220 MW units size, our ability to expand power capacity could increase substantially. Finally, the HTSC technology will be of even greater interest if India goes for larger unit sizes of say 800 to 1,000 MW. To reach out to the next unit size is certainly desirable considering our plans for the expansion of grids.

Transmission lines: Due to the zero resistance property of SCs, this application is mentioned most often but seems to be the least relevant for India. The often-cited transmission and distribution losses of 25 per cent actually include thefts, losses on account of rural electrification and energization of far-away agricultural pumps etc. Obviously, these distribution losses could not be prevented by using SCs for transmission lines. The transmission technology using SCs, envisages underground cables which are rare in India due to their high costs. India has only 5,000 km of underground vs 3 million circuit km of overhead lines. Therefore, as a possible application one could only think of bulk transmission i.e. from power plants to major consuming centres. Transmission losses for such bulk transmission are around 3 per cent to 7 per cent at present. In future, one may think of large nuclear, hydro or solar power plants far away from consumption centres. However, in this case, the superconducting transmission cables will have to be stable and reliable enough to cope with different terrains and climates. In addition to high initial costs, to maintain refrigeration along lines extending hundreds of kilometres will require electricity. It is yet to be seen if the net loss of electricity is larger or smaller than in conventional high voltage transmission lines. Therefore, until the RTSCs are available, it is difficult to foresee this application in India. Moreover, this technology will have to compete with the currently available high voltage DC transmission technology which can also transmit power over long distances with overhead rather than underground transmission lines.

In addition, the difficulties of maintaining highly sensitive transmission lines vulnerable to minute temperature variations and vibrations makes this application difficult to develop.

Storage of electricity: If off-peak electricity could be stored and delivered at peak times, a smaller generating capacity could be required and thermal efficiencies of generation could also be increased due to more uniform operating conditions. Bechtel Corporation of the USA has already demonstrated storage of 5,000 MWH of electricity which could be delivered at 1,000 MW at acceptable costs even with the LTSCs. It could be even cheaper and less cumbersome with the HTSCs. However, in India, once the scope of using hydro-electric plants for peaking is fully exploited, we do not have that much extra generating capacity which leads to substantial differences between peak and off-peak electricity that could be stored and off-loaded. Even then, the economics of storage of electricity may be still worth investigating assuming different operating requirements for the next two decades. Yet storage of electricity, not for the power plant managers, but for the users is a different matter altogether. This would include small storage devices for hospitals, computers and perhaps even cars and trucks. The values of stored energy per gram of dry cell, crude oil and lead batteries are 48, 57, 52 kilojoules respectively whereas the LTSC materials could store energy from 200 to 1,000 kilojoules. In addition, it could provide high-pulse peak power required for specific applications such as in defence, transport, etc. Thus, by providing high density decentralised energy sources with relatively longer lifetimes, a large number of options arise, extending the SC applications from only the conventional power sector to a wider range of possibilities; namely, oil-substitutions, renewable energy options of solar, wind, and so on. However, technical snags such as stability from vibrations, temperature fluctuations, and mechanical stresses as well as cost barriers need to be overcome.

D C motors: This again is not a supply-side technology but a "demand-side" technology i.e., the actual users will have them rather than the electric utilities. Demonstrations have already been made of 20,000 HP motors. In India, 60 per cent of the total power generated is used in industries, of which 80 per cent is used by motors of different kinds. SC motors could lead to substantial conservation of electricity and power.

The conclusion that emerges is that, under the conditions in India, applications for storage and DC motors are as relevant as, if not more than, power generation. These will require spread of technological competence to many large and middle-level manufacturers. The least relevant application may be for transmission.

The message that comes across for research and development priorities from this analysis is that for successful applications of magnetic properties of the SCs are as important as zero resistance. This translates into a goal of materials with high electric current densities which can generate high magnetic fields. Thus, there are several characteristics required for successful applications. The LTSCs went through a prolonged development phase in which gains were achieved in reproductibility, stability over time and temperature, ductility (i.e. ability to draw wire from materials) and high current densities (100 times higher than what is available with the HTSCs at present) resulting in high magnetic sides. In the coming decade, the HTSC materials, which are brittle ceramics would have to go through a similar development phase that the LTSCs went through until now.

In India, while we have advanced research institutes such as the Tata Institute of Fundamental Research (TIFR), the Bhabha Atomic Research Centre (BARC), the Indian Institute of Science (IISc), the National Physical Laboratory (NPL), etc. which are engaged in research to develop HTSCs, counterparts of large corporations such as IBM, Bell Laboratories, Bechtel, General Electric or Westinghouse working on the development of applications from commercial and industrial angles are missing. Even if our scientists were to do path-breaking research, it would not move India towards applications by an inch. When and where will we find counterparts on the application sides that could use the new materials and ideas emerging from our research laboratories? They have much to do and follow up if they are to be ready to take advantage of these exciting developments which could, by the turn of the century, alter the course of development of not only the power sector but many other sectors besides. (This article, written by Jyoti K. Parikh, was published in Indian Express on 27 October 1987.)

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5. POSSIBLE APPLICATIONS

Superconductor applications sought

1. Energy storage

As researchers are discovering new revolutionary properties in recently developed high-temperature superconductors, application research for these new materials is gaining momentum. One such research effort is directed at the development of a technology to store a massive quantity of energy using a superconductor. Here is an introduction to possible developments in the future.

Feasibility studies for commercial superconductor technology for energy storage were conducted by the New Energy Development Organization (NEDO) and the Engineering Advancement Association of Japan from 198 to 1987. The studies were continued at the Association for Research of Superconducting Magnetic Energy Storage (chairman, Takashi Mukobo) founded in May 1986. The findings report that such technology can be achieved at an economic cost by about the year 2000. The report also presents a scenario for research and development activities.

In the mean time, rapid developments in the superconductor field that have been taking place since late last year are affecting the original course of research and development. It turns out that the newly discovered superconducting substances offer superior cost effectiveness as well as a better chance of achieving the storage technology.

It is not exaggerating too much to say that the discovery of high-temperature superconductors is one of the most significant scientific discoveries made in this century. It is certain that the advanced superconductor will affect the industry just as the transistor did when it replaced the vacuum tube. The superconductor industry should grow in the same way as the transistor industry did. Meanwhile, the recent discovery of these materials is prompting reassessment of technology for superconducting magnetic energy storage.

When a certain material is cooled below a critical temperature, it suddenly loses its electrical resistance. This phenomenon is called superconductivity. Since a superconducting circuit has zero electrical resistance, a current once drawn into it will never suffer a loss, and hence, circulate permanently. SMES takes advantage of this electrical behaviour.

In its primary use, SMES will be replacing existing pump generator facilities; it stores excess power, available during the late night, as perpetual current and supplies it back during the daytime peak hours. While a typical pump generator has an operation efficiency of 65 to 70 per cent, SMES is expected to deliver an efficiency of more than 90 per cent since the storing and generating of power is accomplished by direct conversion from electrical energy to magnetic energy or vice versa.

What would a commercial SMES facility that could replace an existing pump generator look like?

In a SMES plant, the superconducting magnets measure about 400 metres in diameter, and are buried with the liquid helium containers at an underground depth of about 150 metres within the bedrock. The helium container will be designed around the principle of a thermos where a vacuum space is provided for heat insulation. The magnets will generate a maximum intensity of 70,000 gauss - compare this to the maximum field intensity of 20,000 gauss by the current best steel electromagnet. Because of its ability to withstand this enormously intense magnetic field and its high cost effectiveness, a natural bedrock formation was picked as the place to install the magnets.

So far, only Japan and the United States have conducted assessment on this type of SMES - SMES designed for commercial use. In Japan, it was conducted by the Association for Research of Superconducting Magnetic Energy Storage while the University of Wisconsin and Bechtel have been engaged in such studies in the United States. According to these research institutions, "We either possess or can achieve in time a sufficient engineering level for each technological step necessary for the construction and operation of such a facility".

It is estimated that the construction of a commercial-size SMES would cost 290 billion yen, about 190 billion yen in direct expenses and 100 billion yen in indirect and preparation expenses. This corresponds to a unit price per kilowatt of 290,000 yen. Compare this to 320,000 yen for nuclear power, 170,000 yen for oil power, and 250,000 yen for a pump generator.

The Japanese and American studies have concluded that with its outstanding efficiency and ability to instantaneously switch between the power generating and storing modes, SMES can be competitive in terms of cost effectiveness, even at the present technological level.

Some problems do exist, however. The biggest problem deals with helium that is used to refrigerate the superconductors; however, this problem is not restricted to SMES as all superconductor-related technologies require helium.

Helium is collected mixed with natural gas, and only natural gas with a helium content of 0.3 per cent or more can be used because of its cost effectiveness. Since wells of such natural gas exist mainly in the United States, and Japan has few helium wells, the helium used in Japan has been imported from the United States. In 1985, when the Americans suddenly announced a big price hike on helium for export, the Japanese supply of helium was devastated. So, helium has been an Achilles' heel for all superconductor-related fields, SMES being one of them.

The race which started late last year to discover a superconductor with a higher critical temperature has been exhilarating indeed, as newspaper headlines have been lavishly reporting the discoveries just made. Now, substances that become superconductive even at nitrogen's liquifying temperature are being developed.

The use of such a superconductor in SMES would bring about the following advantages. The previous SMES' storage efficiency of 90 per cent could be raised to 95 per cent. There would be no need for helium. A less involved scheme for heat insulation could be adopted, resulting in a reduction of up to 30 per cent of the construction cost. Such an advanced superconductor would have more stable characteristics than conventional superconductors.

If commercial cables made of such an advanced superconductor can be produced, and adopted in the SMES design, the construction cost will go down by 30 per cent. The unit cost per kilowatt will then be 200,000 yen, cheaper than the conventional pump generator. SMES will be a viable choice to replace dams used to store electrical power if not for dams for water supply, since it does not damage the environment.

Comparison of low temperature states

	Celsius degrees	Absolute temperature (K)
Dry ice	-78.5	194.5
Liquid nitrogen	-196	77
Liquid hydrogen	-253	20
Liquid helium	-269	4
Absolute zero	-273	0

As for the cost, the above-mentioned assessment studies cite an advantage in building a large-scale facility for SMES as opposed to a compact one since the latter cannot be made economically. But, given the reduction in construction cost, made possible by use of an advanced superconductor, it may well become feasible in the not-too-distant future to build a compact power storage unit for a corporation, if not for a private home, and to install such units around the metropolis. (Source: NIKKEI SANGYO SHIMBUN, 3 April 1987)

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2. Power generator

MITI's Agency of Industrial Science and Technology has compiled an official assessment for launching a government project to develop superconductor power generators which are expected to play a key role in the future energy-saving technology. An Assessment Committee (chairman, Tokyo University's Professor-Emeritus Noboru Yamamura) was formed with experts from industry, academia and government for the task. The major recommendations for the project are: (1) to establish as soon as possible the technology for making superconducting wires, which is to be implemented on a commercial basis some time in the 1990s, (2) to develop and test experimental models with an output capacity of 70,000 kilowatts and 200,000 kilowatts, and (3) to form a dedicated organization with experts from related manufacturers. The projected total funding ranges from 20 to 25 billion yen. MITI believes that establishing a firm foothold in this field would prompt a tremendous number of activities in the development of applications.

This project is part of the Moonlight Project, which is targeted at developing energy-saving technologies, and has been studied by the Assessment Committee since 1985. Taking into account the recently intensifying race to discover advanced superconductors, MITI's agency rushed the programme assessment that was based on the committee's findings.

In addition to the early establishment of production technology for superconducting wires, the assessment calls for early establishment of the design and selection of materials for the rotor and armature (stator). Regarding the selection of superconducting materials, MITI observes that the existing oxide substances are not good enough as they suffer a loss in efficiency when the current density is increased, and so, new alloys with advanced properties need to be developed. As for the development of the rotor, MITI sees that a special structure and material are needed to come up with a rotor that, when run at high rotational speeds, retains its stability in characteristic and stays at a specified low temperature.

As for the cost - calculations are based on the use of niobium and titanium alloy - it was learned that the larger the facility becomes the lower the cost will be and that a generator capable of a 300,000 kilowatt output can beat a similar conventional machine. According to MITI, the switch to a superconductor generator in the 1 million kilowatt class would save about 700 million yen annually, or about 10 per cent of the current cost, and it would be possible to gain a dramatically sharp drop in the cost as more advanced substances are being developed. (Source: NIKKEI SANGYO SHIMBUN, 8 April 1987)

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3. New Josephson junction device

Nippon Electric Company (NEC) announced that it has developed the world's first Josephson junction (JJ) device that can operate at up to 90° Kelvin, a value higher than the nitrogen liquifying temperature. NEC researchers not only found the superconductivity of a fired oxide alloy made of yttrium, barium and copper, but they also produced an experimental junction device by joining the cleansed surfaces of two such fired oxides. When they tested the device for the Josephson effect, they observed that the effect was maintained almost up to the substance's critical temperature of 9° Kelvin). The conventional JJ devices work only at the helium liquifying temperature, whereas NEC's experimental device can operate even at the nitrogen liquifying temperature. Thus, NEC has paved the way to development of future supercomputers that incorporate Josephson junctions. NEC will be pushing the development of technology for producing thin-film oxides and the development of materials to be used for large-current applications. NEC speculates that such effort could lead to a dream super-fast switching device that can switch as fast as 10 times the speed of a conventional JJ device.

Targeting the development of a next-generation supercomputer, NEC has been pouring its research effort into the search for JJ devices that serve as the fast switching devices used in such a computer. At the onset of the research, NEC researchers were using metal materials made of niobium and lead to develop JJ devices. But since these materials worked only below the helium liquifying temperature, they had to face the problems of conducting research into the effects of helium and cost performance. Thus, rather than attacking those problems, they initiated research to develop advanced superconductors and produce switching devices that can function at about the nitrogen liquifying temperature - 70° Kelvin or more.

Recognizing that perovskite oxides can make superconductors, the researchers developed a technique to synthesize a single-phase oxide of yttrium, barium and copper. Measurement of the electrical resistance revealed that the experimental oxide thus synthesized had zero resistance to 90° Kelvin. Also, it was verified that when subjected to the measurement for the Meissner effect, every bit of the substance behaved as a superconductor at the liquifying temperature for nitrogen.

Further, through the continued effort to devise a structure for a Josephson junction, NEC researchers succeeded in developing an experimental JJ device which exhibited the Josephson effect even at up to 90° Kelvin, a value very close to the substance's critical temperature.

The following points regarding the Josephson effect were verified of NEC's JJ device: (1) The DC Josephson effect; voltage versus current measurements, taken on the direct current at the junction, showed zero resistance for the range of current from zero to the critical current level, and showed a certain resistance above this level. (2) The AC Josephson effect is observed by measuring the voltage and current while shooting the junction with 8 to 12 giga-hertz microwaves; the measurements verified that the frequency of the microwave is directly proportional to the voltage step and that the proportionality is governed by the relation, $h/2e$, where h represents Planck's constant and e is the electron charge. (3) The tunneling effect due to electron pairs, sustained as the temperature was varied from an extreme low - helium liquifaction temperature - to 90° Kelvin.

In order to achieve fast switching devices, NEC now has to overcome some problems standing in the way; the development of technology for producing thin-film junctions and producing substances that can withstand a large current, as well as the development of high-integration technology. But NEC's recent achievement with its experimental JJ device, verified as operating at the liquifying temperature for nitrogen, suggests that the next-generation supercomputer will be here sooner than expected before. (Source: Kagaku Kogyo Nippo, 27 April 1987)

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4. Permanent electric current

Furukawa Electric Industry announced that it has developed a high-temperature superconducting ring made of an yttrium, barium and copper oxide (Y-Ba-Cu-O). Furukawa researchers verified the Meissner effect in the ring and succeeded in activating their permanent-current ring - the world's first successful operation of such a Y-Ba-Cu-O ring. Furukawa's superconductor has a critical temperature of 90° Kelvin and achieves a critical current density of 150 amps per square metre at 77° Kelvin. This was the first ring-shaped magnet that incorporates the permanent-current system. It is speculated that Furukawa's achievement will prompt R&D effort in superconductor application fields.

Furukawa's superconducting ring that measures 4 centimetres in its inner diameter incorporates the permanent-current system. There are two systems available in designing a superconducting magnet: a system where the current is input into the superconducting coil from an external source, and the permanent-current system. The permanent-current method makes it possible for engineers to design with relatively simple circuitry a magnet that generates a highly stable field. Such magnets are in use for MRI and NMR instruments.

The company is planning more research to raise the current density of its superconductor and push commercialization of the magnet. (Source: Kagaku Kogyo Nippo, 22 April 1987)

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5. Discrete components

While research activities are picking up in the field of devices that utilize a thin-film superconductor, researchers at Nippon Telephone and Telegraph (NTT) verified the ability of a superconducting thin film to respond to infrared with a hundred or more times the sensitivity of a conventional infrared sensor material. NTT's work followed the verification at IBM's Watson Research Centre, of the SQID (current, voltage) effect. The age of application devices that use a superconducting material has indeed arrived. It is generally agreed that the application of a thin film superconductor is targeted for development of Josephson junction (JJ) ICs. But it is speculated that, in the mean time, the technology for discrete semiconductor components that incorporate a superconductor will reach a commercially applicable level within 3 or 4 years since such components require less involved processing compared to JJICs.

Experimental superconducting thin films made of a lanthanum, barium and copper oxide (La-Ba-Cu-O) are being produced using the flux or electron-beam vapour deposition technique at Matsushita Electric, NTT, IBM and Nippon Electric.

At IBM, researchers formed an La-Ba-Cu-O thin film with the electron-beam vapour deposition and verified its SQID effect, thus opening the possibility of using the thin film as a sensor device for detecting voltage and current. So far, the electronics field has been unable to offer a voltometer with a comparable extreme accuracy. Industry experts see that since the use of a superconductor could make it possible to achieve a very precise measurement of voltage, manufacturers would be first in developing the superconducting semiconductor technology that incorporates this voltage-sensitivity advantage.

Following IBM's success, NTT researchers grew an La-Ba-Cu-O thin film with the flux method. They found out that compared to an existing infrared sensing material such as mercury-cadmium-tellurium, the thin film possesses a high sensitivity to infrared, which is as much as a hundred or more times greater than the former material's.

The refrigeration of a high-temperature superconductor can be done with liquid neon or liquid nitrogen, and so the cost for it would be low. The advent of high-temperature superconductors, therefore, as seen in the above examples, is now prompting efforts to develop superconducting sensors which used to be impossible to create.

In developing JJICs, semiconductor manufacturers will have to solve numerous problems in integration technology, the achievement of reliability and the device-processing techniques. On the other hand, since discrete components require less complex production processing, manufacturers should be able to commercialize such components in a time much shorter than that for JJICs. (Source: Kagaku Kogyo Nippo, 27 April 1987)

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Superconductor applications updated

1. Electromagnetically propelled boat

The arrival of new superconducting materials has led to a surge in interest in the development of superconductivity-based ship propulsion. Such a propulsion system, not requiring the use of either an engine or screws, could produce ships that are free of noise and vibration. It is a dream technology with a potential to bring about super-fast boats travelling over "100 knots, at least as a matter of theoretical possibility", according to Yoshiro Saji, a professor at the Kobe University of Mercantile Marine. Although the technology is still fraught with many unresolved issues, Japan is considered most advanced in this line of research. The following describes the current status of research and development in superconductivity ship propulsion.

"Since the development of new superconducting materials, we have been inundated with inquiries both from within Japan and from abroad," says Japan Shipbuilding Promotion Corporation, in charge of development of superconductivity-based ship propulsion systems, who is busy answering questions.

Until now superconducting magnets could be produced only at liquid helium temperatures (-269°C). Now, there is a possibility that they might be realized at liquid nitrogen temperatures (-196°C). Given that nitrogen is much cheaper and much more readily available than helium, this is a significant development indeed.

The Japan Shipbuilding Promotion Corporation (JSPC) established a "Superconducting Electromagnetic Ship Propulsion Research and Development Committee" in 1985, marking the beginning of full-fledged research efforts by the corporation in this field.

The committee agenda calls for experimental construction of a ship 25 metres long and 150 tons in total displacement by 1990, to conduct open sea navigational experiments. The 4 to 5 billion yen total developmental cost will be funded by a grant-in-aid from the Japan Shipbuilding Industry Foundation.

The superconducting magnets that are being considered by the JSPC for potential use are all based on existing metallic compound superconducting materials, as would be expected.

The experimental ship, whose main features are to be drawn up by the end of this year, will be carrying superconducting magnets made of such conventional wire materials as niobium-titanium and niobium tristannate. However, the Corporation is keeping the door open to any new and better superconducting substances that might come into being so that the superconducting material being considered now can easily be replaced as circumstances justify.

The committee consists of a Superconducting Electromagnet Propulsion Boat Subcommittee headed by Seizo Motoyoshi, professor emeritus of Tokyo University, and a Superconducting Electromagnet Propulsion System Subcommittee chaired by Kensaku Imaichi, professor emeritus of Osaka University. The subcommittees, respectively, are carrying out research in the design of a ship most appropriate to superconducting electromagnetic propulsion; and the development of a propulsion system, the heart of a superconductivity ship, based on a superconducting magnet.

The subcommittees have the participation of Hitachi Shipbuilding and Engineering, Ishikawajima-Harima Heavy Industries, Nippon Kokan, Mitsubishi Heavy Industries, Hitachi, Ltd., and a total of a dozen major shipbuilding, heavy machinery, and electrical concerns, reflecting the degree of interest shown by the industrial sector in this venture.

The idea of an electromagnetic ship propulsion was first put forth by an American, W.A. Rice, for which he was granted a patent in 1961.

In 1966, Dr. S. Way of Westinghouse Corporation (US) constructed a 3-metre long model and conducted navigational experiments in the coastal waters of California. However, the experiments were less than impressive, earning the general assessment that "an electromagnetic ship is an unrealistic goal".

The problem with those experiments was the use of an ordinary magnet, with a limited magnetic field intensity and hence an inadequate force generated to push the seawater backwards, i.e., insufficient propulsion. However, banking on the premise that the advent of superconducting technology should bring the electromagnetic ship to the realm of reality, Professor Saji at the Kobe University of Mercantile Marine undertook research work some 10 years ago. In 1980, this group constructed a 3.6-metre long model ship "ST-500". It attained a speed of 0.7 metre per second (2.52 kilometres per hour) and a 0.3 per cent propulsion efficiency, certainly modest accomplishments relative to the performance level that would be needed in a practical ship, but still serving to confirm that design values can be put into a physical reality, thus suggesting ultimate feasibility of the technology. This attracted worldwide notice, producing a renewed interest in electromagnetically propelled ships, and prompting the Japan Shipbuilding Promotion Corporation to start a research effort based on Professor Saji's results.

As the name implies, the electromagnetically propelled ship runs on electromagnetism, using the underlying principle of "Fleming's left hand rule" which states that when a current is discharged perpendicular to the direction of a magnetic field, a new force is generated in a third direction, perpendicular to both the magnetic field and the electrical current.

In its basic structure, an electromagnetic boat has a magnet and electrodes attached to the body of the ship such that the magnetic field has a vertical direction, and the current runs perpendicular to the direction of the ship and into the seawater.

When current is applied, the seawater is pushed back vigorously, according to Fleming's left hand rule. The reaction from this force drives the ship forward.

The most significant aspect of this system is the complete absence of an engine, screws, and other mechanical moving parts, making the ship free of noise and vibration.

Another advantage is the possibility of realizing a super-fast ship. The conventional screw-propelled ship has an inherent speed limitation in that when the rotational speed of a screw exceeds a certain point, the screw begins to "slip", beyond which no additional gain in the forward motion of the ship can be obtained however fast the screw may rotate. The electromagnetic propulsion ship knows no limitation of this kind. "We might see small-scale cruise ships designed for pleasure trips in about ten years", predicts Professor Shoji Tanaka of Tokyo University, an expert on superconductivity, concerning the timeframe for practical utilization of this technology.

A ship free of noise and vibrations would be ideally suited to pleasure rides. These advantages also make superconductivity an attractive candidate for submarine construction, since the absence of noise would enable the submarine to elude detection by sonar.

Super-fast ships running at over 100 knots, compared to scores of knots for conventional ships, would confer significant military advantages.

At a symposium on superconductivity held by the US Materials Science Association in Los Angeles in April, a participant from the US Navy said: "We have been pursuing superconductivity research precisely because of a desire to develop an electromagnetically propelled ship". Although simple in underlying principles, however, electromagnetic propulsion would have to overcome many technical issues before it can prove practicable.

The greatest question is how to reduce the size and weight of a magnet while producing a sufficiently high magnetic field. The power of propulsion of an electromagnetic ship is proportional to the strength of the magnetic field and the electrical current. The electrical current, which is allowed to pass through the seawater, cannot be made very strong, since too strong a current would cause electrolysis of the seawater, resulting in deposition of hydrogen and chlorine on the electrodes. Heat dissipation due to electrical resistance would also produce large losses, with a substantial drop in the propulsive power.

For this reason, in the view of experts "a strong magnetic field in the order of 10 to 20 teslas (tesla being a unit for expressing the intensity of a magnetic field) is needed in order to make an electromagnetically propelled ship practicable. Without using a superconducting magnet, it would be difficult to produce a magnetic field with that intensity. The highest magnetic intensity that has been attained by existing metallic compound superconducting materials has been approximately 19 teslas, of which 12 to 13 teslas can be though of as being available for practical use (Science and Technology Agency National Research Institute for Metals). Thus, a superconductivity electromagnet propulsion ship is now on the verge of practical reality.

According to preliminary calculations by the JSPC research committee, it would take 150 tons of a superconducting magnet to drive a 50-ton boat at a speed of 8 knots; with such a weight, the ship would sink. However, subsequent superconductivity technology research has reduced the weight requirements of a magnet to under 100 tons. This development prompted the JSPC to undertake the construction of an experimental vessel.

If a new ceramic-based superconducting material proves feasible, the required cooling system can be reduced in size, and a powerful magnetic field can be generated. These prospects have made the "realization of a superconducting electromagnetic ship quite promising," according to Professor Saji.

2. Optical switching device

Hitachi, Ltd., has succeeded in the experimental fabrication of an optical switching device using a high-temperature superconducting material. When a ceramic-based substance, the focus of much recent interest as a high-temperature superconducting material, is made into a thin film, the substance conducts electricity without any resistance, allowing the current to flow virtually forever. The Hitachi research group formed a cadmium sulfide optical conductor semiconductor on the thin film. By directing a light beam on the semiconductor they were able to turn the electrical current flowing in a superconducting state on and off. Using this principle, the Hitachi group created the world's first device capable of exhibiting optically actuated switching actions under liquid nitrogen conditions.

The high-temperature superconducting device was made by creating a trench in a part of a ceramic thin film, made of yttrium (Y), barium (Ba), and copper (Cu) oxide to inhibit the flow of superconducting current, and by providing electrodes at two ends of the thin film. This thin film was produced by high-frequency sputtering of a Y-Ba-CuO amorphous thin film to form a film 2 microns (1 micron = 1/1000 millimetre) thick, and heat-treating the result under an oxygen atmosphere. This substance completely loses electrical resistance at 85° absolute temperature (-188°C).

Hitachi personnel irradiated the current-regulating part of the superconducting thin film with a light beam 0.7 to 0.8 micron in wavelength. This caused a maximum current density change of 3,000 amperes per square metre at 77° absolute temperature, demonstrating the feasibility of switching actions. When the part of the film to be irradiated with light was covered with cadmium sulfide, switching was induced with 10 times less amount of irradiated light.

The recent experimental fabrication of a high-temperature superconducting optical switching device is drawing much attention as the first such device demonstrating specific results.

Note: Switching device: A device endowed with the function of turning an electron-flowing circuit on and off. The difference between response wave forms, one representing the state of electron flow and the other the absence of electron flow, is used for information transmission purposes.

3. Ceramic coil

Toshiba Corporation has accomplished experimental fabrication of a coil from a wire made of a new ceramic superconducting material. Toshiba researchers have confirmed that coil loses electrical resistance completely at liquid nitrogen temperatures and is capable of conducting current at a density of 510 amperes per square centimetre. Making a coil out of the hard and brittle ceramics presents singular technical difficulties, but is necessary for the realization of a magnetically floating train or an electromagnet for use in nuclear fusion. Because of the low amount of current that can be supported, the new coil may be little more than a laboratory curiosity, but the important point is that the accomplishment has established a basic process for coil fabrication, according to Toshiba personnel.

The experimental coil is made by winding a 60-70 centimetre long wire; the coil has a 2 centimetre diameter and is 2.5 centimetres long. It has 10 turns. It loses electrical resistance completely at 85° absolute temperature (-188°C).

The superconducting material employed is a compound of yttrium, barium, copper, and oxygen. The raw materials yttrium oxide, barium oxide, and copper oxide powders were mixed and heat-treated at a temperature not exceeding 900° C without causing solidifcation of the powder mixture. Then the material was packed into a silver pipe and elongated, producing a wire less than an ordinary match in thickness.

After being wound into a coil, the material was heat-treated again under an oxygen atmosphere to transform it into a ceramic.

The reason that the material was covered with silver was that oxygen, necessary for the creation of a quality superconducting material, would be taken up by the material through the covering during the heat treatment and ceramic transformation. A cover made of copper or other substances, on the other hand, would withdraw oxygen from the ceramic, thus preventing the production of a good superconducting material.

The technique of covering a superconducting material with silver during the wire-making process has been announced by American Telephone and Telegraph Corporation (ATT); however, Toshiba contends that it developed a similar technique independently, and disclosed that patent application for the technique has already been completed.

4. Coil with strongest magnetic field

On 15 May, Hitachi Cable, Ltd. (President: Hironaru Hashimoto) announced the successful joint development with Hitachi, Ltd. (President: Katsushige Mita) of a superconducting coil having the world's strongest magnetic field, 17.2 teslas, at 4.2° K (absolute temperature). Until now, niobium tristannate compounds have been used for the fabrication of high-magnetic field superconducting materials offering 8 teslas or higher magnetic intensity. Using a cable consisting of extremely thin wires of niobium tristannate, the Hitachi group has succeeded in the generation of a magnetic field strength surpassing the 17.1 teslas achieved by Kyushu University. On the strength of this achievement, Hitachi Cable will be producing wires as well as small-size superconducting magnets for applications ranging from analytical magnetic resonance imagery (MRI) to research in the physical properties of substances.

Although there has been a feverish push for the development of superconducting ceramics which have the characteristic of losing electrical resistance completely at room temperature, practical utilization of such substances is still considered a long shot. Hitachi Cable has already produced 5,000 kilometres worth of wires of niobium-titanium alloys and niobium-tristannate compounds. These wires are now being used in large-scale magnets for nuclear fusion and magnetohydrodynamics (MHD) power generation.

The recently developed superconducting coil is intended for use in small-scale magnets. It has an effective inner diameter of 42 millimetres, an outer diameter of 114 millimetres, and is 150 millimetres high. Niobium-titanium-tricin was formed by winding the raw material into a coil form and by subjecting the result to heat treatment to confer on it a superconducting property. The technique is intended to compensate for the low mechanical strength of ordinary ceramic substances.

Hitachi also achieved a coil size reduction by reducing the proportion of copper present in the superconducting wire to 80 per cent of the total material content. This has produced a high mean current density for the coil of 54 amperes per square millimetre at 17.2 teslas (Kyushu University reported achieving a current density of 28.1 amperes per square millimetre at 17.1 teslas). The accomplishment means that Hitachi Cable now has expertise in both large-scale and small-scale strong magnetic field superconducting coil technology. The company will be waging a product offensive in the cryogenic superconductivity arena while at the same time accelerating the development of room-temperature wire materials. (Source: Nikkei Sangyo Shimbun, May 1987)

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6. CURRENT AWARENESS

Energy-related developments

Transformer success

The research group headed by Assistant Professor Kazuo Funagi of the Superconductive Magnet Research Centre of Kyushu University's Engineering Department announced on 13 April that it had succeeded in developing a superconductive transformer having an output of 72 kilovolt-amperes. This is the highest level in the world, exceeding the capacity of 70 kilovolt-amperes of the superconductive transformer developed by the French company Alsthom-Jeumont. This transformer has the advantages that the voltage fluctuation rate is lower and the transmission efficiency is higher than those of ordinary conduction transformers of the same capacity, and the overall safety of the system is superior to that of superconductive equipment of the past. With the success in developing this superconductive transformer, the goal of putting AC superconductive power generation equipment into practical use has been realized.

The superconductive transformer developed by the Kyushu University group uses an ultrathin multicore superconductive wire of a niobium-titanium alloy as a coil, and the coil and iron core were cooled with liquid helium to absolute 4.2 degrees (-268.8 C). The volume and weight of the apparatus is 1/10 that of photoconductive transformers of the same capacity. (Source: Nihon Keizai Shimbun, 14 April 1987)

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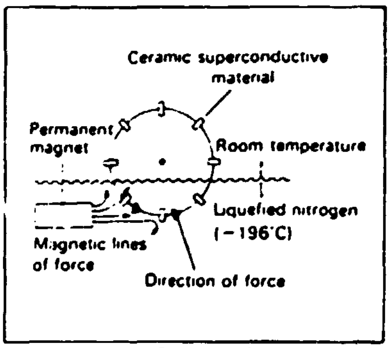
Motor using superconducting material

Sanyo Electric Co., Ltd. has come out with a motor using a superconducting material which is revolved by utilizing the phenomenon of a superconducting material and a magnet repulsing each other.

This new motor has a shape resembling that of a water wheel. A plastic ring with a diameter of 6 cm is fitted with 16 disc blades made of a ceramic superconducting material. One half of this wheel is immersed in liquified nitrogen to render it superconductive, and impressing the magnetic forces with the permanent magnets causes the runner to revolve.

A superconducting material has the property of repulsing a magnetic force. The motor utilizes this property; the discs made of superconducting material act to repulse the magnetic lines of force of the installed magnets. The upper part of the motor's runner lies above the liquified nitrogen and is not superconductive, so no Meissner effect is generated. As a result, no counter-revolution force is exerted from the runner's upper section, and the motor tends to revolve permanently.



Sanyo Electric's Superconducting Motor

The motor presently has a maximum speed of only 20-30 rpm and cannot be used as a source of motive power, but the company plans to conduct research to develop a superior superconducting material that can be used even at room temperature.

(Sanyo Electric Co., Ltd., Public Relations Dept., 1-10, Ueno 1-chome, Taito-ku, Tokyo)

(Source: JETRO, December 1987)

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The fruits of superconductivity

The world's first electrical motor based on the properties of new superconducting materials was on show (February 1988) in Boston at a meeting of the American Association for the Advancement of Science. Superconductors transfer electricity without loss of energy.

The motor is a simple demonstration model that operates at about 50 revolutions per minute. The ceramic material that it uses - yttrium-barium-copper oxide - becomes a superconductor at 94 K or -179° C.

The motor is too small for practical use and produces negligible power, but it demonstrates for the first time that these motors are possible.

The motor is based on the Meissner effect - the property of superconductors that causes them to reject lines of magnetic force. It consists of 24 small electromagnets mounted along the bottom of a circular aluminium plate which rotates above two disks, shaped like hockey pucks and made of yttrium-barium-copper oxide. The disks become superconducting at about 94 K.

As one of the electromagnets approaches the superconductor, the electromagnet is switched on to create an electric field. The superconductor responds by producing its own magnetic field to repel the magnet. The aluminium plate continues to spin as the electromagnets in turn rotate past the superconductors, are switched on, and then get pushed away. As an electromagnet is pushed away, the circuit is broken, but another one comes in to keep the cycle going and the plate spinning.

The Argonne laboratory in Illinois, USA, where the motor was developed, has more than 100 people working with the new superconductors. It is operated by the University of Chicago. (This first appeared in New Scientist, London, the weekly review of science and technology, 14 January 1988)

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Electronics and computer related developments

Superconducting transistor operated successfully

Hitachi, Ltd., has succeeded in developing and operating a transistor-type superconducting three-terminal element.

A superconducting element that utilizes the tunnel effect in the superconductive state theoretically has a switching speed that is about a hundred times faster and a power consumption rate that is about a thousand times lower than silicon semiconductors, so research on the element has been conducted intensively. However, conventional superconducting elements, or "Josephson devices" are two-terminal elements that do not permit the use of existing computer-mounting technologies that work with existing transistors.

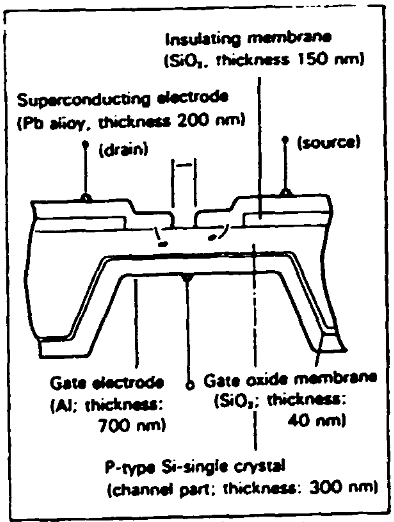
The new superconducting transistor arranges the source and drain electrodes, which are made of superconducting materials, in close proximity on a pure silicon semiconductor, and provides a third gate electrode that has been insulated with a thin oxide coating on its rear side.

The element's operation principle is explained by the quantum theory. That is, considering the superconducting electrons as a wave source, then placing two superconducting materials close together will permit the superconducting electron waves emitted from both these electrodes to be used. This superconductivity range will be further expanded by impressing a voltage on the insulated gate electrode on the silicon semiconductor's back side.

When no potential is being impressed on the gate electrode, the superconducting electron waves from the source and drain electrodes do not overlap, so there is no flow of superconducting electron tunnel current between the two electrodes, and a potential is generated to cause a flow of normal conductance current. When a potential is impressed on the gate electrode, the waves of superconducting electrons from both electrodes expand to overlap, so no potential is generated between the two electrodes and a flow of tunnel current will be generated by the superconducting electrons. These two conditions are created by switching the d.c. current flowing through the source and drain electrodes by action of the d.c. potential impressed on the third, or gate electrode, thereby enabling the superconducting transistor to function through the d.c. current source.

The switching speed of the newly developed superconducting transistor is 20 picosec (calculated value) and its power consumption only 5 W, so the element is believed to display performances comparable to those of Josephson devices.

(Hitachi Ltd., Electromagnetic Instrument Design Dept., 882, Ichige, Katsuta City, Ibaraki Pref.)



Structure of superconducting three-terminal element

(Source: JETRO, June 1987)

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Printed circuit board

The Furukawa Electric Co., Ltd. announced that it has developed a printed circuit board that uses a new ceramic superconductive material for its wiring. This is the first time that a new material has been used in a printed circuit board in which the electrical resistance is reduced to zero, using the inexpensive and easy to use liquid nitrogen (at -196° C). The company expects to use the printed circuit board in electronic equipment that throws off a lot of heat because of power loss.

The new circuit board is a 5-6 centimetre square ceramic substrate with circuit wiring formed from the new superconductive material. The wiring is in the form of a thin film having a thickness of 0.08 millimetres, and the minimum wire width is about 1 millimetre.

Superconductivity occurs at -183° C that is above the temperature of liquid nitrogen and at the temperature of liquid nitrogen, a current of 100 milliamperes was observed to flow.

Since last year, there have been rapid advancements in the field of ceramic semiconductor materials. Heretofore, attempts have been made to create electronic devices from wires and thin film crystals, but now that printed circuit boards have been produced, the move toward practical application of this technology should reach a new stage. (Source: Nihon Keizai Shimbun, 22 April 1987)

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General Electric has patented a superconducting magnetic device for magnetic resonance imaging. The unit allows examination of specific parts of the body while suppressing background signals. Patent 4,701,708 was granted to two GE employees for the device. (Source: New York Times, 24 October 1987, p. 18)

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A superconductive 3-terminal device that could be developed into a microchip has been developed at Yokohama National University, Japan. The new phase quantum tunnel device is similar to a field-effect transistor in structure. It can be activated by as little as 1 electron's worth of electrical charge. An experimental Josephson junction device needs over 100 electrons. (Source: Japanese Economic J., 3 October 1987, p.21)

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Company formed to commercialize superconducting electronics

A new company has been formed to explore and manufacture superconducting electronics. Called Conductus Inc., the company's advisory board includes six scientists from Stanford University and the University of California at Berkeley.

The company plans to explore superconducting electronics using thin film technology. These electronics applications include very high speed digital devices, magnetic field detectors, other types of detectors and sensors and high speed interconnects in ICs and circuit boards.

Conductus does not expect immediate commercialization of these applications, knowing that it will probably take several years of research and development to effectively exploit technological breakthroughs in the marketplace. It does plan to undertake joint R&D projects with established computer and electronics companies and will also pursue available government contracts to help advance this new technology. (Extracted from Semiconductor Int., December 1987)

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Magnets and magnetic devices

Superconducting SQUID works at 81 K

The first superconducting electronic device that operates above the temperature of liquid nitrogen (77 K) has been made at the NBS laboratories in Boulder, Colorado, USA. The NBS device is a high-temperature version of the superconducting quantum interference device, or SQUID, which can measure magnetic fields with exquisite sensitivity. It operates at 81 K. The SQUID, which uses yttrium-barium-copper oxide superconductive material, was fashioned by physicist James E. Zimmerman and coworkers Ronald Ono and James Beall. Previously, such devices were made from metallic materials that became superconductive - and hence useful - only at temperatures near absolute zero. The new high-temperature SQUID makes applications, such as the measurement of electrical signals in the brain, more convenient and cheaper. (Source: Chemical and Engineering News, 1 June 1987)

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Hitachi has developed a prototype ceramic-based superconducting quantum interference device (SQUID) for use in medical equipment. The SQUID works in a liquid-cooled environment and can detect magnetic flux as small as 1/10 millionth of terrestrial magnetism. Significantly, the SQUID was fabricated with thin-film process technology, using lithographic techniques similar to those used in semiconductor manufacturing. The prototype SQUID has a current density of more than 6,000 A/sq-cm, high enough for practical applications. The SQUID is essentially a superconducting ring incorporating one or two Josephson junctions and a pair of electrodes connected to the ring. The company hopes to use the SQUID as a magnetic resonance image (MRI) sensor for use in nuclear magnetic resonance (NMR) equipment. IBM developed a SQUID in April 1987, and Sharp has developed a magnetic sensor containing a ceramic superconductor, dubbed the Super Magneto-Resistor. (Source: Electrical Engineering T., 17 August 1987, p. 15)

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Superconducting ship propulsion system

Sumitomo Heavy Industries, Ltd., has developed a small-sized lightweight superconducting ship propulsion system that can develop 650 horsepower. The new system, which is being jointly developed with the Japan Marine Machinery Development Association (JAMDA), is the second stage of a project expected to lead to the development of a 20,000 horsepower superconducting ship propulsion system in four to five years, the spokesman said.

The new system, which is based on superconducting materials that lose their resistance to the flow of electrons when cooled close to absolute zero, uses a direct current motor and liquid helium refrigerator for cooling its niobium- titanium superconducting coils. When installed in a ship, the system will consist of a gas turbine, superconducting generator and power supply for supplying electrical power, liquid helium cooling and recovery devices, and the superconduction motor and helium refrigerator. The generator of the proposed 20,000 horsepower system will be from one-fifth to one-eighth conventional size, while the motor will be from one-third to one-fourth conventional size. Ships equipped with the new propulsion system will not require a mechanical power transmission path, and will have good manoeuvrability. (Excerpts from Tokyo KYODO, 28 July 1987)

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Electro-Kinetic Systems (Trainer, PA) and MIT will jointly develop custom superconductor composites for electromagnetic shielding. The programme is planned to bring development of new products with more shielding capacities versus present products. MIT has announced that it had attained a breakthrough in developing metal precursors to superconducting ceramics. EKS recently submitted a proposal for government funding of more research on superconductive composites, based on new developments in superconductivity and EKS' proprietary technology in composites and coatings. (Source: Metalweek News, 7 September 1987, p. 8)

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Mitsubishi Electric will unveil the MMI-150S superconductive-resonance diagnostic device with magnetic field strength of 1.5 tesla. Mitsubishi will sell five units the first year. The specially designed structure of the superconductive magnet minimizes use of liquid helium without refrigeration. (Source: Dempa Dig, 21 September 1987, p. 9)

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Oak Ridge National Laboratories (Oak Ridge, TN) has passed six large superconducting magnets in its first tests, three coming from the US and one each from the Federal Republic of Germany, Japan and Switzerland. The results for the magnets marked the end of the test programme involving the International Energy Agency's organized four-nation, $180 million Large Coil Task. All six D-shaped coils, each 20' tall and weighing 40 tons, produced enough magnetism to uphold scientific beliefs that magnetism could keep hydrogen fuel plasmas that reach 100 million degrees away from fusion reactor walls. Each magnet reached peak magnetic fields of 9 teslas, 180,000 times the Earth's natural magnetic field, although the design goal was 8 teslas. The force of each coil in the last test was 5,000+ tons. The US magnets came from Westinghouse Electric, General Dynamics' Convair division, and General Electric. (Source: Metalweek News, 26 October 1987, p. 37)

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Development of superconducting magnetic storage

The US Defence Nuclear Agency in the Department of Defence has named Bechtel National Inc., San Francisco, California, and Ebasco Services Inc., New York, as prime contractors in a project to develop a superconducting magnetic energy storage (SMES) test model.

The pair of two-year contracts, solicited last June are for $13.8 million and $13.9 million, respectively. They will demonstrate the feasibility of developing a full-scale SMES system to power ground-based lasers and other equipment as part of the Strategic Defence Initiative, but the potential application in the civilian utility sector is considerable.

The engineering test model of the SMES will feature a cylindrical coil measuring 100 metres in diameter, placed in a 9-m-deep trench. The SMES will be able to deliver both steady power at 10-25 megawatts for two hours for peace-time uses or, for laser weapons applications, 400-1,000 MW for only 100 seconds.

Working with Bechtel are such major subcontractors as General Dynamics, GA Technologies and General Electric, plus Pitt-Des Moines, CVI, Cryogenic Consultants and Ansaldo, General Dynamics, whose contribution will be superconducting magnets, will be assisted by the Texas Accelerator Centre and Intermagnetics General.

Ebasco has brought together a team of the University of Wisconsin, the Madison Gas and Electric Co. subsidiary Central Wisconsin Development Corp., Westinghouse Electric Corp., Chicago Bridge and Iron Co. and superconducting materials supplier Teledyne Wah Chang. (Extracted from International Solar Energy Intelligence Report, 1 December 1987)

Ceramic-based superconducting magnet

The Furukawa Electric Co., Ltd., Tokyo Electric Power Co., Inc., and two other companies have jointly succeeded in producing a ceramic-based superconducting material in wire form, winding the wire into a coil and fabricating a superconducting magnet. The magnet's current density is about 1,000 A/cm^2 at a temperature of 77 K (-196° C).

Metal-based superconducting materials made of niobium-titanium, for example, are already being produced into coils and magnets, and being used in sophisticated equipment such as MRIs. However, since these materials require an extremely low critical temperature in order to render them superconductive, there is an inconvenience that expensive liquefied helium has to be used as a coolant. Ceramic-based superconducting materials, however, can be cooled with much cheaper liquefied nitrogen, and are thus attracting attention.

Produced into coil form this time were oxide superconducting materials such as yttrium, barium and copper. Pressure was applied by extrusion to the substance (activated superconducting powder), producing a wire of about 1 mm in diameter, which was then wound on a bobbin and heated/cooled (wind-and-react process), and transformed into coil form.

The coil has an inner diameter of 21.4 mm, 20 turns, and a wire length of about 1,500 mm. When it was cooled with liquefied nitrogen (70 K) and a current passed through at a rate of 2 A/min, it was confirmed to generate a magnetic field of 20 G. The critical current density at zero magnetic field intensity was equivalent to 1,330 A/cm^2, and a stable superconducting state was confirmed even after the coil had been stored for a month.

(The Furukawa Electric Co., Ltd., Publicity and Advertising Div., 6-1, Marunouch 2-chome, Chiyoda-ku, Tokyo) (Source: JETRO, January 1988)

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Production of wire, films and powder

Practical wire coming

The US Department of Energy has given Argonne National Laboratory the job of developing a practical conducting wire from the new superconducting ceramics. The goal is to produce within five years a practical wire that loses all electrical resistance at 77 K.

A wire to meet the goals might be about one-seventh of an inch thick and able to carry about 100 amperes of current when cooled by liquid nitrogen. It must also be reasonably flexible. A wire with those properties would make transmission lines economical.

Today's working superconductors must be cooled to liquid-helium temperatures of 4 K. But practical applications are limited, because liquid helium costs about $11 per gallon and is difficult to handle. Liquid nitrogen, on the other hand, costs only about 22 cents per gallon and is far easier to handle.

Working closely with Argonne on the project will be Brookhaven National Laboratory and Ames Laboratory. (Source: Machine Design, 25 June 1987)

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Rhone-Poulenc plans to supply superconductor raw materials

Rhone-Poulenc Inc. has launched a major development effort to produce ready-to-use rare earth/copper/alkaline earth oxide powders as raw materials for the production of superconductors. C.R. Tevebaugh, Rhone-Poulenc's vice president and general manager for fine inorganic chemicals, said, "We have combined all of our inorganic chemical expertise and have taken the first step to removing the worry of high-quality raw materials from the companies working in the emerging superconductor field, allowing them to concentrate their resources on speeding their new developments to commercial reality."(Source: Ceramic Bulletin, Vol. 66, No. 7, 1987)

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Kawasaki Steel has announced the capability of producing commercial quantities of ceramic oxide wires that become superconducting when cooled with liquid nitrogen to 93 K (-180° C; -356° F). The material, which is an oxide of yttrium, barium, and copper, begins to show a drop in resistivity at 95 K (-178° C; -352.4° F), becoming completely superconductive at 93 K. The company is now producing wires that are claimed to be of uniform quality, measuring 1 mm (0.04 in.) in diameter and 10 m (3.3 ft) in length, in lot sizes of 10 kg (22 lb) or more. Kawasaki Steel uses a proprietary ceramic processing technology to draw these small diameter wires into 10 m lengths.

In recently conducted tests, a critical current density of 410 A/cm^2 was recorded. This current flow is considered to be indicative of the absence of impurities. X-ray analysis has confirmed the material's homogeneous microstructure. (Source: Materials and Processing Report, August 1987)

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American Superconductor (Boston, MA) will produce MIT developed metal alloy superconducting wire that researchers think has more commercial potential versus other superconducting material produced made mainly of ceramic. American Superconductor, an American R&D (Boston) subsidiary, said the wire made from europium, barium, copper and gold may possibly be commercially offered by 1988. American Superconductor expects to begin shipping wire samples to customers in 1988. The wire's use of metal would make it easier to turn into wire for generators or transmitting lines. While ceramic materials show a full loss of electrical resistance at temperatures closer to room temperature, they are brittle, it is hard to produce wire from them, and they are superconductive in a small part of the material. However, the MIT alloy loses all resistance to electricity in 70 per cent+ of the metal and it occurs at temperatures of 90+ K. (Source: Am Mtl Mkt, 10 August 1987, pp. 1, 8)

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A filament made of superconductive ceramic materials has been developed by researchers at Nagoya Institute of Technology (Japan). The filament, which has a diameter of 80 microns and a maximum length of 1 m, becomes superconductive at temperatures below -191° C. Composed of yttrium-barium-copper oxide, the filament is produced using a technique similar to wet spinning for synthetic fibre production. The process involves injecting an alkali solution from a syringe, a procedure that better suits mass production versus the conventional way of inserting ceramic materials into a copper or silver pipe. (Source: Japan Economic Journal, 12 September 1987, p. 21)

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NBS jointly prepared and characterized bulk target materials for a new laser-ablation technique with the Johns Hopkins University Applied Physics Laboratory (USA). The laser ablation technique was developed at the Applied Physics Laboratory (APL) to deposit superconducting oxide thin films on substrates. The superconducting transition temperatures for ablated thin films of barium, yttrium, copper and oxygen - the BYCO-1,2,3, compound - at 94.5 Kelvins and for films of lanthanum, strontium, copper and oxygen at 41.5 Kelvins are the same as those measured for the bulk materials used for ablation. Thin films were produced on unheated substrates and no further processing was required. The hybrid superconducting/semiconducting systems offer potential for smaller and faster ICs. (Source: NBS, 21 September 1987, pp. 1-2)

Startups make bulk forms and electronic devices

A new company uses explosive compaction to form superconductors into bulk forms up to 24 cm diameter. The ceramic powder is laid into a channel between two plates of aluminium or copper. The sandwich is then shock wave-bonded into a monolith by a precise explosion of ammonium nitrate. The metal cladding overcomes problems with ceramic brittleness and atmospheric degradation. The company, formed by two Oregon Graduate Centre professors, is interested in pushing through commercial applications, such as energy storage rings for motors and generators. They can produce kilogram amounts of superconducting powders daily, and are looking for venture capital, co-operative research, and want to get into the market quickly. (Extracted from High-Tech Materials Alert, November 1987)

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Metal Manufacturers (Australia) has developed a power transmission cable that is superconductive at 98 K. The cable, sheathed in copper and cooled with liquid nitrogen, is far from being ready for commercial use but could ultimately be used by power station switchyards where power losses from customary cable are extensive. Metal Manufacturers, which recently lent $200,000 to the University of New South Wales for superconductor research, said the cable could have major implications for firms with interests in various electronics businesses. (Source: Am Mtl Mkt, 9 November 1987, p. 5)

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A fast way to make superconducting thin films

Researchers at the General Motors Research Laboratories say they have come up with a quick, inexpensive process to make and alter the composition of superconducting thin films - a development that could accelerate the already rapid pace of development in the field.

Unlike most researchers, who have been working with vacuum-based techniques such as laser or electron-beam evaporation and sputtering, GM researchers at the Warren, Mich., laboratories have turned to metallo-organic deposition. Because the approach is nearly identical to standard liquid spin-coating photoresist techniques, and because it is done entirely at atmospheric pressures, the method can be accomplished with a minimum capital investment - in the $5,000 range, GM workers say. This could open up the field for researchers at more universities and other places with limited budgets.

What is more, the technique allows compositions of superconducting materials to be altered and made into thin films much more quickly than with other methods. "If someone came out tomorrow with a material that is a room-temperature superconductor, we could have a thin film of that material within a week," contends Joseph V. Mantese, a GM research engineer. By contrast, he says, vacuum-based sputtering techniques can take a month just to change the composition of a compound while a new sputtering target is obtained.

Researchers at AT&T Bell Laboratories and Purdue University have used the same method for making superconducting thin films, but GM says it was first to publish results and has filed for a patent on the technology. The GM team reported last month on the technique's use in fabricating thin films of yttrium-barium-copper oxide on single-crystal strontium titanate and polycrystalline barium titanate. The films superconduct at 90 K.

Next is the preparation of similar superconducting films on a silicon substrate. The key is the development of a suitable diffusion barrier that will prevent silicon migration into the thin film, which can destroy its superconducting properties. (Source: Electronics, 7 January 1988)

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Breakthrough in thin-film superconductors

A Japanese company is claiming a breakthrough in the manufacture of high-temperature superconductors. Nippon Kokan (NKK) has been working with professor Kyoji Tachikawa at Tokai University on making superconducting films by spraying oxides of yttrium, barium and copper in the form of a charged plasma on to a substrate. The films are superconducting (show no resistance) at 91 K.

NKK has developed a way of plasma spraying the oxides at low pressures - between one-fortieth and one-quarter of an atmosphere - in a chamber containing ambient gas. This, it claims, has proved much more successful than previous approaches involving plasma spraying at atmospheric pressures. One of the advantages of NKK's technique is that the film adheres more effectively to the substrate.

The technique has produced films that are 100 micrometres thick, show no resistance at 91 K and have a critical current density of 700 amperes per square centimetre at 77 K. The Meissner effect - where superconductors exclude magnetic fields, occurs at 77 K.

NKK also claims that its technique is 1,000 times faster than non-spraying techniques, which lay the film down at a speed of less than 0.05 micrometres per minute. (This first appeared in New Scientist, London, the weekly review of Science and Technology, 14 January 1988.)

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Tape-form high-temperature superconducting wire of high current density

Hitachi, Ltd. and Hitachi Cable, Ltd. have jointly come out with a tape-form high-temperature superconducting wire having a high current density of 1,890 A/cm^2 at a liquified nitrogen temperature of 77 K.

This wire is made of superconducting yttrium oxide and has a thickness of 0.1 mm and width of 5 mm. It is made into tape form by packing its raw material powder into a silver pipe and elongating the pipe, then heat treating it in an oxygen environment at a temperature of 900° C.

The taped wire's core part is very fine with a thickness of 60 microns and the wire is further compacted by rolling, by which its current density is raised conspicuously. The wire becomes superconducting at a temperature of 93 K, its super critical temperature is 90 K, and it has been confirmed to pass a current as large as 5,700 A/cm^2 in a liquified helium environment (4.2 K).

Regarding the application of high-temperature superconducting materials to the field of energy, the fabrication of superconducting magnets will be fundamental, and in order to fabricate these magnets, the fabrication of high-temperature superconducting wires will, in turn, become indispensable.

Therefore, in future, the company plans to upgrade the wire's current density by further compaction and by decreasing the particle surface boundaries, with the aim of developing more sophisticated wires for various kinds of superconducting magnets.

(Hitachi, Ltd.
Public Relations Secretary's Office
6, Kanda-Surugadai 4-chome
Chiyodaku, Tokyo)

(Source: JETRO, January 1988)

Oxide superconducting wire with critical current density of 11,000 A/cm^2

Fujikura Ltd. has come out with an oxide-based superconducting wire capable of passing a current as large 11,000 A/cm^2.

While superconducting wires made of yttrium-, barium- and copper-based ceramics have so far attained a critical current density of 1,000 A/cm^2 at best, the company succeeded in surpassing its target of over 10,000 A/cm^2. It achieved this by raising the powder density during the wire fabrication process, and by introducing a new technology for removing the wire's sheathing material and subjecting the wire to sintering treatment.

More specifically, in the process of packing raw material powder into metal pipes for sintering, the properties of the raw materials are known to be degraded by the reaction occurring between the oxide material's oxygen and the sheathing material. To cope with this problem, a non-oxidizing metal (silver) is used as the sheathing material, but even with this silver sheathing, the critical current density is, at best, only about 2,000 A/cm^2.

In order to raise the current density, Fujikura first increased the powder sintering density in the process of packing the raw materials into the sheaths. They also increased the powder density by a special treatment, with the result that the powdered body, previously full of voids, was made hermetically tight. In addition, the sheathing material was removed to enable the oxide material to be heat-treated in an exposed state, thereby preventing the cracks which can be generated when heat treatment is performed together with the sheath.

By introducing these new technologies in the wire fabrication process, liquified nitrogen test data have corroborated the passage of a critical current of 81 A with a wire having a diameter of 0.97 mm, which is equivalent to a current density of 11,000 A/cm^2.

(Fujikura Ltd.
11-20, Nishi-Gotanda 2-chome
Shinagawa-ku, Tokyo)

(Source: JETRO, January 1988)

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Flexible tape fabricated by new method

A superconducting composite tape of $Yba_2Cu_3O_{7-x}$ that has a certain amount of flexibility has been developed by K. Togano and co-workers at the National Research Institute for Metals in Japan. It is made by the solid state surface reaction of a barium carbonate ($BaCO_3$) and yttria (Y_2O_3) coating on copper tape or copper electroplated silver tape. The 200 um thick Cu tape was spray coated with an ethanolic suspension of a mixture of $BaCO_3$ and Y_2O_3 powders, followed by heat treatment at 900° C for 10 minutes to three hours in air and then slow cooling in the furnace.

To suppress the formation of a copper oxide (Cu_2O) layer, the powder mixture was reacted with a 30 um thick Cu layer electroplated on a 200 μm thick Ag tape. After reacting at 900° C for 10 minutes, micrographs of the fracture surface showed that the grains (a few to 10 μm in diameter) of the superconducting oxide are more densely packed than in bulk samples prepared by conventional sintering. This tape could be bent to small diameters (<50 mm) without the reacted layer either breaking or separating from the tape. The ceramic oxide layer also had better superconducting properties than on the Cu tape. The T_c at 0 resistance was about 85 K and the highest J_c was about 42 A/cm^2 at 77 K and 0 Tesla. The researchers are now optimizing their process to improve the superconducting properties. They believe this work demonstrates the potential feasibility of processing $Yba_2Cu_3O_{7-x}$ into long lengths of ductile superconductive tape. (K. Togano, National Research Institute for Metals, Tsukuba Laboratories, 1-2-1, Sengen, Sakura-mura, Niihari-gun, Ibaraki 305 Japan) (Source: Materials and Processing Report, January 1988)

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Versatile process for preparing superconducting thin films

A simple and economic metallo-organic spin-on process for preparing superconducting thin films has been developed by Michal Gross and co-workers, also at AT&T Bell Laboratories. It is the first thin film process in which solutions of the combined precursors are spin-coated and fired to produce superconducting films. The films formed can be from a few thousand angstroms to several microns thick, and the technique allows precise stoichiometric control of the metal atom ratio.

Specifically, the method involves spin-coating a substrate such as zirconia (ZrO_2) or magnesium oxide (MgO) at 2,000 rpm with a solution of the metallo-organic precursors (2-ethylhexanoate complexes of the rare earth, barium, and copper ions), or dipping the substrate in the solution. The coated samples are prebaked at 100° C to remove residual solvent, then fired in a steady stream of O_2 (at 800°-900° C) followed by annealing at 400° C. The onset of the superconducting transition occurs at 89 K, the critical temperature (T_c) at 0 resistance is 77 K, and the critical current density (J_c), measured at 65 K, is about 10^3 A/cm^2. Crack-free films prepared by two coatings of 0.5 μm each followed by firing at 990° C show an improved J_c of 10^4 A/cm^2 with no change in T_c. The improvement in J_c is attributed to the second coat filling voids in the base coat.

The researchers believe that their spin-coating process offers several advantages over other reported solution techniques for preparing films in its ability to apply more uniform films of varying thicknesses. Even though the T_cs and J_cs are not particularly high, because the method is so "low-tech" it offers a relatively easy and inexpensive way to prepare multiple samples for applications development work. (Source: Materials and Processing Report, January 1988)

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Novel powder preparation technique

A freeze-drying technique that can produce high quality powders of superconducting oxides has been developed at the Oregon Graduate Centre. Sintered samples prepared from these freeze-dried powders are very pure (require no additional sintering aids) and have higher densities than sintered samples prepared by conventional solid state powder reaction. In addition, as shown on Figure A, the resistance of an yttrium 1:2:3 superconducting oxide prepared from freeze-dried powders drops very sharply to 0 within a range of 1 to 4 K, with the transition temperature in the 93 to 97 K range. And its diamagnetic effect (as measured by the levitation height of a magnet) is stronger than an annealed sample prepared by a solid state mixing reaction.

The freeze-drying process consists of mixing stoichiometric aqueous solutions of pure salts of the starting materials, freezing the mixture by spraying with an atomizer into a sample holder filled with liquid nitrogen, sublimation of the solvent, and decomposition to form the powdered product. After pressing into pellets (50,000 psi) and sintering (95° C for eight to 72 hours in oxygen), X-ray spectroscopic studies indicate high chemical homogeneity with almost no variation in composition from one grain to another across the sample. Micrographs show largely the twin orthorhombic $YBa_2Cu_3O_{7-x}$ phase running all across the sample with very few other phases detected. The developers believe that this cryochemical technique can be used to prepare commercial quantities of high quality precursor powder for superconductors.

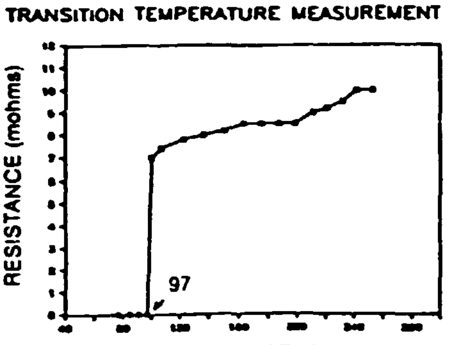

Fig. A Temperature dependence of the electrical resistance of the $YBa_2Cu_3O_{7-x}$ heated to 950°C for 36 hr in O_2

(Nicholas G. Eror, Professor, Department of Materials Science and Engineering, Oregon Graduate Centre, 19600 N.W. Von Neumann Dr., Beaverton, OR 97006-1999) (Source: Materials and Processing Report, January 1988)

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In situ production of superconducting thin films

A high-pressure reactive evaporation process that forms highly oriented films of the superconducting phase of yttrium-barium-copper-oxide in situ is under development at Cornell University, USA. The process is based on the electron beam co-evaporation of Y, Ba, and Cu wires onto heated (600°-750° C) substrates in oxygen (at 0.65 mtorr). By backfilling the deposition chamber with ca. 100 torr of oxygen while the films cool, T_cs of 81 to 83 K were achieved without any post annealing, on both strontium titanate ($SrTiO_3$) and yttria stabilized zirconia substrates. Critical current densities (J_c) above 10^6 A/cm^2 at 4.2 K were obtained with films on both substrates. This demonstrates that at least one substrate other than $SrTiO_3$ can yield high J_c values.

The researchers believe that as their process becomes optimized the properties of these films will improve. They suggest that this approach to growing superconducting thin films is particularly promising for the rapid development of a successful high T_c thin film technology. (Robert A. Buhrman, Professor, School of Applied and Engineering Physics, Clark Hall, Cornell University, Ithaca, NY 14850-2501) (Source: Materials and Processing Report, January 1988)

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Introduction of superconductive powders

W.R. Grace's Davison Chemical Division, USA in co-operation with Grace's corporate research division, has developed high-temperature 1-2-3 superconducting powders and a full line of high purity rare earth oxides, which it now offers for electromagnetic applications in the computer and electronics industries.

Grace says its $YBa_2Cu_3O_{7-x}$ powder is 99.9 per cent pure, and shows more than 92 per cent superconductivity when pelletized at liquid nitrogen temperatures. Grace also offers a submicron precursor grade, which requires calcination by the customer.

The new substances are being made at Grace's Washington Research Centre in Columbia, Maryland. (Source: Chemical Marketing Reporter, 18 January 1988)

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Miscellaneous

Dutch fillip for superconductors

Philips of the Netherlands has formed a team of 25 top scientists to seek a breakthrough in the development of superconductors for commercial applications. The team, working in Eindhoven in the Netherlands, Aachen in the Federal Republic of Germany and Briarcliff Manor in New York State in the US is the first privately-funded initiative in Europe aimed to produce a superconducting material that has no electrical resistance at room temperature.

Speaking in Eindhoven last week, the team's leader, Piet Bongers, said that Philips would work closely with researchers at several Dutch universities. The researchers are to rely on a technique called electron microscopy to find the best combination of materials to achieve their objective. The company will also call on applied physicists whose work on Josephson junctions and simple switching devices could lead to new methods of producing on a large scale superconducting chips. (This first appeared in New Scientist, London, the weekly review of science and technology, 18 June 1987.)

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Superconductivity update

We are starting to see a shift in focus in superconductivity from the theoretical to the practical. The conference on applications, sponsored by the Department of Energy, held on 28-29 July in Washington, D.C., is one example. For once the spotlight is not on incremental increases in temperature at which superconductivity has been observed. We are also starting to see some market forecasts and studies. Strategic Analysis, Inc., for instance, is under way with a nine-month multiclient study that should be out early next year. Cost is $25,000 if you sign up after 1 August, $5,000 less before.

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Superconductivity market: 1986-2005*

End-use industry	$ million 1986	$ million 2005	Level of activity (worldwide)
Electronics	40	400	Very high
Instrumentation and medical	200	780	High
Aerospace and defence	25	350	Moderately high
Industrial	20	200	High
Power generation	< 5	50	Very low
Transportation	< 5	20	Low
Total	$290	$1,800	

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* Source: Strategic Analysis, Inc.

Earliest applications of new superconducting materials will be in retrofit of existing designs for products such as medical imaging equipment and selected test sections of high-energy accelerators.

Another practical application getting attention - and funding from the US Navy - is development of superconductor-based electric powered submarines and ships.

Donald Gubser, who runs the Naval Research Laboratory's superconductor programme, predicts the Navy will be making motors with the new superconductors by the mid-1990s.

Joining the effort to organize superconductor research into focused working groups is MIT. Its plans involve forming a large-scale regional research organization, perhaps in the form of a National Science Foundation-sponsored science and technology centre. (Extracted from Inside R&D, 29 July 1987)

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Sumitomo Cement has developed high purity alkoxides of transition elements for use in high-temperature superconductors. The 99.9-99.999 per cent pure alkoxides include titanium, tantalum, niobium, zirconia, iron, aluminium, silica, tungsten, gallium, tin, yttrium, barium and copper. High purity chloride anhydrides are used as raw materials, and are reacted with alcohol and ammonia to form the alkoxides, which are available as liquids or powders. Hydrolyzing in alcohol produces a gel-like material that can be sintered into ceramics. (Source: Japan Chem, 9 July 1987, p. 5)

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Electro Technical Laboratory (Japan) has developed a metallic superconductor that operates at room temperature with no need for coolants. Strontium is added to standard "warm" semiconductors - comprising barium, yttrium, oxygen and copper - that operate at -180° C. In the UK, Cambridge University, General Electric (UK) and other firms are co-operating with each other and with Electro Technical Laboratory to develop superconductors. In preliminary tests, ETL's material remained superconductive for one day, longer than in similar reported instances but not long enough to have commercial applications. (Source: Financial Times, London, 28 August 1987)

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Intermagnetics General introduced a superconductor tester

The new unit determines the potential and characteristics of material samples of high-temperature superconductors. Called Superconductor Characterization Cryostat (SCC), the unit was designed to provide a method of producing the low-temperature environment needed to test HISC superconductors. It is designed for basic material measurements, superconducting electronic studies and power applications studies. It requires no cryogenic liquids. It uses industry standard fundamental measurements at closely controlled temperatures from 12-350+ K regulated at p/-0.5 K stability. The SCC can also be used to detect very small fractions of high temperature superconductors in otherwise non-superconducting materials. (Source: Electric News, 28 September 1987, p. 33)

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Superconductivity probably does not exist above 250 K, according to IBM researchers. Any findings of superconductivity above this temperature may be ascribed to measurement error. Researchers have become increasingly sceptical of reports of superconductivity at temperatures over 250 K, because the transient observations are not reproducible. The apparent superconductive signals can be attributed to changes in the resistance of the contacts between the electrical leads and the sample, and the heterogeneity of the samples can produce misleading electrical signals. A.W. Sleight of DuPont agrees with the IBM researchers, saying that months of work have not uncovered any evidence for superconductivity over 200 K. 95 K remains the highest temperature at which superconductivity has been confirmed. Still, IBM's J.B. Torrance says that higher temperature superconductors might still be found someday. (Source: C & E News, 7 September 1987, pp. 6, 7)

Japan aims to develop single-crystal and thin-film superconductors. The Science and Technology Agency's National Research Institute for Metals (NRIM; Tokyo) hopes to launch a $140-million, five-year programme in fiscal 1988 that would produce single crystals for high-speed instrumentation, and thin films for more-powerful magnets. NRIM plans to develop crystals by lowering the solution temperature to generate crystal formation, using zone melting (heating a material to remove impurities), and using Czochralski techniques (crystal growing by seeding a molten bath).

The Institute's film effort is likely to focus on: sputtering for substrate production; precisely controlling the amounts of yttrium, copper and barium present; and lowering the sintering temperature from its current level of about 700° C. (Source: Chemical Engineering, 26 October 1987)

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Japanese progress

Japanese researchers have been piling up patents for superconductor materials and devices. They have filed more than 1,500 applications with the Japanese Patent Office. Sumitomo alone has 700 of them. Granted, Japan awards patents to the first company to file, so they have reason to get their applications in the mail. But the amount of activity is extraordinary. Here are some of the results:

Superconducting films can be made by dipping a zirconia-based wafer into a molten solution of yttrium stearate, naphthenic acid barium, and naphthenic acid copper. The resulting film is 2μ thick, and superconductive at 90° K.

Ube Industries is also interested in thin films, but plans to stick to more conventional semiconductor techniques. It hopes to optimize a ceramic superconductor that can be spattered onto a substrate. Critical temperature should be 90° K.

Most interesting breakthrough is an optical switching device that uses an amorphous film of high-temperature superconducting ceramic. While it is still in the basic research stage, early results show promise. Researchers are very close with their data, but superconductors could be used to rapidly transmit optical signals into digital electrical pulses. (Source: High-Tech Materials Alert, October 1987)

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High-temperature superconductors could be worth $3-7 billion/year, according to P. Winson of Oxford Instruments (UK). Sales of superconductor products are currently about $750 million/year. Superconductors are suitable for any applications requiring transmission of electricity over large or small distances. Superconducting coil magnets can produce strong magnetic fields without requiring large amounts of energy, and so could be used for maglev vehicles, particle accelerators or NMR scanners. Magnetic fields can be used to switch the superconductivity on and off, so allowing superconductors to be used for transistor-like devices and Josephson junctions. High-temperature superconductors could easily displace low-temperature superconductors in their current applications, as liquid helium coolant could be replaced by the much cheaper liquid nitrogen coolant. This would reduce the cost of operating an NMR scanner UK£17,000/year. Planners also estimate that high-temperature superconductors will make it cheaper to build and operate particle accelerators.

It is not yet clear, however, what properties high-temperature superconductors will have when they become commercially available or how they can be processed into useable products. IBM says current density of 100,000 amps/sq cm are possible, sufficient for most applications. Claims of superconductivity at temperatures of over 0 C have yet to be verified. Superconducting electric transmission lines could save enough in transmission losses to equal the power output of 50 US power plants, according to researchers at Brookhaven National Laboratory. Superconducting cable could also eliminate the need for booster stations along communications cables.

Plasma spraying has already been used by IBM to deposit thin coats of superconductors on a substrate. Such coatings might act as magnetic shields in power generators or computer chips. But the technology cannot be commercially introduced until it is thoroughly tested. Producing uniform materials with the proper characteristics may be difficult. The thin films might also be adversely affected by small magnetic fields. Etching superconducting films for computer chips is also a difficult task. The brittleness of ceramics might limit their use in cable, although a polymer binding might solve this problem. Superconductors might not be commercially profitable for at least 10 years, according to Oxford Instruments. And developing the latest generation of superconductors might be made obsolete if room-temperature superconductors can be developed. Meanwhile, Japanese firms are pushing ahead to develop a superconductor computer by 1991. (This first appeared in New Scientist, London, the weekly review of science and technology, 22 October 1987)

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Ceramic superconductor commercialization moving swiftly

The first commercial products coming since the announcements of superconductivity above 90 K are hitting the market. Aside from the number of firms offering market analysis for dollars, and the few publications containing comprehensive reports of the science and engineering involved, some firms are producing commercial products based on ceramic superconductors. Kawasaki Steel Corporation indicates it has established a basic technology for manufacturing commercial quantities of ceramic superconductor wire with 93 K transition temperatures. Current carrying capacity however is reported at only ~10 A/cm^2. Mitsubishi Metal Corp. has started shipping ceramic superconductor sputtering targets to firms interested in creating thin films for SQUID devices from the material. American Superconductor Corp. has been founded with the sole purpose of exploiting the new technology developed by MIT - the oxidation of metal wires based on the Y-Ba-Cu composition which will form the superconductor after oxidation. Guernsey Coating Laboratories is gearing up to begin coating materials with ceramic superconductors for research purposes. Similarly, Superconductive Components has indicated it will be producing ceramic superconductors for research scientists to further study. These firms hope to capitalize on the need to have reliable superconductor properties for further analysis rather than constantly throwing the efforts of physicists into manufacturing technologies already known by ceramic engineers. Other firms being founded on venture capital, such as Conductor Technologies, Inc., plan to wait until the technology begins to mature before setting up laboratory and manufacturing facilities, believing the discoveries of higher and higher T_c superconductor materials are yet to come. (Source: Ceramic Bulletin, Vol. 66, No. 10, (1987))

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Superconducting transmission lines could be built to carry 100 times more digital data than optical fibres because the shorter the pulses, the more information can be sent. The new 90 K superconductors can carry electrical pulses as short as 10-15 picosec without absorption or distortion, impossible with today's transmission lines. One superconducting data transmission line could carry up to 1 trillion bits/second of information, according to G. Mourou of the University of Rochester. Mourou et al worked on a thin film of yttrium-barium-copper oxide that had been grown on an yttrium-doped zirconium oxide substrate by physicist R. Buhrman's group at Cornell University and patterned into a high-speed circuit at Cornell's National Nanofabrication Facility. The thin film was grown, via vapour deposition, at 700 C, lower than the usual temperatures required to make the ceramic. This means that the material can be produced as part of an integrated circuit with less likelihood of damage to other chip components. (Source: C & E News, 12 October 1987, p. 16)

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A theory that the property making a recently discovered ceramics family superconducting would prevent them from carrying high electrical currents has been developed at MIT (Cambridge, MA) and Princeton University (Princeton, NJ), according to the Boston Globe. If proved, the theory could stop the momentum to make practical use of the new superconductors, especially their ability to carry electricity with no loss of energy at very high temperatures. Laboratory scientists have not been able to run large electrical currents through the new ceramic compounds, and form powerful magnetic fields, without losing the materials' ability to attain superconductivity at 100 K. The researchers have found, when a large current is passed through the ceramic material, the electrons jumping between crystals end up bumping into each other and losing much of their energy, the material developing electrical resistance and losing its ability to superconduct. MIT said a remedy would be to develop ceramic crystals oriented so all planes are parallel to each other, but "there may be fundamental limits to what can be overcome". (Source: Metalweek News, 16 November 1987, p. 36)

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Superconductor contact resistivity cut

Electrical applications of the new high-temperature superconductors are being stymied by the high-contact resistance that occurs where normal metallic wire is attached to the superconductor. Now, a research team has developed a way to make such connections so that the contact resistivity is about 10^{-5} ohm sq. cm. at 76 K - three to four orders of magnitude lower than in conventional contacts. Moreover, the connection is achieved below 200° C, which has important advantages over higher-temperature processes. The method described by Jack W. Ekin of NBS's laboratory in Boulder, Colorado, and Armand J. Panson and Betty A. Blankenship of Westinghouse R&D Centre in Pittsburgh consists of three parts: minimizing the superconductor surface's exposure to air before the contact is made, sputter etching the superconductor surface to remove the degraded surface layer, and then immediately depositing a thin layer of silver or gold to protect the surface and serve as a contact pad. Of the 14 contacts made using the new method, the researchers say, all showed consistently low resistivity during a four-month exposure to dry air and cycling between room temperature and 76 K. (Source: Chemical and Engineering, 23 November 1987)

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Hunt goes on for superconductivity patents

All over the world, research scientists are itching to get their hands on the patent applications which IBM has filed on its new materials for high-temperature superconductivity. They want to know what materials and electronic devices IBM will be able to monopolise. IBM, however, is playing a sharp game to try and conceal what others want to know.

The superconductive materials known before IBM's discovery lost their electrical resistance only at

23° C above absolute zero. Georg Bednorz and Alex Mueller, at IBM, discovered a new class of materials which work in the same way at higher temperatures. In October they received the Nobel Prize for Physics, so any patents must name Bednorz, Mueller or IBM. So far though, no such patents have been filed.

The discoveries posed IBM a dilemma. To protect the breakthroughs, the company must file patent applications. Filings in the US are secure because they are not published until granted. In Europe, however, all patent applications are published after 18 months, so any secrets are revealed.

The longer IBM delayed on filing, the longer the secret could be kept. Delaying, however, is a risky game. Someone else may hit on the same idea and file quickly, excluding IBM.

Bednorz and Mueller made their first discoveries in January 1986 and have been letting information filter out ever since. If IBM had filed immediately, patent applications would by now have shown up. But IBM will not have dared to wait until the public announcements were made because these would invalidate any patent subsequently filed. Therefore, publication of the patents is likely to take place in the first half of 1988.

Searchers watching out for the Bednorz and Mueller patents should be on their guard against a clever ploy used by IBM seven years ago. IBM then succeeded in hiding its patent on the quiteron, a possible replacement for the transistor, by filing it as a European application written in German rather than in English. It sat unread on library shelves for two years.

As the work on superconductivity was done at IBM's Research Centre in Zurich, the company may well try to pull the same stunt again. Meanwhile, Japanese companies are filing hundreds of patents relating to work on superconductors. (This first appeared in New Scientist, London, the weekly review of science and technology, 26 November 1987.)

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Japan: An organic material that is superconductive at 10.4 K has been developed by researchers at the Institute for Solid State Physics and Tokyo University. The material is called BEDT-TTF, and is based on bis(ethylenedithio)-tetrathiafulvalene cations and bis(thiocyanato) cupric acid anions. The new organic superconductor is easily separated. (Source: Japan Chem., 10 December 1987, p. 5)

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$1 million study of markets for superconductivity

A $1 million superconductivity market research programme has been launched by the Department of Energy and the Electric Power Research Institute, Palo Alto, California. Funding will be split evenly by DOE and EPRI, with all but $75,000 of the federal funds coming from the Energy Conservation and Utilization Technologies (ECUT) Office.

Through the end of June, DOE, EPRI, several national energy laboratories, led by Oak Ridge National Laboratory, and Battelle Memorial Institute will study power electronics, magnetically levitated trains, small electric motors, electromagnetic pumping, and magnetic materials processing and fabrication. One application with direct bearing on renewable energy is superconducting magnetic energy storage, which could help the economics of remotely site plants. (Source: International Solar Energy Intelligence Report, 22 December 1987)

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Fully automated superconductivity test system

Chino Corporation has developed and put on the market a precision "superconductivity test system" that is designed to automatically measure the critical temperatures of several superconducting specimens simultaneously.

The system was developed by drawing on cryogenic measurement technology relating to temperature calibration equipment. The testing system is essentially a cryogenic temperature measurement system with a range of 15 ~ 300° K. It consists of a temperature measurement sensor, a CRT for data display and a helium circulation cryogenic refrigerator that is used for cooling. The system is capable of measuring critical temperatures fully automatically by means of the electric resistance method and electromagnetic induction method.

When measuring by the electric resistance method, for example, it is possible to select either the d.c. four-probe method or the a.c. bridge method. Other methods are also available such as the hysteresis measurement and cyclic measurement methods, through which the properties of specimens can be exhaustively examined. Up to six speciments can be measured simultaneously by this electric resistance method, and evaluation tests can be conducted very effectively.

Another distinct advantage of this test system is that the sensor uses a platinum-cobalt (Pt-Co) alloy resistance thermometer. This resistor features excellent stability and duplicity of measurements, by which precision measurements are possible to an accuracy of ± 1.5° K.

Specifications

Measurement method: Electric resistance method: d.c. 4-probe method and 4-wire a.c. bridge method

Electromagnetic induction method: Hartshorn method

Temperature measurement range: 15 ~ 300° K or 25 ~ 300° K

Sample holding space: 23φ x 45 mm (15 ~ 300° K type), 40φ x 45 mm (25 ~ 300° K type)

Number of measured samples:
  Electric resistance method: 6
  Electromagnetic inductance method: 1

Temp. measurement accuracy: ± 0.15° K

Control stability: ± 0.01° K

Resistance measurement accuracy: ± 0.3° mΩ

Time required for temp. fall: about two hours (300° K→15° K).

(Chino Corporation, International Div., 1-1,
Higashi-Ikebukuro 3-chome, Toshima-ku, Tokyo)
(Source: JETRO, December 1987)

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Irradiation of ceramic oxides with fast neutrons yields superconductors with zero electrical resistance near room temperature, according to H. Yoshida of the University of Kyoto. The ceramic oxides maintain their superconductivity for at least 45 days. Irradiation raised the superconducting temperature of yttrium-barium-copper oxide from 90 K to 200 K and that of erbium-barium-copper oxide from 90 K to 270-290 K. A semiconductor made of lanthanum-barium- copper oxide became superconducting at 271 K after neutron bombardment.

Mixtures of the various raw materials were calcined at 800° C for 10 hours, ground and sintered at 900° C for 25 hours and irradiated in a 5 MWt nuclear reactor. The ceramic oxides were cooled at -250° C to 54° C in helium to prevent hydration. Yoshida does not yet know why irradiation enhances superconductivity. (Source: Chemical Engineering, 7 December 1987, p. 18)

Copper oxide-based materials for superconducting above water's boiling point have been observed by A. Erbil, a Georgia Tech. physicist. He said the materials made several times in the laboratory seem to be stable and reproducible. Superconductivity was seen in several different copper oxide compound samples that stayed superconductive at up to 550 K, the highest level yet reported. Due to the danger that temperature fluctuations could push the materials beyond the temperature at which they lose their special features, superconductors would be operated under the transition temperature attained at Georgia Tech. With a 500 K transition temperature, the superconductor could safely be operated at room temperature or 300 K. (Source: Metalweek News, 7 December 1987, pp. 8, 10)

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New recipes create cheaper superconductors

Two research groups have developed independently superconducting materials that work at high temperatures but contain far cheaper constituents than existing rare earths. One group is at the University of Houston in Texas and the other at the Institute of Metallic Material Research in Japan.

Their materials differ slightly in composition and superconductive temperature. Both conduct electricity without resistance somewhat above the 90 Kelvin (-183° C) superconducting temperature of the best-known high-temperature material, yttrium-barium-copper oxide.

Both groups claim that their materials are stable and that their results are repeatable - key problems with materials that have been the subject of other recent claims of superconductivity above 90 K. Researchers hope that by avoiding the need for expensive rare earths, the costs of high-temperature superconductors could fall dramatically.

Paul C.W. Chu's group at Houston, which sparked the current frenzy of activity on superconductivity when it discovered the yttrium-barium-copper oxide superconductor a year ago, has found that atomic size and valence strongly influence superconductivity.

The group tried changing the compound's composition and structure by substituting elements with similar valence and atomic size to rare earths. The researchers found that a compound of bismuth, aluminium, strontium, calcium, copper and oxygen starts to become superconducting at 114 K (-159° C).

Bismuth and aluminium replace the rare earth yttrium, while strontium and calcium replace barium in the original compound. Like the earlier compound, the new material is granular, although its exact composition is not yet clear.

Japan Economic News reported on 22 January that H. Maeda's group at Tsukuba has developed a similar material containing bismuth, strontium, calcium, copper and oxygen, but no aluminium. Its first large drop in conductivity was at 120 K, ending with full super-conductivity at 107 K. Chu doubts whether aluminium plays an important role in the Houston material, and says that his findings "appear in agreement" with the Japanese results. (This first appeared in New Scientist, London, the weekly review of science and technology, 4 February 1988)

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7. HIGH TECHNOLOGY BUSINESS GUIDE

High Technology Business' Guide to Superconducting 1988

The following directory lists the 48 companies active in superconductor research and sales around the world. Alphabetical listings within categories - United States, European, Japanese, or start-up companies - represent the full spectrum of superconductor activity, from small entrepreneurs to large corporations doing small-scale research to major players already profiting from this growing technology. The list includes all companies our researchers could find, no matter how significant or insignificant their current programmes may appear.

The US Companies:

COMPANY	OFFICERS	FINANCING	STAFF (SUPERCONDUCTING)	SUPERCONDUCTOR ACTIVITY
1. American Magnetics Box 2509 Oak Ridge, TN 37831 (615) 482-1056	Kenneth Efferson, president Robert Jake, v.p., general manager E.T. Henson, v.p., marketing and sales	Privately owned; sales of $1 million to $5 million	20	Building custom niobium superconducting magnets and instruments for research use; pursuing the specialty-magnet market.
2. AT&T Bell Labs/ Bell Communications Research (Bellcore) 600 Mountain Ave. Murray Hill, NJ 07974 (201) 582-3000	Robert Dynes, director, chemical physics research Donald Murphy, head of solid-state chemistry research Paul E. Fleury, director, physical research laboratory	AT&T subsidiaries; Bell Labs has an annual budget of $2.25 billion, 10 per cent dedicated to basic research	40	In superconductivity research since 1950; developed niobium alloys, did early work on Josephson junctions. Made major contributions to the discovery of high-temperature ceramic superconductors. Currently pursuing basic research.
3. Bechtel National Box 3965 San Francisco, CA 94119 (415) 768-1234	Robert J. Loyd, project manager, Superconducting Magnetic Energy Storage (SMES)	Privately held; sales of $140 million. SMES contract worth more than $10 million	6 (more expected in early 1988)	Developing SMES as part of the Strategic Defense Initiative; may use experience to enter commercial utility market.

The US Companies (continued):

COMPANY	OFFICERS	FINANCING	STAFF (SUPERCONDUCTING)	SUPERCONDUCTOR ACTIVITY
4. Biomagnetic Technologies 4174 Sorrento Valley Blvd. San Diego, CA 92121 (619) 453-6300	Stephen O. James, president, CEO William C. Black, senior v.p. Eugene Hirschkoff, v.p. operations	Privately held. Raised $5.2 million in first-round financing in 1985, $4.2 million in second round, 1987. Projected 1987 revenues, $3.7 million	85	Marketing SQUIDs and related equipment, including its Neuromagnetometer for observing brain functions. Seeking partnership with medical-equipment company to sell and support products.
5. E.I. Du Pont de Nemours 1007 Market St. Wilmington, DE 19898 (302) 774-1000	Edward Mead, manager, superconductor business development Rudolph Pariser, director, advanced materials research Arthur W. Sleight, research leader	Listed on New York Stock Exchange. 1986 earnings, $1.1 billion; sales, $29.4 billion	30	Attempting to apply its expertise in chemical processing to the large-scale production of superconductors. Wants to supply high-temperature superconductor markets as they emerge.
6. Energy Conversion Devices 1675 W. Maple Rd. Troy, MI 46084 (313) 280-1900	Stanford R. Ovshinksy, president, CEO Stephen J. Hudgens, v.p., R&D Rosa T. Young, sr. scientist, group leader	Traded on NASDAQ. Fiscal 1986 net loss of $27.9 million on revenue of $21.1 million; superconductivity work internally funded at $1 million	About 10	Studying ceramic and niobium-based superconductors. Developed a process for mixing fluoride with ceramic for higher-temperature superconductivity, but process not independently verified. Plans to license fluorination technology if a market develops.
7. Eriez Magnetics/ Eriez Manufacturing Asbury Road at Airport, Erie, PA 16514 (814) 833-9881	Chester F. Giermak, president Jerry Selvaggi, consultant/engineering manager	Privately held; $40 million in sales	10	Designed and installed the first superconducting magnet for industrial use, a separator that removes impurities from clay. Plans to compete with conventional separators that remove particles from waste water
8. Ford Motor Box 1899 Dearborn, MI 48121 (313) 322-3000	John McTague, v.p., research Marga Roberts, director, chemistry and physical sciences Craig L. Davis, manager, physics dept.	Traded on New York Stock Exchange. 1986 earnings of $3.3 billion on sales of $62.7 billion	5	Working with Detroit's Wayne State University on high-temperature superconductors. Looking for electronic applications that would be pursued by its Aeronutronic Division in Newport Beach, Calif.
9. GA Technologies/ Applied Superconetics Box 85608 San Diego, CA 92138 (619) 452-3400	Tihiro Ohkawa, vice chairman Kenneth Partain, president, Applied Superconetics John Alcorn, manager, Superconducting Magnet Group	Privately owned; 1986 sales of $154 million	100	Designing and building specialized magnets. GA's subsidiary, Applied Superconetics, sells magnets for use in magnetic-resonance imaging. Strong candidate to supply magnets for the Super Collider.
10. Garrett Box 92248 Los Angeles, CA 90009 (213) 776-1010	Anil Trivedi, assistant manager, advanced applications	Parent company, Allied-Signal, on New York Stock Exchange; Garrett had 1986 sales of $2.15 billion	10 to 20	Developing a fine-grained superconductor ceramic powder for electronics and industrial use.

The US Companies (continued):

COMPANY	OFFICERS	FINANCING	STAFF (SUPERCONDUCTING)	SUPERCONDUCTOR ACTIVITY
11. General Dynamics Space Systems Division 5001 Kearny Villa Rd. San Diego, CA 92123 (619) 573-8000	David Walker, chief, R&D designs Robert Johnson, programme manager, energy programmes	Traded on New York Stock Exchange. 1986 revenues, $8.9 billion; loss of $63 million due to $420-million write-off of purchase price of Cessna Aircraft	60 at peak; now only a few preparing proposals	Built large magnets for Department of Energy research programmes; may use expertise to supply magnets for the Super Collider.
12. General Electric Medical Systems Group Box 414 Milwaukee, WI 53201 (414) 544-3011	John Trani, sr. v.p., group executive Michael J. Jeffries, R&D manager, GE R&D Center	Traded on New York Stock Exchange. 1986 earnings of $2.5 billion on sales of $35.2 billion	20 at R&D Center; the Medical Systems Group employs several hundred	Supplying magnetic-resonance-imaging equipment. The R&D Center developed superconducting generators and is working on high-temperature ceramic superconductors.
13. General Motors Technical Center 30200 Mound Rd. Warren, MI 48090 (313) 575-1188	Donald J. Atwood, vice chairman Robert Frosch, v.p., GM Research Laboratories	Traded on New York Stock Exchange; 1986 earnings of $2.9 billion on earnings of $102.8 billion	5	GM Research Labs is developing ways to deposit thin films of ceramic superconductors on silicon wafers. Has demonstrated a metallo-organic deposition technique that lays down films without the use of vacuum.
14. Hypres 500 Executive Blvd. Elmsford, NY 10523 (914) 592-1190	Sadeg M. Faris, president, CEO Gerald M. Haines, v.p., CFO Eric Hanson, v.p., product development	Privately held; venture funding of $2.2 million in August 1983 and $6.4 million in December 1985	75	Produces a commercial Josephson-junction microchip that it uses in electronic instruments. Plans to introduce more such devices; seeks partner to develop and market a computer.
15. IBM Watson Research Center Box 218 Yorktown Heights, NY 10598 (914) 945-3000	Prauveen Chaudhari, v.p., physical-science research Alex Malozemoff, co-ordinator, superconductivity programme	Traded on New York Stock Exchange. 1986 earnings of $4.8 billion on revenues of $51.2 billion; 1986 R&D and engineering budget, $5.2 billion	Not available	Studying high-temperature materials to achieve superconductivity at room temperature.
16. Intermagnetics General Charles Industrial Park Box 566 Guilderland, NY 12084 (518) 456-5456	Carl Rosner, chairman, president C. Richard Mullen, sr. v.p., operations Bruce A. Zeitlin, v.p. materials technology	Traded on NASDAQ. Lost $3.9 million on revenues of $14.3 million in 1987; 1986 profit of $1.6 million on revenues of $21.2 million	More than 300, including production workers	The leading US maker of wire and cable, and magnets for commercial and research markets. Saw 1987 loss after its largest customer, Johnson & Johnson, discontinued product line. Positioned to be leading supplier of magnets for the Super Collider.
17. Microelectronics and Computer Technology 3500 W. Balcones Centre Dr. Austin, TX 78759 (512) 343-0978	Grant A. Dove, chairman, CEO Barry Whalen, v.p. Harry Kroger, technical director, packaging and interconnects	Owned by consortium; $75 million operating budget	7	Co-ordinates research efforts of electronics companies that own it. Developing high-temperature superconductors for electronics packaging and interconnects. Seeking new participants.

The US Companies (continued):

COMPANY	OFFICERS	FINANCING	STAFF (SUPERCONDUCTING)	SUPERCONDUCTOR ACTIVITY
18. Quantum Design 11578 Sorrento Valley Rd. San Diego, CA 92121 (617) 481-4400	William B. Lindgren, president, general manager Michael B. Simminds, v.p.	Privately held; recently topped $1 million in annual sales	22	Making instruments that measure magnetic properties, using SQUIDs from Biomagnetics Technologies. A subsidiary, Quantum Magnetics, will market additional SQUID-based instruments, including a rust detector.
19. Supercon 830 Boston Turnpike Rd. Shrewsbury, MA 01545 (617) 481-4400 842 0174	James Wang, president Eric Gregory, v.p., general manager	Privately held; annual sales of $1 million to $5 million	30	Manufacturing niobium-alloy wire and cable. Supplies research labs, GE, and GA Technologies. Manoeuvering to supply the Super Collider.
20. Teledyne Wah Chang Albany Division Box 460 Albany, OR 97321 (503) 926-4211	Al Riesen, president Chet Leroy, v.p., technology	Traded on New York Stock Exchange. Earned $129 million on sales of $1.6 billion for the first half of 1987	10 in R&D; many more in production	Leading supplier of niobium-alloy wire for magnets made by companies including Oxford, Intermagnetics, and Supercon. Plans to be major supplier of wire for magnets in the Super Collider.
21. TRW 1 Space Park Redondo Beach, CA 92077 (213) 535-4321	William Simmons, director, group research Arnold Silver, head, superconducting electronics	Traded on New York Stock Exchange. 1986 earnings of $217 million on sales of $6.4 billion	About 20	Researching Josephson-junction circuits for the Defense Department. Will develop products for military and aerospace markets.
22. Westinghouse Electric Research and Development Centre 1310 Beulah Rd. Pittsburgh, PA 15235 (412) 256-1352	John Hulm, director, research Richard D. Blaugher, manager, cryogenic technology and electronics Alex Braginski, manager, superconducting materials	Traded on New York Stock Exchange. 1986 earnings of $671 million on revenues of $10.7 billion	7	Researching high-temperature ceramic superconductors; developing Josephson-junction technology for the Air Force. Well positioned to be a major magnet supplier for the Super Collider. Superconducting generator technology may interest the Navy.
The Start-ups:				
23. American Superconductor 21 Erie St. Cambridge MA 02139 (617) 499-2600	George McKinney, president Terry Loucks, v.p., technology Francis Hughes, treasurer	Privately held; $4.35 million from American Research & Development, Rothschild Ventures, and Venrock	4	Holds a license on an MIT process for making ceramic wire and tape; plans to open pilot plant in 1988 to produce wires and ribbons, windings for magnets, and possibly thin wires for electronics. Significant profits not expected for 7 to 10 years.
24. AppliTech of Indiana 8150 Zionsville Rd. Indianapolis, IN 46200 (317) 872-6109	N. Quick, founder	Privately held; financial data unavailable	4	Developing a process for making very high-quality ceramic; testing a laser process for eliminating flaws. Pilot plant expected in two years.

The Start-ups (continued):

COMPANY	OFFICERS	FINANCING	STAFF (SUPERCONDUCTING)	SUPERCONDUCTOR ACTIVITY
25. Arch Development 1115-25 E. 56th St. Chicago, IL 60637 (312) 702-7417	Steven Lazarus, president, CEO Brian R.T. Frost, director, Technology Transfer Center, Argonne National Laboratory Janett Truhatch, associate v.p. for Research, University of Chicago	Non-profit; funded by Argonne National Laboratory and University of Chicago	50 scientists and technicians at Argonne	Setting up a company to develop a way to make ceramic wire. Plans to license patents, form co-operative R&D partnerships, and create new companies.
26. Ceramics Process Systems 840 Memorial Dr. Cambridge, MA 02139 (617) 354-2020	H. Kent Bowen, chairman Clayton M. Christensen, president, director George A. Neil Jr., exec. v.p., operations	Common stock traded on NASDAQ. 1986 revenue, $2.6 million; net loss, $4.1 million	As many as 12	Developing metal-ceramic layered packages for integrated circuits. Wants to link marketing with other companies. Focusing on developing products that can be made using micro-smooth sheet forming, metal-ceramic laminates, and molding.
27. Conductor Technologies 1001 Connecticut Ave. N.W. Washington, DC 20036 (202) 452-0900	Stephen J. Lawrence, president Laurence Storch, v.p.	Privately held; undisclosed amount from private sources	None full-time	Supports the work of MIT researchers who are developing electronic devices made from ceramic superconductors; seeking priority in licensing resulting patents.
28. Conductus 2275 E. Bayshore Rd. Palo Alto, CA 94303 (415) 494-7836	John Shoch, president, CEO Tony Sun, CFO	$6 million in first-round financing	None full-time	Developing fabrication methods using thin-film techniques similar to those used to produce semiconductors. Exploring very high-speed digital devices, magnetic field detectors (SQUIDs) and other sensors, and high-speed electronic interconnections.
29. Electro-kinetic Systems 701 Chestnut St. Tranier, PA 19013 (215) 497-4660	Jack Reilly, chairman, CEO Burton Lederman, director, R&D	Listed on NASDAQ. Sales of $2 million, earnings of $65,000	2	Developing ceramic-based materials that can be applied as coatings and which superconduct at liquid-nitrogen temperature. Working with MIT.
30. Guernsey Coating Labs 4464 McGrath St., Unit 106 Ventura, CA 93003 (805) 642-1508	Peter Guernsey, president Sam Pellicori, consulting physicist	Privately held; sales of $500,000 in optical coatings; seeking $500,000 in venture capital	1 part-time	An established optical-coating lab, diversifying into custom coating with ceramic superconductors.
31. Monolithic Superconductors Box 1654 Lake Oswego, OR 97035 (503) 684-2974	Lawrence E. Murr, owner, founder Alan Hare, owner, founder	Privately held; financial date unavailable	6	Developing a way to produce bulk ceramic material by using shock waves to bond particles. Seeking venture capital and co-operative research to help commercialize the technique.

The Japanese:

COMPANY	SUPERCONDUCTOR ACTIVITY	COMPANY	SUPERCONDUCTOR ACTIVITY
32. **Fujitsu** Marunouchi Building 6-1 Marunouchi, 1-chome Chiyoda-ku, Tokyo 100, Japan (03) 216-3211	Researching high-temperature ceramics, with particular interest in thin films. Working on Josephson junctions to develop a superconducting computer.	35. **Kawasaki Steel** 2-2-3, Uchisaiwaicho Chiyoda-ku, Tokyo 100, Japan (03) 597-3111	Developing an experimental superconducting wire made of ceramic.
33. **Furukawa Electric** 2-6-1, Marunouchi Chiyoda-ku, Tokyo 100, Japan (03) 286-3001	Major electrical cable maker; developing a ceramic-based, ring-shaped superconducting magnet.	36. **Matsushita Electric Industrial** 1-1-2, Shibakoen Minato-ku, Tokyo 105, Japan (03) 437-1121	Working on ceramic thin films for silicon wafers, possibly leading to a process that uses superconductors in integrated circuits.
34. **Hitachi** Central Research Laboratory Kokubunji, Tokyo 185, Japan 0423-23-1111 x 3217	Leading developer of niobium-based Josephson junctions. Also developing ceramic-based superconductors for electronics. Hitachi Cable division makes niobium-based wire.	37. **Mitsubishi Electric** 2-2-3, Marunouchi Chiyoda-ku, Tokyo 100, Japan (03) 218-2111	Researching superconductivity since 1958; experimenting with ceramic-based, high-temperature materials. Makes superconducting tape.
38. **NEC** 5-33-1, Shiba Minato-ku, Tokyo 108, Japan (03) 454-1111	Researching Josephson-junction technology for computers and other electronic applications.	41. **Sumitomo Electric Industries** 3-12-1 Moto-Akafaka Manato-ku, Tokyo 107, Japan (03) 423-5111	Has more than 400 Japanese patent applications in ceramic superconductors. Affiliate Sumitomo Heavy Industries is building a superconducting synchotron, expected by 1989, to etch chips.
39. **Nippon Steel** 2-6-3, Otemachi Chiyoda-ku, Tokyo 100, Japan (03) 242-4111	Developing ceramic-based, superconducting wire.	42. **Toshiba** 1-1-1, Shibaura Minato-ku, Kawasaki 105, Japan (03) 597-7111	Developing experimental ceramic wire and tape by bonding superconducting powders inside a metal capillary.
40. **Nippon Telegraph & Telephone** 1-6-1, Uchisaiwaicho Chiyoda-ku, Tokyo 100, Japan (03) 509-5035	Pursuing Japan's largest development effort in Josephson-junction technology; also experimenting with techniques for producing ceramic crystals and films.		

The Europeans:

43. **ASEA-Brown Boveri** S-721 83 Vafteraf, Sweden 021-10 00 00	Researching high-temperature superconductors for use in high-powered magnets and generators.	46. **Oxford Instruments Group** Eynsham Oxford OX8 1TL, England (0865) 881-437	Has about 50 per cent market share in magnets for magnetic-resonance imaging; also makes niobium-alloy wire and cable. Expected to become major supplier of wire and cable for magnets used in the Super Collider.
44. **Cryogenic Consultants** Metrostore Building 231 The Vale London W3 7QS England 01-743-6049	Designing and manufacturing superconductor and superconductor-cooling equipment, including magnets for research, mineral separators, SQUIDs, and related electronic devices.	47. **Plessey** Vicarage Lane Ilford, Essex IG1 4AQ, England 01-478-3040	Developing ceramic superconductors; studying applications in electric-power cables, Josephson-junction circuits, SQUIDs, and thin films.
45. **General Electric** 1 Stanhope Gate London W1A 1EH England 01-493-8484	Makes magnetic-resonance-imaging equipment with magnets from Oxford Instruments. Researching high-temperature superconductors for use in large magnets, electrical machines, and electronics.	48. **Siemens** Wittelsbacher-platz 2, München Postfach 103, D-8000 1 Federal Republic of Germany (089) 234-10	A leading builder of superconductor magnet systems and magnetic-resonance imaging equipment. Developing test magnets for medical market.

(Extracted from High Technology Business, January 1988)

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8. PUBLICATIONS ON SUPERCONDUCTORS

High-temperature superconductivity

The most recent issue of Logos (Vol. 5, No. 3), a publication of Argonne National Laboratory, is devoted to high-temperature superconductivity (HTSC). This clear and concise discussion of progress in understanding and working with high-temperature superconductors, written by members of the laboratory's HTSC team, is available on request while the supply lasts. Contact: Aileen Abernathy, Editor, Office of Public Affairs, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439.

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The proceedings of Superconductors in Electronics - Commercialization Workshop, held September 1987, have been published by the workshop's sponsor, Advantage Quest. The topics include new HTSC materials, electronic applications, specialized materials technologies for electronics applications, raw materials, cooling technology, and patent law and venture capital perspectives. As would be expected, the emphasis is on thin film technology. A presentation by IBM describes its plasma spray deposited films. There is also an examination of the possible applications of these materials as low distortion and moderately low attenuation transmission lines for system interconnections by AT&T Bell Laboratories. And Ed Zschau of Brentwood Associates offers a sobering look at the prospects for investing opportunities. To order: Advantage Quest, 1110 Sunnyvale Rd., Suite C2, Sunnyvale, CA 94087-2515.

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Superconductors: Exploiting Electronics and Computer Applications

by Richard K. Miller, is a compilation of information about superconductivity technology, programmes, and research groups that was available at the time the author assembled it. The overviews of superconductor, Josephson junction, and SQUID technology could be useful introductions to these subjects for nonspecialists. To order: SEAI Technical Publications, P.O. Box 590, Madison, GA 30650.

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Superconductivity: A Guide to the Corporate Players

Mini-report (6" x 9", 92 pp.) includes a fold-out table showing each of the 42 superconductivity leaders in a detailed activity and application. Matrix-Technical Insights, Inc., P.O. Box 1304, Fort Lee, NJ 07024, USA.

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Current research on ceramic superconductors

From The American Ceramic Society, Inc., 757 Brooksedge Plaza Dr., Westerville, Ohio 43081-6136. A special, supplementary issue of "Advanced Ceramic Materials" - a quarterly periodical.

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Data base on superconducting materials

The US Department of Energy has launched a computerized data base to help American scientists keep up with research results in superconducting materials. The data base is accesible through DOE's Office of Scientific and Technical Information (OSTI) at Oak Ridge National laboratory, Tenn.

The first phase, on line today, is an electronic bulletin board where researchers leave their names and telephone numbers and areas of research. The second phase, due in August, will allow researchers to summarize their works in progress. The third phase, slated to go on line in early September, will offer more detailed information on test results ahead of normal technical journal publication schedules.

For more information, Department of Energy, Office of Scientific and Technical Information, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37831, USA.

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Superconductor materials

Brochure lists more than 35 specialized products suited for superconductor research. Featured materials include barium, stronium, lanthanum, scandium, yttrium, copper metals and compounds in various purities that represent the most frequently requested items for superconductor research. In addition, the brochure explains the firm's fabrication service for confidential development and engineering of customized research materials. Johnson Matthey/Aesar, Seabrook, New Hampshire.

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Superconductivity reprints

The American Physical Society has put together a 400-page volume of 112 refereed papers on high-temperature superconductivity published in the first half of 1987. Price: $35. (American Physical Society, Publications Liaison Office, 500 Sunnyside Blvd., Woodbury, NY 11797.)

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High-Temperature Superconductors

High-Temperature Superconductors is the latest in the Key Abstracts series published by INSPEC, the information division of the Institution of Electrical Engineers.

The coverage of High-Temperature Superconductors will include: theory; preparation; physical properties (structure and characterization, critical temperature, critical currents and fields, Josephson effect); applications and devices.

High-Temperature Superconductors will be published monthly starting January 1988, at a subscription price of £56 per annum. For more details, including a sample issue and order form contact: INSPEC Marketing, Institution of Electrical Engineers, Station House, 70 Nightingale Road, Hitchin, Herts. SG5 1RJ, United Kingdom.

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A 200-page report titled "Superconductivity: A Practical Guide for Decision Makers" reports on the significance of high-temperature superconductivity (HTS) developments to organizations and translates that understanding into effective monitoring, research and product development plans. The report identifies five superconductor applications: electrical conductivity, diamagnetism, tunneling, thermal conductivity and hybrid effects. A users' application grid will help readers analyse a specific application in regard to its present state of development, projections for future progress, special problems that may be encountered, and related applications. Technology Futures, Austin, Texas.

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Publications: miscellaneous

Automotive materials

"The Material Network: A Driving Force in Automotive Innovation" is a 12-page overview of company's products and capabilities. Thermoplastics, fabricated foams, epoxy and vinyl ester resins, polyurethane, adhesive films, random fibre composites, and magnesium are discussed. Brochure shows how these materials can be used in automotive exteriors, structures, drive trains, and interiors. Chart lists available literature and specific material properties. Dow Chemical Co., Midland, MI 48640.

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Quality control, tooling book

Quality control products, machine tools accessories, specialized adhesives, and safety equipment are the focus of this detailed 265-page catalogue. Over 500 different products are featured, including surface finish comparators and gauges, inspection lights and magnifiers, replica and proofing compounds and alloys, electronic gauges, data collectors, machine tool safety guards, and gauge stands. Catalogue 687 provides technical, application, selection, and ordering data. Flexbar Machine Corp., 250 Gibbs Rd., Central Islip, NY 11722.

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Advancing Materials Research, published by the National Academy Press, is based on the discussions and formal presentations at a 1985 symposium held at the National Academy of Sciences to celebrate the 25th anniversary of the Materials Research Laboratories. The book, a comprehensive overview of materials science from its early history through current developments and future areas for further research, reflects the symposium's exploration of the status and prospects in materials research. Of particular interest are the discussions, by leading experts, of recent developments and future trends in the frontier of materials science and engineering in such areas as metallurgy, condensed matter physics, quasi-periodic crystals, artificially structured electronic and magnetic materials, advanced ceramics, organic polymers, surface science, and materials synthesis and processing. To order: National Academy Press, 2101 Constitution Ave. NW, Washington DC 20418. Phone: (202) 334-3318.

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Corrosion Resistance Tables, Second Edition, Philip A. Schweitzer, ASM International, Metals Park, Ohio 44073, 216-338-5151, 1986, 1,231 pp. One source from which every component of a system may be selected, including materials for constructing vessels, storage tanks, valves, piping systems, and other items that come in close contact with chemicals. There are two pages for corrodents - one containing the resistance of metals, glass, and carbon, and the other containing the resistance of plastics and rubbers.

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Materials information, a joint service of ASM International and Institute of Metals (London), has announced the publication of the Thesaurus of Engineered Materials. This 132-page, first edition is the basis for the terminology used in the recently introduced Engineered Materials Abstracts. The Thesaurus of Engineered Materials contains the vocabulary for classification, processing, and properties of polymers, ceramics, and composites.

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Tomorrow's Materials, K. E. Easterling. The Institute of Metals, Publications Sales Dept., 1 Carlton House Terrace, London SW1Y 5DB. Tel: 01-839-4071; telex: 8814813; fax: 01-839-2289. Order No. 414, 234 x 156mm, 100 pp., ISBN 0 90146240 3, paperback. Aimed at a general readership including school leavers, students and undergraduates of all scientific and engineering disciplines, as well as individuals requiring updates on advanced materials, this innovative text begins with an introduction to the fundamentals of materials science and investigates a wide range of new materials which have formed the basis of many recent technological advances, completely transforming our manufactured environment.

Advanced materials searches available

A new series of published searches on advanced materials has been launched. Thirty topics have been chosen, researched and packaged to present an attractive product for about one third of the cost of a customized literature search. Titles range from the synthesis of ceramics to the corrosion of polymers. Each search contains up to 250 abstracts of the literature from 1985 to August 1987. Each title costs £45. A full descriptive list is available from Sara Fonseca, Materials Information, The Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB.

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Companies and research institutions needing a detailed picture of advanced materials development in Japan can obtain the Japanese New Materials Yearbook 1986/1987. The Yearbook is a complete survey of the major developments that have taken place in Japan in the field of new materials over the last year. It costs £145 and is published by Elsevier International Bulletins, Mayfield House, 256 Banbury Road, Oxford OX2 7DH.

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P. A. Psaras and H. D. Langford (eds): "Advancing materials research"; 1987, Washington, DC, National Academy Press, xvi + 391 pp., casebound. 155 x 235mm, ISBN 0 309 03697 6. This authoritative book prepared under the auspices of the National Academy of Engineering and the National Academy of Sciences, provides a lively and comprehensive account of achievements in materials science research and development over the period 1960-1985.

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"Advanced Structural Ceramics" published by Business Communciations Co. (BCC), projects that the total value of advanced structural ceramic product shipments will increase from $171 million in 1987 to $430 million in 1990, $1.6 billion in 1995, and $2.6 billion in the year 2000 (all projections are in current dollars). The average annual growth rates are expected to be 36 per cent from 1987 to 1990, 22 per cent from 1990 to 1995, and 18 per cent from 1995 to the year 2000. Overall the BCC projections are more conservative, and th[illegible]e probably more realistic.

The markets covered in the report are for automotive/heat engines, cutting tools, wear parts and other industrial applications, heat exchangers, aerospace and defence-related applications, and bioceramics. The large growth rate projected over the next three years is attributed largely to increased shipments of cutting tools, wear resistant parts, and defence-related applications such as ceramic armour.

Although the study was conducted for the US only, Japanese and European companies, and the competition they pose to US companies, have been included for each market segment. To order: Business Communications Co. Inc., 25 Van Zant St., Norwalk, CT 06855, USA.

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High-Technology Ceramics Past, Present, and Future, subtitled The Nature of Innovation and Change in Ceramic Technology, W. D. Kingery editor, the proceedings of a 1986 American Ceramic Society symposium on ceramic history and archeology, "brings together specific case histories, analyses of the driving forces for innovation, cultural and corporate influences, policies of national self-interest, and a historical viewpoint that allows the reader to shape a new understanding of the process of innovation and how it may affect the future of high technology ceramics". The book, which is divided into three sections, opens with a provocative essay on recent trends in the history of technology. The second section contains numerous specific examples of high-technology ceramic innovations from Egyptian faience, the first high tech ceramic, to more recent innovative developments such as sialons, ferroelectrics, and multilayer ceramics. The final section, on the nature of innovation and management, includes discussions on the sources of innovation, the managment of innovation, how to nurture technology, and a look into the future of ceramic technology. This interesting and informative book should prove valuable both to those already working in this field and to those considering entering it. To order: Book Service Dept., American Ceramic Society, 757 Brooksedge Plaza Dr., Westerville, OH 43081-2821. Phone: (614) 890-4700.

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Better Ceramics Through Chemistry II

Symposium held 15-19 April, Palo Alto, California. Edited by C. Jeffrey Brinker, David E. Clark and Donald R. Ulrich. Pittsburgh, PA: Materials Research Society, 1986. 832 pp. (Materials Research Society Symposia Proceedings; Vol. 73) 86-17969. ISBN 0-931837-39-1. Contents: Solution chemistry and synthesis I: gels. Solution chemistry and synthesis II: powders. Characterization of chemically derived ceramics. Drying and consolidation. Non-oxides. Comparisons of chemically conventionally derived ceramics. Applications of MO/MD calculations. Poster session. Materials for electrical packaging. New initiatives/novel materials. Indices.

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Reinforced Plastics for Commercial Composites, Source Book, edited by Gerald Shook, ASM International, Metals Park, Ohio 44073, 216-338-5151, 1986, 400 pp. Introduction to using reinforced plastics in everyday applications. First part covers resins, fillers, and reinforcements. Then comes curing systems and releases. The actual fabrication of reinforced plastics is the subject of the next two sections. Articles on open and closed-moulded processes discuss fabrication techniques such as compression moulding, resin-transfer moulding, squeeze moulding, foam-reservoir moulding, and resin injections. Following that, automated processes such as filament winding, pultruding, and pulforming are covered. A section on fabrication processes for reinforced-plastic assemblies surveys articles on bonding and fastening methods, including drilling of reinforced plastics.

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Plastics Technology Handbook. Manas Chanda, Salil K. Roy. IX + 553 pages. Marcel Dekker Inc., 270 Madison Ave., New York, NY 10016. 1987.

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Polymer Science. V. R. Gowariker, N. V. Viswanathan, Jayadev Sreedhar. XV + 505 pages. John Wiley & Sons Inc., 605 Third Av., New York, NY 10016. 1986.

Multicomponent polymer materials. Edited by D. R. Paul and L. H. Sperling. Washington, DC: American Chemical Society, 1986. 354 pp. (Advances in Chemistry Series; 211) 85-20475. ISBN 0-8412-0899-9. Contents: Review. Characterization of polymer blends. Characterization of block copolymers. Interpenetrating polymer networks. Mechanical behaviour. Rheology and application. Indexes.

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Plastics technology handbook. Chanda, Manas and Salil K. Roy. New York: Marcel Dekker, 1986. 598 pp. (Plastics Engineering; 12) 86-19730. ISBN 0-8247-7564-3. Characteristics of polymers. Fabrication processes. Plastics properties and testing. Industrial polymers. Addition polymers. Condensation polymers. Special polymers. Index.

Principles of polymer composites. A. A. Berlin, S. A. Volfson,, N. S. Enikolopian and S. S. Negmatov. Berlin: Springer-Verlag 1986. Pp. x + 120, ISBN 3 540 1505 1 X. This book, using ideas developed at the Institute of Chemical Physics of the USSR Academy of Sciences, discusses the principles of the design of advanced polymer composites for use in furniture, building, electrical appliances, vehicles and other equipment.

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Silicon Processing for Photovoltaics II. Edited by Chandra P. Khattak and K. V. Ravi. 1986. xii + 474 pages. ISBN 0-444-87024-5. North-Holland Physics Publishing, P.O. Box 103, 1000 AC Amsterdam, The Netherlands.

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Current topics in photovoltaics. Edited by T. J. Coutts and J. D. Meakin.

Volume 2. September 1987, 244 pp., ISBN 0-12-153412 X. Preface. Physics, Measurement and Systematic Design Theory for Silicon Solar Cells. High Efficiency MINP and PESC Silicon Solar Cells. Space Solar Cells. Index.

Volume 1. June 1985, 279 pp., ISBN 0-12-193860-3. Heterojunction Solar Cells. Cu-Ternary Chalcopyrite Solar Cells. Amorphous-Silicon Solar Cells. Advanced Concentrator Solar Cells. Cadmium Sulphide-Copper Sulphide Solar Cells. Each chapter includes references. Index.

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Fundamentals of solar cells. Photovoltaic Solar Energy Conversion. A. L. Fahrenbruch and R. H. Bube. 1983, 576 pp., ISBN 0-12-247680-8. 1 Vincent Square, London SW1P 2PN.

Two publications on the proceedings of the failure analysis programme and related papers presented at the International Conference and Exposition on Fatigue, Corrosion Cracking, Fracture Mechanics and Failure Analysis, 2-6 December 1985, Salt Lake City, Utah.

1. *Analyzing failures: the problems and the solutions*

Edited by V. S. Goel. Metals Park, Ohio: American Society for Metals, 1986. 368 pp. 86-071195. ISBN 0-87170-270-3.

2. *Fatigue life: analysis and prediction*

Edited by V. S. Goel. Salt Lake City, American Society for Metals, 1986. 415 pp. 86-071194. ISBN 0-87170-271-1.

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Nondestructive testing handbook

Second edition, Vol. 4: *Electromagnetic testing eddy current, flux leakage and microwave nondestructive testing*. Edited by Robert C. McMaster, Paul McIntire and Michael L. Mester. Columbus, Ohio: American Society for Nondestructive Testing, 1986. 677 pp., ISBN 0-931403-01-4. 86-71347.

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Wenk, Samuel A. and Robert C. McMaster. *Choosing NDT: applications, costs and benefits of nondestructive testing in your quality assurance program*. Columbus, Ohio: Amerrican Society for Nondestructive Testing, 1987, 96 pp. Paper. 87-1788. ISBN 0-931403-09-X.

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Failure analysis and prevention, 9th ed. Vol. 11. Gordon W. Powell and Salah E. Mahmoud, co-ordinators. Metals Park, Ohio: American Society for Metals,

1986. 843 pp. 78-14934. ISBN 0-87170-007-7. This updated and expanded volume essentially maintains the format used in the 8th edition (Vol. 10) involving a review of the engineering aspects of failure, studies of various failure mechanisms, and related environmental factors, and analyses of hundreds of actual service failures of metallic materials. Some first-time analysis of ceramic polymers, and continuous fibre-reinforced composites are also included plus increased coverage concerned with failure analysis of integrated circuits. As usual, the work is spectacularly illustrated.

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High Performance Fibre Composites. By J. G. Morley, Wolfson Institute of Interfacial Technology, University of Nottingham, deals both with reinforcing fibres and with the physical principles of reinforcement. Its seven chapters cover a wide range of both continuous and discontinuous reinforcing fibres, the elastic properties of fibre composites, the development of matrix cracks in brittle matrix composites, the fracture of unidirectionally reinforced systems under tensile loading, fracture under more complex off-axis and compressive loading systems, and aspects of the long-term strength of fibrous composites. To order: Academic Press, 465 S. Lincoln Dr., Troy, MO 63379.

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Advanced Composites III: Expanding the Technology is a compilation of all but 12 of the presentations at the 1987 Advanced Composites Conference sponsored by ASM International and the Engineering Society of Detroit. The papers cover design, manufacturing, materials science, and secondary processing in polymer matrix composites for aerospace, automotive, and defence applications. To order: ASM Member/Customer Service Center, Metals Park, OH 44073.

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Proceedings of the American Society for Composites

Second Technical Conference, co-sponsored by the University of Delaware Center for Composite Materials, contains papers covering processing science, materials science, characterization, mechanics, design and analysis, durability, and nondestructive evaluation. Most of the presentations concern polymer matrix composites, but there is also a session on fibre reinforced ceramics and one on metal matrix composites. To order: Technomic Publishing Co. Inc., 851 New Holland Ave., Box 3535, Lancaster, PA 17604.

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Engineers' Guide to Composite Materials, edited by John W. Weeton, ASM International, Metals Park, Ohio 44073, 216-338-5151, 1986, 400 pp. Data and information needed to understand and evaluate composites technology. Property section on reinforcements highlights fibre, whisker, textile, paper, felt, and fillers. The section on polymer-matrix composites compares the properties of fibre-reinforced, filled-resin matrix composites, and various epoxy matrix composites. Property data on metal-matrix composites include fibre-reinforced aluminium, titanium-alloy, nickel, nickel-base, cobalt, iron-base, and superalloy composites. The last property data section deals with fibre-reinforced ceramic composites, nonfibre-reinforced ceramic composites, cermets, and other metal-ceramic composites, and carbon/carbon composites.

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Carlsson, Leif and R. Byron Pipes. Experimental characterization of advanced composite materials. Englewood Cliffs, NJ: Prentice-Hall, 1986. 197 pp. 86-18695. ISBN 0-13-294950-4. Contents: Theoretical background. Laminate processing. Determination of fibre volume fraction. Lamina tensile and shear response. Lamina compressive response. Lamina thermoelastic response. Lamina off-axis response. Laminate tensile response. Laminate thermoelastic response. Laminate notched strength. Characterization of interlaminar fracture. Index.

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Nonmetallic materials and composites at low temperatures 3. Proceedings of the Third ICMC Symposium on Nonmetallic Materials and Composites at Low Temperatures, held 23-24 August 1984, Heidelberg, Federal Republic of Germany. Edited by Gunther Hartwig and David Evans. New York: Plenum Press, 1986. 220 pp. 85-24337. ISBN 0-306-42117-8.

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Alloy steel options

Engineer's guide contains 24 pages of information about High Strength Low Alloy (HSLA) steels and high strength carbon flat rolled steels. Design features, performance benefits, chemical compositions, tensile properties, atmospheric corrosion resistance qualities, and other aspects are detailed. Discussion stresses advantages such as resistance to brittle fracture, formability for reduced fabrication costs, weldability characteristics, light weight, and resistance to abrasion and high-temperatures. Gulf States Steel, Marketing Services Associates, University Circle Research Center 1, 11000 Cedar Ave., Cleveland, OH 44106.

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Haasen, Peter. Physical metallurgy. Second edition. Translated from the German by Janet Mordike. New York: Cambridge University Press, 1986. 392 pp. 86-6059. ISBN 0-521-31037-X.

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Aluminium-lithium alloys III

Proceedings of the Third International Aluminium-Lithium Conference sponsored and organized by The Institute of Metals; University of Oxford, 8-11 July 1985. Edited by C. Baker et al. London: Institute of Metals, 1986. 640 pp. ISBN 0-904357-80-5. This 1985 conference report is in two parts: (I) covers areas such as production, products and joining, fatigue behaviour, and powder and mechanically alloyed materials; (II) includes physical metallurgy and structure property relationships. Particular interest, for example, was given aircraft structural applications.

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Powder metallurgy

Cytemp Specialty Steel Div., Cyclops Corp., has a brochure on its powder metallurgy process: Consolidation by Atmospheric Pressure (CAP). "CAP: P/M Made Crystal Clear" outlines the firm's capabilities for producing powder metallurgy alloys, gives a schematic representation of the process, and lists various alloys and product forms available. Compared with conventional wrought metals, CAP P/M materials reportedly exhibit increased toughness, improved machinability, and excellent grindability. Cytemp Specialty Steel Div., P.O. Box 517, Titusville, PA 16354, USA.

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Progress in Metallurgical Research - Fundamental and Applied Aspects

Proceedings of the International Conference, 11-15 February 1985, Indian Institute of Technology, Kanpur, India. Eds. S. P. Mehrotra and T. R. Ramachandran, published by Tata McGraw-Hill Co. Ltd., New Delhi, ISBN 0-07-451640-X.

This is quite an extensive conference report, running to 720 pages and 76 papers. The topics encompass many aspects of metallurgy, from mineral engineering to metal physics.

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10. PAST EVENTS AND FUTURE MEETINGS

Meetings on superconductivity

1987

18 March 1987, New York City	Annual Meeting of the American Physical Society. This meeting was touted as the "Woodstock of physics" because of the excitement it generated among the scientists.
March 1987, Washington, D.C.	Two-day seminar at the National Academy of Sciences. The lead-off speaker was K. Alex Müller, head of the IBM-Zurich group; followed by Paul C. W. Chu, head of a group of materials scientists of the University of Houston, Texas. The academy intends to host about four of these seminars per year, starting 1988.
27-30 March, Nagoya Inst. of Techn., Japan	Symposia on high-temperature superconductive oxides. (Sponsor: Japan Physical Society) and
28-31 March, Waseda University, Japan	(Sponsor: Applied Physical Society)

April 1987

April 1987	The first major meeting of British scientists working on high-temperature superconducting ceramics, held at the Rutherford Appleton Laboratory. Meeting was arranged by the Science and Engineering Research Council (SERC).
April 1987, Denver, Colorado	American Chemical Society's Spring Meeting
21-24 April, Anaheim, California	1987 Spring Meeting of the Materials Research Society

June 1987

2-5 June, Strasbourg, France	1987 Meeting of the European Materials Research Society. (A special day was devoted to high-temperature superconductivity)

July 1987

28-29 July, Washington, D.C.	Conference on New High-Temperature Superconducting Materials. (Sponsors: The US White House Office of Science and Technology Policy, Dept. of Energy, Dept. of Commerce, Dept. of Defense, National Science Foundation, National Academy of Sciences)

August 1987

August 1987 Kyoto, Japan	18th International Conference on Low Temperature Physics. (Sponsors: International Union of Pure and Applied Physics, Science Council of Japan, Physical Society of Japan and the Japan Society of Applied Physics)

September 1987

September 1987, New Orleans, USA	194th National Meeting - Symposium on New High-Temperature Superconductors. (Sponsor: American Chemical Society)
14-15 September, San Francisco, California	A commercialization workshop on superconductors in electronics. The workshop covered Josephson junction devices; application of superconductors for interconnects and other uses; impact of superconductors on GaAs materials markets and also on metals and rare earth markets; and the type of products and companies that will be the winners and losers of the new technology. The organizer, Advantage Quest, Sunnyvale, California, solicited speakers from materials development, electronic device industry, suppliers of liquid nitrogen, refrigeration systems, patent law, government and finance.
18-19 September, University of North Carolina, Chapel Hill	The Symposium on High Temperature Superconducting Materials. The event, sponsored by the North Carolina Section of the American Chemical Society, featured lectures and poster presentations on synthesis, properties, and processing of superconducting materials. (University of North Carolina, Dept. of Chemistry, Venable Hall 045 A, Chapel Hill, NC 27514)
25 September, Coventry, UK	A special session on High Temperature Superconducting Materials was held at the University of Warwick, Coventry, UK. It was organized by Dr. David Dew-Hughes, Department of Engineering Sciences, Parks Road, Oxford University, Oxford OX1 3PJ, England, from whom further details can be obtained. This session was part of the conference titled "New Materials and their Applications" being organized by the UK Institute of Physics, which was held from 22 through 25 September 1987. However, in order to accommodate the rapid advances taking place in high temperature superconductor research, the details and format of session will be determined later than for the rest of the meeting.

October 1987

9 October, Los Angeles, California	Superconductor Applications Meeting: Southern California Symposium on the Progress of Superconductor Applications. (Superconductor Applications Assoc., 24781 El Camino Villa Ave., El Toro, CA 92630)
18-21 October, Denver, Colorado	Special Ceramic Superconductor Session. (Sponsored by the Electronics Division of the American Ceramic Society and Electronics Division of the Ceramic Society of Japan)

November

6 November, Anaheim, California	Thin Film Processing and Characterization of High-Temperature Superconductors - 34th National Symposium (American Vacuum Society, 335 East 45th Street, New York, N.Y. 10017)
9-11 November, Boston, MA	Perspectives in the New Superconductivity - An International Review Conference. (Sponsor: NATURE - The International Weekly Journal of Science)

January 1988

25-26 January, Boston, MA	Commercial Applications of Superconductivity: Focus on which industries will be first to apply new technology, and how much it will cost to implement. (Sponsor: World Tech. Press, 1 Kendall Square, Cambridge, MA 02139)
26-27, January, Boston, MA	High temperature superconductivity: implications for industry. A Symposium at the Massachusetts Institute of Technology. The purpose of this two-day meeting was to put the breakthroughs in perspective for decision-makers in industry, government, and academia. Experts from MIT and industry reviewed the latest advances, summarized the current theories of the physical principles involved, discussed emerging lines of research, explored the potential for the development of devices and systems based on the new materials, and identified the engineering challenges which lie ahead in expanding the use of superconducting technology. (Massachusetts Institute of Technology, Cambridge, MA 02139, USA)

February 1988

16-18 February, Los Angeles, California	International Superconductor Applications Convention. The keynote speaker is K. Alex Mueller, of IBM Research Labs in Switzerland, who shared the Nobel Prize for his superconductor research efforts. Topics include applications of superconductors in electronics, computers, and communications; instrumentation, sensing, and diagnostics; aerospace and defense; utilities; transportation; and consumer products. Also scheduled is a superconductor trade show. (Superconductor Applications Assn., 24781 Camino Villa Ave., El Toro, CA 92630)
22-24 February, Houston, Texas	World Congress on Superconductivity. The World Congress on Superconductivity has been established in Houston, Texas, as a not-for-profit association of scientific, academic, professional, corporate, and governmental organizations. Its objective is to co-operatively advance research and application development internationally in this field. Initial sponsors besides the major Texas universities and Houston organizations include the Institute of Electric and Electronic Engineers, the American Chemical Society, the American Institute of Chemical Engineers, the American Society of Mechanical Engineers, the Association of Energy Engineers, the National Society of Professional Engineers, and the Electric Power Research Institute. Dr. Paul Chu, director of the Texas Center for Superconductivity at the University of Texas is the chairman of the honorary advisory board, which includes among others Dr. William Graham, the President's Science Advisor, Dr. Praveen Chaudhari, vice president of IBM's T.J. Watson Research Center, Dr. Paul Fleury, director of the Physical Research Laboratory at AT&T Bell Laboratories, William F. Hayes, senior research officer of the National Research Council of Canada, Samuel Kramer, deputy director of the NBS National Engineering Laboratory, Dr. Alan Schriesheim, director of Argonne Laboratory, Dr. Ellen Feinberg, editor of High T_c Update, Ames Laboratory, and MPM's editor. The first World Congress event is planned as an international gathering of leaders from the world's research, business, and governmental communities interested in advancing the scientific and practical applications. The programme will cover an international update on scientific advances and applications, a review of application areas, international co-operation, and business opportunities. (World Congress on Superconductivity, c/o Houston Lighting & Power, P.O. Box 1700, ET Room 1105, Houston, TX 77001)
29 February - 4 March, Interlaken, Switzerland	International Conference on High Temperature Superconductors, and Materials and Mechanisms of Superconductivity. (Conference Secretariat, "High Temperature Superconductors", Physics Dept., ETH, Hönggerberg, 8093 Zürich, Switzerland)
20-24 February, Houston, Texas	Superconductor Applications Meeting. (Sponsored by the Materials Research Society, 440 Live Oak Loop, Albuquerque, NM 87122)

March 1988

5 March 1988 Oxford University	"Scientific curiosity to engineering reality" by Dr. David Dew-Hughes, lecturer in engineering science in the University of Oxford. The lecture described the phenomenon of superconductivity and its early history, and also outlined what is required of a superconductor in order that it can be used in an engineering device. The speaker illustrated developments of practical materials to meet these requirements, with examples. Finally, he speculated on the spectacular discoveries of new ceramic superconductors, and their probable impact on engineering. (Sponsored by the Central Electricity Generating Board, UK)

April 1988

5-9 April, Reno, Nevada, USA	Materials Research Society 1988 Spring Meeting, Bally. Standout sessions in diamond films, high-temperature composites (including intermetallics), biodegradability, superconductors, and refractories. (Materials Research Society, 9800 McKnight Rd., Suite 327, Pittsburgh, PA 15237)
11-13 April	Conference to Review Superconductivity Gains. The International Conference on the First Two Years of High-T_c Superconductivity was held at the Bryant-Denny Conference Center, University of Alabama, Tuscaloosa. For information, contact Robert M. Metzger, University of Alabama, Dept. of Chemistry, Tuscaloosa, AL 35487-9671 (205/348-5952)
11-22 April, Trieste, Italy	Experimental Workshop on High Temperature Superconductors (International Centre for Theoretical Physics, Trieste, Italy.)
18-20 April, Buffalo, NY, USA	Conference on Superconductivity and Applications. (Organized by the Institute of Superconductivity headquartered at SUNY-Buffalo, Buffalo, NY 14260, USA). (Sponsored by State University of New York at Buffalo)

May 1988

9-11 May, Rutgers University, USA	Fourth Annual Northeast Regional Meeting High-T_c Superconductors - processing and applications. (Sponsored by the Metallurgical Society, the Materials Research Society, ASM International)
18 May, Baltimore, MD, USA	Planning Meetings on High Temperature Superconducting Ceramics (National Bureau of Standards Materials Bldg., Room B309, Gaithersburg, MD 20899, USA.)

June 1988

1-3 June, West Virginia University, Morgantown, W. Va	20th Central Regional Meeting. (Sponsor: American Ceramic Society)
2-4 June, Togatta-ousen Miyagi, Japan	5th International Workshop on Future Electron Devices: Topical Meeting on High-Temperature Superconducting Electron Devices. (Research and Development Association for Future Electron Devices, Fukide Building, No. 2 4-1-21, Toranomon, Minatoku, Tokyo)
7-9 June, Oak Ridge, TN, USA	High-Temp. Materials Conference. (ASM Inc., Metals Park, OH 44073, USA)
26 June - 8 July, Tuscany, Italy	NATO Advanced Study Institute on Superconductive Electronics. Conference Center, Tuscany, Italy. Contact: Dr. Harold Weinstock, Air Force Office of Scientific Research/NE, Bolling AFB, DC 20332-6448. Phone: (202)767-4933.
27 June - 3 July	First Asia-Pacific Conference on Condensed Matter Physics - High Temperature Superconductivity. National University of Singapore. Contact: Dr. K.K. Phua, Co-Chairman, First Asia-Pacific Conference on Condensed Matter Physics, c/o Dept. of Physics, National University of Singapore, Kent Ridge, Singapore 0511, Republic of Singapore. Phone: (65)2786188/7756666. Telex: RS28561 WSPC. Fax: 27237398.

July 1988

25-27 July, Washington, DC	International Conference on High Temperature Superconductivy (HTS '88). Washington, DC. Contact: HTS '88, Society for Optical and Quantum Electronics, P.O. Box 245, McLean, VA 22201. Phone: (703)642-5835. Fax: (703)642-5838.

August 1988

21-25 August, San Francisco, Calif.	Applied Superconductivity Conf. (Lawrence Livermore National Laboratory, Livermore, CA 94500)

November 1988

28 November - 3 December, Boston, MA, USA	The Materials Research Society Fall Meeting (MRS, 9800 McKnight Road, Suite 327, Pittsburgh, PA 15237, USA)

1989

27 February - 3 March	Superconductors are Topic of Gordon Conference. The Gordon Conference on Superconductivity will be held 27 February - 3 March 1989. The location of the conference will be announced. For information, contact Arthur Sleight, Experimental Station 356/301, E.I. du Pont de Nemours & Co., Inc., Wilmington, DE 19898 (302/695-3536).

Meetings on New Materials

January 1988

17-20 January, Cocoa Beach, Florida	12th Annual Conference on Composites and Advanced Ceramics. (American Ceramics Society. 757 Brooksedge Plaza Drive, Westerville, Ohio 43081-6136)

February 1988

1-5 February, Cincinnati, Ohio	43rd Annual Conference (Society of Plastics Industry)
17-18 February, Brussels, Belgium	Advanced Ceramics - All Ceramic Engine. (European Chemical News, Quadrant House, Sutton, Surrey, BN2 5AS, UK)
21-24 February, Baghdad, Iraq	Third Arab International Solar Energy Conference. (Solar Energy Research Centre, P.O. Box 13026, Jaderiyah, Baghdad, Iraq)

March 1988

21-24 March, Birmingham, UK	9th Materials Testing Show. (British Institute of Non-Destructive Testing)
21-24 March, Los Angeles	WESTEC '88. The Western Metal & Tool Exposition Conference. (Sponsor: ASM International, Society of Manufacturing Engineers, American Machine Tool Distributors' Association)
22-24 March, St. Louis, Mo, USA	1988 Materials Performance and Corrosion Show. (National Association of Corrosion Engineers, P.O. Box 218340, Houston, Texas 77218)
23-25 March, University of Birmingham	METALS & MATERIALS '88. (Inst. of Metals, London, 1 Carlton House Terrace, London SW1Y 5DB)
23-25 March, University of Liverpool, UK	Third International Conference on Fibre-reinforced Composites. (Plastics and Rubber Institute, 11 Hobart Place, London SW1W 0NL, UK)

April 1988

6-8 April, Luxemboug	MACROLUX '88 - Reactive Polymers and Polymers of Interface. (Macrolux Secretariat, Sigma forum, SARL Zone Industrielle, 8287 Kehlen, Luxembourg)
11-12 April, London	Mechanical testing of engineering ceramics at high temperatures. A meeting was held on the mechanical testing of engineering materials at high temperatures. This meeting was organized by the UK High Temperature Mechanical Testing Committee in collaboration with the Institute of Ceramics (UK). Since the measurement standards in the field of engineering ceramics are only now being developed, the purpose of this meeting was to review test equipment and methods and to establish international standards, and it is therefore of significant interest to all those concerned with engineering ceramics. Further details can be obtained from Dr. B.F. Dyson, Conference Chairman, Division of Materials Applications, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK. Telephone: 01-963-6519; Telex: 262344.
11-15 April, Orlando, Florida	Spring Conference. (The American Society for Nondestructive Testing - ASNT - P.O. Box 28518, Columbus, Ohio 43228-0518)
11-14 April, Cambridge, UK	Conference on Deformation - Yield and Fracture of Polymers. (Plastics and Rubber Institute, 11 Hobart Place, London, SW1W 0NL)
13-21 April, Birmingham	International Machine Tool and Manufacturing - Technology Exhibition. (The Machine Tool Trade Association, 62 Bayswater Road, London W2 3PH)
14-15 April	Fifth Annual Conference on Materials Technology, Materials Technology Center, Southern Illinois University, Carbondale, IL. (Southern Illinois University, Materials Technology Center, Carbondale, IL 62901-4303)
15-18 April	International Symposium and Exhibition on Fibre Reinforced Plastics/Composite Materials, Nanjing, China. (The Chinese Silicate Society, Bai Wan Zhuang Bldg., Beijing, People's Republic of China)
19-20 April, Cardiff, UK	Conference on High Temperature Polymers (Plastics and Rubber Institute, 11 Hobart Place, London SW1W 0NL)
20-27 April, Hanover, FRG	New Materials 1988. (Deutsche Messe- und Ausstellungs Ges.m.b.H. Messegelande, D-3000 Hanover 82, FRG)
21 April, Coventry, UK	Developments in Materials Technology for the Automobile Industry. (Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)
24-27 April, Brazil	32nd Brazilian Ceramic Congress. (Association Brasileira de Ceramica, Rua Leonardo Nunes, 82, 04039 São Paulo)
25-26 April, Reno, Nevada, USA	9th Symposium on Metal Matrix Composites: Testing, Analysis and Failure Modes. Held in conjunction with ASTM Committee D-30 on High Modulus Fibers and Their Composites. (ASTM, 1916 Race St., Philadelphia, PA 19103)
25-27 April, Antwerp, Belgium	International Conference on Hot Isostatic Pressing of Materials: Applications and Developments. (K.VIV Technologisch Instituut, Metallurgical Section, Jan van Rijswijcklaan 58, B-2018 Antwerpen, Belgium)

May 1988

1-5 May, Cincinnati, Ohio, USA	90th Annual Meeting of the American Ceramic Society. (American Ceramic Society, 65 Ceramic Drive, Columbus, OH 43214)
2-6 May, Luxembourg	New Applications for Steel in View of the Challenge from Substitute Materials. (UN-ECE Commission for Europe, Palais des Nations, CH-1211 Geneva 10, Switzerland)
3-7 May, Brussels, Belgium	EUROTECH. (Foire Internationale, Parc des Expositions, Place de Belgique, B-1020 Brussels)
9-11 May, Indianapolis	Spring Meeting. (Society of the Plastics Industry)
9-13 May, London	MATERIALS '88 - Materials and Engineering Design. (Institute of Metals, London, University of Sheffield, Materials Physical Laboratory; Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)
9-13 May, Florence, Italy	8th European Photovoltaic Solar Energy Conference. (Prof. J. Solomon/B. Equer, Ecole Polytechnique, Laboratoire de Physique de la Matière Condensée, F 91128, Palaiseon, France)
9-14 May, Milan, Italy	"PLAST '88" - Milan Plastics and Rubber Show. (ENFIPLAST, P.O. Box 24, 20090 Assago/Milano, Italy)
16-18 May, London	British Society of Rheology. Conference on Flow Processes on Composite Materials. (Plastics and Rubber Institute, 11 Hobart Place, London SW1W 0HL)
17-19 May, Copenhagen, Denmark	Society of Plastics Engineers, Scandinavia section, jointly with other organizations representing the European plastics manufacturing and processing industries, conference on plastics recycling, Bella Center, Copenhagen, Denmark.
17-19 May, Bologna, Italy	International Metallurgy Congress, Innovation for Quality (Association Italiana Metallurgia, 20121 Milano 1, Piazzale Rodolfo Morandi 2, Italy)
18-19 May, London	Second International Conference on Short Fibre-Reinforced Thermoplastics. (Plastics and Rubber Institute, 11 Hobart Place, London SW1W 0HL)
20-21 May	26th Special Steels Conference, Université Paul Sabatier France. (Cercle d'Etudes des Métaux, Ecole Nationale Supérieure des Mines, 158 Cours Favriel, F-42023 Saint Etienne, Cedex)
21-24 May, Birmingham, UK	Materials Testing Exhibitions MT 88 (British Info. Services, 845 Third Ave., New York, N.Y. 10022)
24-26 May, Dublin, Ireland	IRPLAST '88 - Ireland's International. Plastics and Rubber Exhibitions. (Sponsored by Plastics Industries Association, Contact: International Fairs and Exhibitions Ltd., Belgrave House, 15 Belgrave Rd., Rathmines, Dublin 6)
25-26 May, Washington, DC	Plastics Institute of America, Recycling Plas III, sponsored jointly with the Department of Energy, Washington, DC.
30 May - 3 June Tokyo	MRS International Meeting on Advanced Materials. (Nikkan Kogyo Shimbun Ltd., 8-10 Kudan Kita, 1-chome, Chiyoda-ku, Tokyo 102)
31 May - 2 June Strasbourg, France	Symposia on Materials. (European Materials Research Society; Centre de Recherches Nucléaires, Les Phase, F-67037, Strasbourg, Cedex, France)
31 May - 3 June Porte de Versailles, France	TECHMAT 88 Exhibition and Conference: Advanced Materials. (TECHMAT/SEPFI, 8 rue de la Michodière, 75002 Paris)

June 1988

1-3 June, Bali, Indonesia	SEAISI 32nd Conference 1988. (South-East Asia Iron and Steel Institute, P.O. Box 7759, Airmail Distribution Centre, Manila International Airport, Pasay City, Philippines)
5-10 June, Orlando, Florida	1988 International Powder Metallurgy Conference and Exhibition. (Metal Powder Industries Federation, American Powder Metallurgy Institute, 105 College Road East, Princeton, N.J. 08540)
7-9 June, Oak Ridge University, TN	International Conference on Whisker and Fibre-Toughened Ceramics (ASM International, Metals Park, OH 44073, USA)
12-14 June, Pittsburgh, PA, USA	International Symposium on Alloy 718. Metallurgy and Applications. (The Metallurgical Society, 410 Commonwealth Drive, Warrendale, PA 15086, USA)
13-16 June, Fredericksburg, MD, USA	10th Biennial Conference on National Materials Policy: The Role of Materials Technology Utilization in US Competitiveness (Federation of Materials Society, 1707 L St., N.W., Suite 333, Washington, D.C. 20036)
13-17 June, Cleveland, Ohio	International Conference on Composite Interfaces. (ASM International, Metals Park, Ohio 44073)
14 June, Argonne, IL, USA	Advanced Materials in the Manufacturing Revolution (Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439)

14-16 June, Seattle, WA, USA	2nd Electronics Materials and Processes Conference. (SAMPE, P.O. Box 2459, Covina, Calif. 91722)
14-16 June, Milan, Italy	Ninth International SAMPE European Chapter Conference/Exhibition: New Generation Materials and Processes. Centro dei Congressi - Milanofiori, Milan, Italy. Contact (Italy): Dr. Franco Saporiti, SOGETUR, via Aurelio Saffi 6, 20123 Milan, Italy. Phone: (39)02-4390013. Telex: 324255. Also contact (Germany): Claus M. Merkert, Secretary, SAMPE European Chapter, c/o Messerschmitt-Bolkow-Blohm GmbH, Postfach 801160, D-8000 München 80, FRG. Phone: (49) Munich 60-00-29-37.
14-16 June, Dayton, OH, USA	Second International SAMPE Metals & Metals Processing Conference (Business Dir., P.O. Box 2459, COVINA, Calif. 94722)
20-22 June, Algeria	Third Arab Iron and Steel Congress. (AISU, BP 04, Cheraga, Algeria)
20-21 June, Nice, France	Composites '88 (Institute for Industrial Technical Transfer, 40 promenade Marx Dormoy, F-93460 Gournay-sur-Marne, France)
20-24 June, Chicago	NPE '88 - National Plastics Exposition and Conference. (Society of the Plastics Industry)
21-22 June, Los Angeles	"Effective Manufacturing Applications of Superplastics Forming for the Engineering Specialist" (Composites Group, Society of Manufacturing Engineering, Box 930, Dearborn, MI 48121)
22-24 June, Boulder, CO	1988 Electronic Materials Conference. University of Colorado, Boulder, CO. Contact: Ms. B. Kamperman, Meetings Manager, The Metallurgical Society, 420 Commonwealth Dr., Warrendal PA 15086. Phone: (4[illegible]2)776-9050. Telex: 910-380-9397.
23-24 June, Milwaukee, WI	Ceramic Matrix Composites Seminar (College of Engineering & Applied Science, University of Wisconsin-Milwaukee, Milwaukee, WI 53203)
27-29 June	Fourth Japan-United States Conference on Composite Materials. Washington, DC. Contact: Dr. James M. Whitney, American Society for Composites, 1350 N. Fairfield Rd., Dayton, OH 45432-2698. Phone: (513)436-2045.

August 1988

1-4 August, Semiahmoo Resort, Wash., USA	International Conference on Superplasticity and Superplastic Forming. (Joint University/UMIST Metallurgy Bldg., Grosvenor Street, Manchester M1 7HS, UK)
10-12 August, University of Illinois, Urbana IL, USA	Nondestructive Testing and Evaluation for Manufacturing and Construction. (University of Illinois, 117 Transportation Bldg., 104 S. Mathews Ave., Urbana, IL 61801)
22-26 August, Sydney, Australia	AUSTCERAM 88 "Ceramic Developments: Past, Present and Future". (Australian Ceramic Society, P.O. Box 56, Highett, Victoria 3190, Australia)
28-31 August, Montreal, Canada	Symposium on structural ceramics. (Metallurgical Society of CIM and the Canadian Ceramic Society, McGill University, 3450 University St., Montreal, PQ, Canada H3A 2A7)

September 1988

6-9 September, Boston, Ma	International Symposium and Exhibition on Fibre Optics, Optoelectronics and Laser Applications (International Society of Optical Engineering (SPIE), Box 10, Bellingham, WA 98227, USA)
7-9 September, Ruhr University, Bochum, FRG	International Colloquium on Crystal Structure, Microstructure and Properties of Minerals and Ceramic Materials (Institut für Mineralogie, Ruhr Univ., Bochum, PF 102148, D4630-Bochum, FRG)
12-15 September, Philadelphia, PA	Fabricating Composites '88 Conf. and Exhibition (Society of Manufacturing Engineers, ONE SME Dr., P.O. Box 930, Dearborn, MI 48121)
13-15 September, Dearborn, MI, USA	4th Annual ASM/ESD Advanced Composites Conference and Exposition. (ASM International, Metals Park, OH 44073)
13-15 September	Specialty Polymers '88: Third International Conference on New Polymeric Materials: High Performance, Extreme Environmental, and Electroactive Polymers. Queens' College, Cambridge University, Cambridge, UK. Contact: Miss Monique Heald, Specialty Polymers '88, Butterworth Scientific Ltd., P.O. Box 63, Westbury House, Bury St., Guildford, Surrey GU2 5BH, UK. Phone: (44)0483-31261. Telex: 859556 SCITEC G.
19-21 September, Richland, WA, USA	"Influences of Interfaces on Materials Synthesis and Properties" (Battelle Pacific Northwest Labs., Box 999, Richland, WA 99352)
19-22 September, Warsaw, Poland	2nd International Symposium on Brittle Matrix Composites (Polish Academy of Sciences, Institute of Fundamental Techn. Research, Swietokrzyska 21, 00 049 Warsaw, Poland)

19-22 September, Wiesbaden, FRG	Verbundwerk '88: International Congress and Exhibit for Advanced Ceramics. Wiesbaden, West Germany. Contact: D. Schnabel, Demat Exposition Managing GmbH. Postfach 110 611, 6000 Frankfurt Am Main, FRG.
19-23 September, Garmisch-Partenkirchen, FRG	First International Conference on Plasma Surface Engineering. Garmisch-Partenkirchen, West Germany. Contact: Conference Secretariat, Deutsche Gesellschaft für Metallkunde EV, Adenaueralle 21, D-6370 Oberursel, FRG. Phone: (49)06171-4081.
19-23 September, Anaheim, CA	American Society for Nondestructive Testing 1988 Fall Conference and Quality Testing Show. Anaheim, CA. Contact: ASNT Conference Dept., 4153 Arlingate Plaza, Caller No. 38518, Columbus, OH 43228-0518. Phone: 1-800-222-ASNT or (614)274-6003. Telex: 245347.
19-23 September, Hamburg, FRG	The International Congress on Optical Science and Engineering. Hamburg Congress Center, Hamburg, West Germany. Contact (US): SPIE, Meetings Dept., P.O. Box 10, Bellingham, WA98227-0010. Phone: (206)676-3290. Telex: 46-7053. Contact (Europe): ESIC-Europtica Services International Communications, 16, av. Bugeaud, 75116 Paris, France. Phone: (33)1-45-53-26-67. Telex: 642632 ANRTF. Fax: (33)1-47-04-25-20.
20-23 September, Philadelphia, USA	SME Conference and Exposition, Fabricating Composites '88. Metal Matrix Composites '88. (Society of Manufacturing Engineers, P.O. Box 930, Dearborn, MI 48121)
22-25 September, Birmingham, UK	OPTICS/ECOOSA '88: European Conference on Optics, Optical Systems and Applications. Birmingham, UK. Contact: The Meetings Officer, The Institute of Physics, 47 Belgrave Square, London SW1X 8QX, UK. Phone: (44)01-235-6111.
22-26 September, Shanghai, China	China Fibercom '88. International Conference and Exhibition on Optical Fibre and Modern Communications. (Shanghai International Trade, 3/F, Gao Yang Bldg., 817-837 Doug De Ming Road, Shanghai)
24-30 September, Chicago, USA	1st World Materials Congress (American Society for Metals, Metals Park, OHIO 44073)
26-28 September, Noordwijkerhout, the Netherlands	Second International Conference on Automated Composites (ECAC '88). Leeuwenhorst Conference Center, Noordwijkerhout, the Netherlands. Contact: The Plastics and Rubber Institute, Conference Dept., 11 Hobart Place, London SW1W OHL, UK. Phone: (44)01-245-9555. Telex: 915719 PRIUK G
26-29 September, Seattle, WA, USA	American Society of Composites Third Annual Technical Conference on Composite Materials. Seattle, WA. Contact: Dr. James M. Whitney, President, American Society of Composites, 1350 North Fairfield Rd., Dayton, OH 45432-2698. Phone: (513)426-2065.
27-29 September, Chicago, IL, USA	Materials, Applications and Services Exposition: An Exposition of International Advanced Materials Processes (ASM and TMS). McCormick Place, Chicago, IL. Contact: Meetings Dept., ASM International, Metals Park, OH 44073. Phone: (216)338-5151.
27-29 September, Minneapolis, MN, USA	20th International SAMPE Technical Conference. Minneapolis, MN. Contact: Ms. Marge Smith, SAMPE, 843 W. Glentana, Box 2459, Covina, CA91722. Phone: (818)331-0616.
27-29 September, Brussels, Belgium	Electroceramics II. Université Libre de Bruxelles, Brussels, Belgium. Contact: P.H. Duvigneaud, Lab Chimie Industrielle et Chimie des Solides, Université Libre de Bruxelles, (C.P.165), 50 av. F. Roosevelt, 1050 Brussels, Belgium.
27-30 September, Minneapolis, Minnesota, USA	20th International Technical Conference on Materials and Processes in all Industries. (Society for the Advancement of Material and Process Engineering, P.O. Box 2459, Covina, Calif. 91722)
28-29 September, University of Bristol	Materials in Modern Energy Systems. (Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)

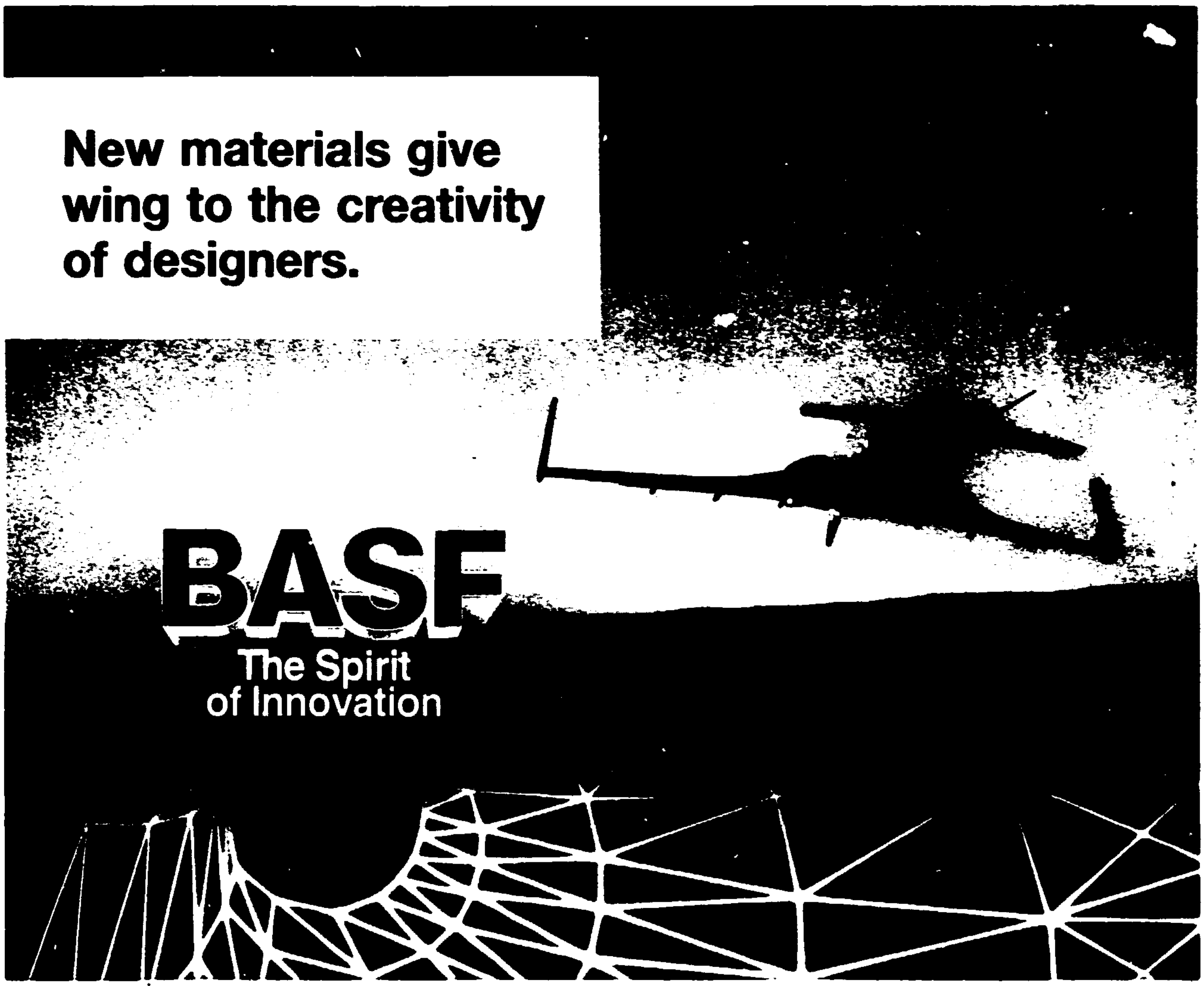
October 1988

5-12 October, Utrecht, The Netherlands	Logistica - International Trade Show on Materials Flow Control. (Koninklijke Nederlandse, Jaarbeurs, Postbus 8500, NL-3503 RM Utrecht, the Netherlands)
10-13 October, Singapore	CITY TRANSPORT - Exhibition of Material and Services in the Field of Public Transport. (Oy Lindberg Organisers AB, Kaskenkaatajantie 18, Swedjefallarvages, SF-02100 ESPOO, Finland)
18-22 October, Munich, FRG	CERAMITEC - International Trade Fair of Machinery Equipment, Plant and Raw Materials for the Entire Ceramics Industry. (Münchner Messe- und Ausstellungs ges.m.b.H., Postfach 121009, D-8000, München 12, FRG)
27-28 October	"Future Shock: Preparing for Tomorrow's Challenges in Plastics Processing." Sponsored by the Society of Plastics Engineers Central Indiana Section. Contact: Gerald Steele, (317)285-5655, USA.

November 1988

2-6 November, Turin, Italy	International New Technologies and Innovations Fair. (Torino Esposizioni SpA, Corso Massimo d'Azeglio 15, 10126 Turin, Italy).
7-11 November, Sarajevo, Yugoslavia	International Plastics and Rubber Fair. (Centre "Skenderija", Ulice Mice Sokolovica bb, YU-71000, Sarajevo, Yugoslavia).
8-10 November, Stratford-upon-Avon	1st International Conference on the Behaviour of Materials in Machining. (Engineering Committee of Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)
10-15 November, Tokyo, Japan	12th Plastics and Rubber Fair. (Ginza-Yamagishi Bldg., 2-10-6, Ginza, Chuo-ku, Tokyo 104)
27-30 November, Las Vegas, NV, USA	3rd International Symposium on Ceramic Materials and Components for Engines. (Sponsor: American Ceramic Society)
30 November - 1 December, London	Plastics on the Road '88. (Plastics and Rubber Institute, 11 Hobart Place, London SW1W 0HL).

New materials give wing to the creativity of designers.



Technical designs, in all fields, demand increased performance but manufacture requires reduced costs, energy saving and environmental consciousness.

Designers are not at a loss for creative ideas but it is often the knowledge of a new material that provides the innovation.

That is why BASF is investing in plastics technology to meet future requirements.

We are among the top international group of manufacturers of new materials and are involved in research and development in Europe, the United States and Japan.

One outstanding example of our work is the revolutionary construction of the Beechcraft Starship 1.

The whole body of the plane is made of carbon fibre composites – a material which, weight for weight, is much more rigid and stronger than steel. Further features in its favor: it is absolutely dimensionally stable and resistant to corrosion and high temperatures. Experience has shown that such developments in the aircraft and aero space industries provide important stimuli for other markets.

There are already fascinating prospects for this material in automobile manufacture, mechanical engineering, and modern products for the domestic market.

The basis of our commitment and experience with composites is leading to a natural systematic development of a wide variety of potential applications. This approach coupled with the cooperation of our customers is resulting in benefits, through versatility and efficiency, to industry and individuals.

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Resources available

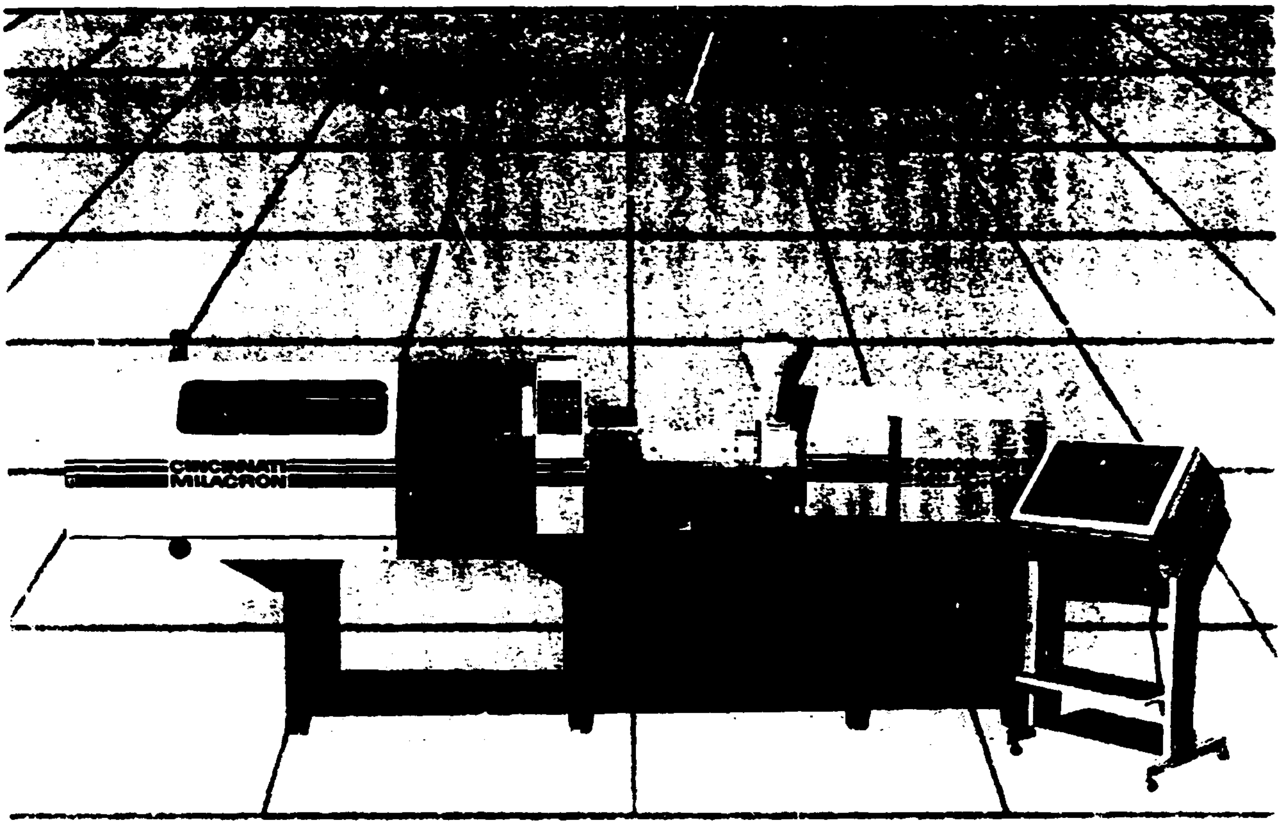
Know-how, designs and licences offered to manufacture drilling machines for water wells of up to 2.5-m diameter and 80-m depth and for concrete-injected piles of up to 2-m diameter and 45-m depth. Claude Bourg, Drill-France, B.P. 15, Le Haillan 33160, France.

Know-how available to manufacture synthetic ceramic from mineral wastes, sand and a binding synthetic resin for use as sanitary ware, material for furniture, decorative items etc. L. Valette, Administrateur Gerant, Science, 98 avenue de Tervueren, 1040 Brussels, Belgium.

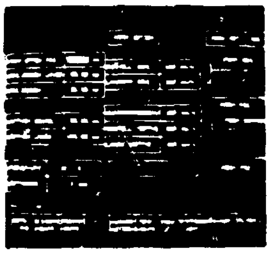
Manufacturers of various metal powders offer know-how for the production of electrolytic copper and iron powder, atomized aluminium powder and synthetic iron oxide. R. Devroy, Radar International, Post box No. 2014, Calcutta 700 001, India.

Technical know-how and complete turnkey plants available for the production of monocrystalline and poly-crystalline solar photovoltaic cells and modules and integration of systems, such as photovoltaic powered pumping, refrigeration, communication and water purification systems. N. R. Jayaraman, Vice-President, TPK International Inc., 36 Bentley Avenue, Nepean, Ontario K2E 6T8, Canada.

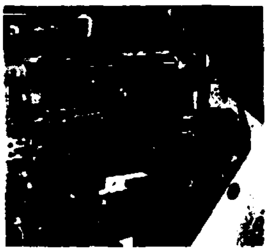
Technology and licensing available for manufacturing polyurethane from saturated polyester polyols, polyether polyols, isocyanate intermediates, one- and two-component polyurethane systems. Capacity tailored to requirements, from 2,000 tonnes upwards. Application: flexible, semi-rigid polyurethane foams, industrial and domestic appliance insulation, shoe soling, coating and sealants. Synthesia Inter AG, Tigerbergstr. 2, CH-9000 St. Gallen, Switzerland.



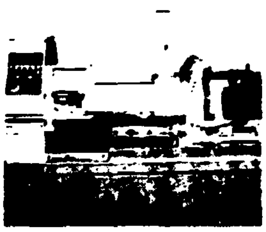
Fully electronic plastic injection molding machines "ACT" provide versatile, high-precision molding.



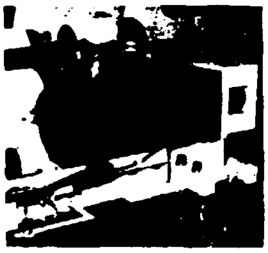
All "ACT"-models come equipped with advanced CNC controllers as well as AC servo motors. Fast, easy setting of parameters using a versatile 1[illegible] colour graphic CRT. Without need for setting limit switches, valves and other mechanical adjustment. All molding parameters are recalled within seconds from the built in memory. With additional external memory, capacity can be expended up to 240 molds. CNC controllers and AC servo motors provide high precision molding.



The "ACT" clamping unit features a double-toggle design. It ensures high speed and repeatability. An AC servo motor is also used in the ejector mechanism. Programming from CRT, number of strokes, length, speed and starting position provides maximum flexibility. Each AC servo motor operates with a precision of 0.01 mm for each movement and also during movement. All AC servo motors are maintenance free and carbon brushes are not required.



The ACT's combined use of powerful AC servo motors and precision ball screws has enabled exact control of injection screw positions and injection speeds. The ACT's extra heavy-duty AC servo motor features advanced phase control technology which maintains powerful torque even in the higher speed range. In addition a pressure sensor is mounted at the base of the screw to provide pressure control accuracy.



The AC servo motors utilized in the ACT are extremely efficient since they run only when needed and only to the extent needed. They thereby result in a significant saving in energy. Power consumption is reduced by up to 75%. Oilless bushings are used in the toggles and platen guides. As a result, molded products are kept free of oil and the work environment is kept extra clean. All "ACT" models, from 150 kN up to 3000 kN, with direct drive by AC servo motor make for extremely quiet operation and a clean, pleasant work environment. Ideal for clean room applications.

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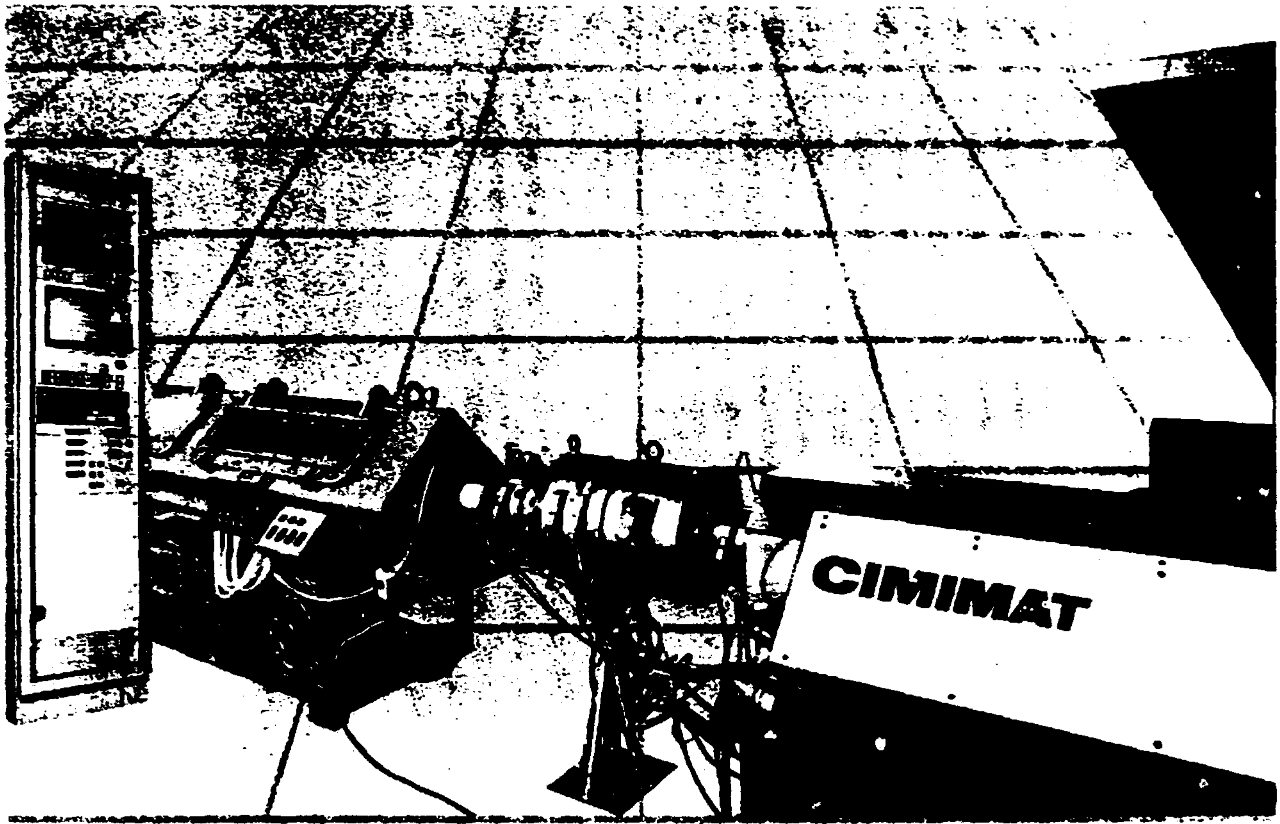
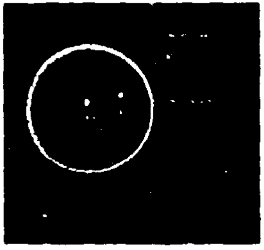
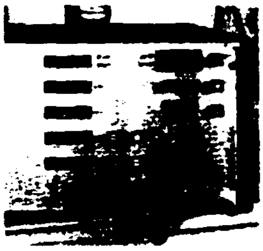


Why should pipe producers consider the new automatic pipe plant "CIMIMAT®"?





Because:

You will be able to control wall thickness tolerances not only over the full pipe length but over pipe circumference as well.
This feature yields wall thickness tolerances of below ¼ of those admitted by DIN standards, and you save expensive raw material!
CIMIMAT® is meant to increase the efficiency of your operation and helps you to reduce raw material costs while at the same time producing better quality pipe products.

Because:

You will be fully independent of fluctuations in different raw material compounds:
The new weighing system SAVEOMAT controls the precise material consumption of the extruder. When employed in standard pipe plants, the SAVEOMAT system makes for controlling haul-off speed so as to reach contant meter weights. And when employed in a CIMIMAT® pipe line, the data acquired are used for automatic gauging in ultrasonic wall thickness measuring.
In this way you are independent of temperature fluctuations and the wall thickness meter will control haul-off and centering units to minimum wall thickness

Because:

The automatized pipe extrusion line CIMIMAT® is equipped with the thermal pipe centering system CIMICENT®.
This is replacing a complicated and mechanically sensitive die-head construction.
The thermal pipe centering system CIMICENT® works fault-free and is able to centralise thin or thick areas by equalising oposing sides.
With CIMIMAT® you'll have an advantage in the very competitive pipe market.

Because:

The automatic pipe plant CIMIMAT® means reliability to you.
Microprocessor control CIMICRON 9/16 guarantees pipe production within closest tolerances and it warrants moreover that once optimized process parameters are reliably reproducible.
Only the automatic pipe plant CIMIMAT® from CINCINNATI MILACRON AUSTRIA offers you the combined advantages of the thermal pipe centering system CIMICENT® and of automatic gauging of the wall thickness measuring

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Advances in Materials Technology: Monitor
Reader Survey

The Advances in Materials Technology: Monitor has now been published since 1983. Although its mailing list is continuously updated as new requests for inclusion are received and changes of address are made as soon as notifications of such changes are received, I would be grateful if readers could reconfirm their interest in receiving this newsletter. Kindly, therefore, answer the questions below and mail this form to: The Editor, Advances in Materials Technology: Monitor, UNIDO Technology Programme at the above address.

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Optional

Which section in the Monitor is of particular interest to you?

Which additional subjects would you suggest be included?

Would you like to see any sections deleted?

Have you access to some/most of the journals from which the information contained in the Monitor is drawn?

Is your copy of the Monitor passed on to friends/colleagues etc.?

Please make any other comments or suggestions for improving the quality and usefulness of this newsletter.

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Readers' comments

We should appreciate it if readers could take the time to tell us in this space what they think of the 11th issue of Advances in Materials Technology: Monitor. Comments on the usefulness of the information and the way it has been organized will help us in preparing future issues of the Monitor. We thank you for your co-operation and look forward to hearing from you.