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ADVANCES IN MATERIALS TECHNOLOGY MONITOR

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TO OUR READERS

The materials sector of industry has an enormous influence on the economic well-being and quality of life in a country, but by its very nature the resources are dispersed among many science and engineering disciplines and between the public and private sectors of the economy. Materials are vitally important to our economic security and quality of life. Thus, the incremental funding, coupled with the strategic approach to national goal-oriented planning and implementing initiatives in the area of new and advanced materials are essential to enhancing the competitiveness of a country.

Technological developments in such important industrial sectors as automobile manufacturing, electronics/electrical engineering, energy engineering, machine and appliance building or chemistry, are often based on advanced materials. The further development and support of materials technology are important precisely because of the very sizeable impetuses, and spill-over effects on virtually all sectors of the processing industry, which result from them.

At present, there is a clear understanding of the interrelationships between new and advanced materials, technological leadership, competitive advantages and the challenge in the 1990s, and beyond. Both government and industry should also have a very clear understanding of the role of materials technology for sustained competitive advantages and long-run growth as well as of the rising importance of advanced materials in the process of industrial restructuring. The global restructuring process also entails an impact on the demand for traditional industrial raw materials, the global resource base, corporate strategies and global location patterns. All these interrelated changes require an urgent increase in the role of governments in promoting national competence in new materials production and use, which are deemed necessary for current, and future, domestic competitiveness.

The experience of India in the formulation and implementation of a national programme for the development of new materials clearly indicates what results developing countries may obtain if such programmes are carried out in clear relation to the advances that have taken place in science and technology abroad, and to the needs of the country's society. These efforts, in India, have led to capacity building in many areas leading towards achieving self-reliance in the country.

We have decided to publicize this experience in order to demonstrate that there are many opportunities for developing countries to enter into various stages of the materials and manufacturing cycles, whilst judiciously building on existing strengths in domestic materials, manufacuturing technologies and human skills.

Vladimir Kojarnovitch
Technical Editor

UNIDO's *Advances in Materials Monitor* is established as a mechanism of current awareness to monitor developments in the materials sector and to inform governments, industry and academia, primarily in developing countries.

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A. LEAD ARTICLE

INDIA'S EXPERIENCE IN THE DEVELOPMENT OF A NATIONAL FACILITY FOR PROMOTING NEW MATERIALS

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Abstract

The development of new materials has been an integral part of industrial expansion in economically developed countries, resulting thereby, apart from an improvement in the efficiency of production and the quality of products, in a revolution in the nature of certain industries.

Certain raw materials of which India has the largest deposits in the world, were until recently exported, only to be re-imported as a finished product, and that too at a high cost so as to satisfy the needs of certain industries. This necessitated the need for materials development within the country to satisfy its immediate requirements.

It is significant to note here that now, due to the expertise and infrastructure developed in many areas of new materials, research work in materials science, leading to the development of new materials, has progressed well in many academic and research and development laboratories in India. Most programmes geared towards developing indigenous technology would invariably culminate in the further growth of new industries in these emerging high-tech areas, for manufacturing special materials.

The author describes in detail the current scene highlighting future plans of research and development activities in the fields of materials science and technology under way in India. Although no single national facility, as such, exists in the country, and projects are being executed at many academic and research and development laboratories, there is a recommendation for the establishment of a National Materials Research and Development Board, to coordinate and concentrate the development activities of materials programmes in India.

The world today is witnessing a major technological revolution with newer technologies being introduced in various sectors to enhance productivity, the production of high quality and precision products and the efficient utilization of available resources. The possibility of the introduction of such new technologies has always depended, to a large extent, on the availability of newer and better materials having special properties. With the discovery and processing of each new material, the scope of applications has broadened, thus making a decided impact on the economic and technological development of a nation.

Information technologies, telecommunications, micro-electronics, lasers, fibre-optics, advanced materials and biotechnology are new fields where an industrial revolution is taking place in developed countries. While the developed countries are progressing very well on this front, developing countries are faced with the urgent need to mobilize their own scientific, technical, and other resources, in developing related technologies in order to reduce the ever-growing gap between themselves and developed countries, and to accomplish their own overall socio-economic and technological development. India, with a view to developing capabilities and capacities, has also launched a programme based on the future needs of advanced materials as well as on the availability of her natural resources, trained manpower and vast science and technology infrastructure. Aiming at promoting the indigenous development of the technology of performance materials, the Technology Information, Forecasting and Assessment Council has recently published techno-market survey, in four volumes, clearly showing the current research status in India, the technology gap, supply and demand scenario, environmental issues, applications in India and abroad, and a plan of action. A detailed market analysis of performance materials is covered, based on Indian and international scenarios, focusing on the following areas:

- Structural ceramics
- Advanced composites
- Light alloys
- High-tech coatings and surface engineering.

The research, development and design (RD&D) capacities, coupled with some of the production aspects being carried out in India, are described here in respect of the following:

1. Semi-conducting materials
1.1 Crystalline materials
1.2 Non-crystalline materials
1.3 Super-conducting materials
2. Ceramics
2.1 Sensors
2.2 Bio-ceramics
3. Glass and Glass-based products
3.1 Optical fibre materials
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4.1 Polymers
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5.1 Titanium
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1. Semi-conducting materials

Silicon-based microelectronics is the predominant component of the present-day electronics industry worldwide. In India, special concerted efforts were made to develop programmes in the fields of:

(a) Crystalline silicon and other materials for electronics; and
(b) Amorphous silicon for solar cells.

1.1 Crystalline materials

The main integrated circuit facility based on silicon in India is at the Semiconductor Complex Limited (SCL), Chandigarh. The present feature size is around 5 μm and will decrease to 1 μm in the near future, thus, Indian capability reaches LSI. Recently, major facilities for silicon MBE, reduced vapour phase epitaxy and electron beam lithography have been set up within the Defence Research & Development Organization. Following the installation of these facilities, submicron feature sizes will be possible in the near future. A major programme in the fields of III-V compounds is being carried out at the Solid State Physics Laboratory (SPL), New Delhi, where facilities have been established for the synthesis and growth of single crystals, epitaxial processing facilities such as molecular beam epitaxy (MBE) and metalorganic chemical vapour deposition (MOCVD) for GaAs devices, including ion implantation, electron beam micro fabrication (EBMF) and plasma CVD techniques for producing devices such as Gun diodes, millimetre wave devices and MMICs, together with such new devices as HEMT (high electron mobility transistors) and InGaAs devices. Several sophisticated diagnostic facilities such as EPMA, SIMS, SEM, DLTS, (deep level transient spectroscopy) have also been installed. The Solid State Physics Laboratory, New Delhi, has recently taken the challenging initiative of setting up India's first (on an advanced production size) crystal growth system, thereby becoming the country's pioneering wafer/device fabricator. Another place where substantial work is being done is the Central Electrical and Electronics Research Institute (CEERI), Pilani, where the emphasis is on device design and development.

The Tata Institute of Fundamental Research (TIFR), Bombay, is concentrating on theoretical and basic studies, while the Indian Institute of Technology (IIT), Kharagpur, is engaged in liquid phase epitaxy (LPE) studies on InP.

With regard to work on raw materials, India is a potential major source of gallium in the world, as this is a by-product of aluminium production from bauxite and, Indian bauxite is among the best in the world, in terms of the contained gallium. The Central Electrochemical Research (CEERI), Pilani, and the Bhabha Atomic Research Centre (BARC), Bombay, have developed processes for gallium recovery, which have been adopted by the Madras Aluminium Company (MALCO) and the Hindustan Aluminium Company (HINDALCO). The Nuclear Fuel Complex (NFC) have established purification techniques to produce 4-6N electronic grade gallium. The suitability of these materials, required for semiconducting applications, is being evaluated. A project on trimethyl gallium has been launched at the Defence Science Centre (DSC), New Delhi. Work will be intensified in this area which is of great importance, since the success of MOCVD technology ultimately depends upon the availability of high purity metal alkyls.

Laboratory scale facilities for growing some of the crystals and their characterization exist at the Indian Institute of Science (IISc), Bangalore; BARC, Bombay; and Anna University, Madras. The facilities set up at the SPL and the Defence Science Centre (DSC) (both part of the Defence Research and Development Organization), New Delhi, are quite considerable and can be regarded as being suitable for a pilot-scale production of YAG and GaAs crystals. Production of electronic grade silicon crystals is under way at Super Semiconductors near Calcutta, Silitronics, Hosur, and at Mettur Chemicals (metchem), Tamil Nadu.

The Department of Electronics of the Government of India, is placing considerable importance on the development of materials for electronics. In addition to support through research and development (C-DOME), it is establishing an Electronics Materials Development Agency (EMDA), under which the Materials Development Centre (MDC) (C-METS) has been created with an emphasis on electronic chemicals; high purity metals and alloys; semi-conductor materials and ceramics.

1.2 Non-crystalline materials

The development of amorphous silicon solar cell technology has perhaps been one of the first attempts to develop an emerging high technology in a planned manner leading to its commercial production. The development of a-Si solar cell technology started at the Indian Association for the Cultivation of Science (IACS), Calcutta, in 1978, with a small project funded by the Government of India's Department of Science and Technology, New Delhi. Later, a nationally coordinated project was formulated involving the following organizations and industries:

1. Academic and research and development organizations.
   - Indian Association for the Cultivation of Science (IACS), Calcutta;
   - Poona University, Poona;
   - Indian Institute of Technology, Delhi.
2. Industries
   - Bharat Heavy Electricals Ltd. (BHEL);
   - Central Electronics Ltd. (CEL), Sahibabad (U.P.);
   - Rajasthan Electronics and Instrumentation Ltd. (REIL), Jaipur.

Subsequently, the following organizations joined the programme to develop new materials for solar cells:

- National Physical Laboratory (NPL);
- Indian Institute of Technology, Kharagpur;
- Indian Institute of Science, Bangalore;
- Indian Institute of Technology, Madras.

The initial outlay for the three research and development organizations was approximately Rs. 1.5 crore. The IACS was given the major responsibility for the development of materials and the fabrication technology for a-Si solar cells.

The most important feature of the a-Si solar cell technology development programme in India is that within a year of the first fabrication of a-Si solar cell in the USA, a formal project was submitted to the Department of Science & Technology by the IACS, in 1978. This has to a large extent helped to keep the technology gap between developed countries and India within a manageable limit.

In 1985, the Department of Non-Conventional Energy Sources (DNES) decided to establish a pilot plant for the production of a-Si solar cells for power applications. Accordingly, a global tender was floated by the DNES for the creation of this pilot plant together with the basic know-how for processing. The decision to import the pilot plant was taken so as to reduce the time required to set up a highly sophisticated plant. Indian research and development was to provide the processing know-how to upgrade the product.

In 1986, the Government of India identified the development of a-Si solar cells as one of the eight science and technology projects to be implemented during the Seventh Plan period (1985-1990). The target was to set up a plant with a capacity of about 1 MW/year. The initial efficiency to be achieved in the production line was 6 per cent, which was to be eventually increased to 8 per cent. M/s Bharat Heavy Electricals Ltd., was entrusted with the task of the installation and commissioning of the plant, which was set up on the campus of the Solar Energy Centre, Gwalpahari, Haryana.

In 1987, the United Nations Development Programme (UNDP) provided US$ 2.6 million for upgrading the facilities at the IACS. The Ministry of Non-Conventional Energy Sources (MNES) provided a rupee component support of Rs.1.41 crore, with the objective of establishing a lead centre for the development of amorphous silicon solar cell, which was to be very closely linked with the BHEL/MNES amorphous silicon solar cell plant.

Considerable efforts were made to stabilize the plant and process by the BHEL/IACS teams following the commissioning of the plant in 1990. The National Physical laboratory has provided the necessary engineering support. The plant and the process have been stabilized and passed the criteria set by the MNES to be achieved by 31 March 1994. The following products have been developed so far and are being marketed on a trial basis:

1. Chargers for solar lanterns;
2. Solar powered clock; and
3. Battery chargers.

Another product which is being marketed is transparent conducting oxide coated glass substrates. This is one of the few facilities in the world for this type of product.

The plant is, at present, producing single junction a-Si modules which have conversion efficiencies comparable to the best currently available in the world for this type of modules. The present cost/pW (at a low level of production) is close to the cost of Indian single crystal silicon solar cell. However, plans have been made to modify the hardware and upgrade processes (in collaboration with the IACS) so that the cost will decrease by 15-20 per cent. A major plan has been drawn up for the introduction of multi-junction a-Si solar cell technology and to establish a larger-size plant (5-10 MW/year). This will further reduce the cost to US$ 1-2/pW with modules having a conversion efficiency of about 8 per cent (stabilized) for use in power applications.

1.3 Superconducting materials

Recently a National Superconductivity Programme (NSP) was launched by the Ministry of Science and Technology, Department of Science and Technology, New Delhi, to develop high temperature superconductors in India. A high powered apex body (Project Management Board), with an allocation of substantial funds, has been created to guide and coordinate the activities of various research and development laboratories towards the theoretical and applied development of different superconducting alloys in the country. For the first time, the Government of India has taken this initiative at the highest level.

The National Superconductivity Programme is being coordinated among various research groups engaged in basic and applied fields, namely:

(a) Major Department of Atomic Energy Institutes TIFR, BARC, VECC, IGCAR, I.O. Phy, I.O. Math Sc.;
(b) Major CSIR Laboratories - NPL, NCL;
(c) Major Universities - Bombay, Delhi, Madras, Pune, Hyderabad and all the five IITs.

National Superconductivity Programme

The first phase of the National Superconductivity Programme (NSP), which was started in April 1988, came to an end in September, 1991. In Phase II (October 1991 to March 1995) of this programme, 62 projects at 37 institutions have been supported. As a matter of policy, only those projects on basic research have been supported, or considered for support, which would lead to a significant increase of knowledge in this field and thereby lead to major breakthroughs. Financial support from the Government for national superconductivity fellowships and superconductivity technical staff positions also continued.

In the second phase of the NSP, research and development and activities related to technology development, are being focused on areas such as: an improvement in critical temperature (T_c) and critical current density (J_c); the workability of yttrium-, bismuth- and thallium-based compounds, superconducting around liquid N_2 temperature; the preparation of bulk high - T_c sample especially by QMG and MTMG techniques; synthesis and characterization of new materials; thick/thin film growth; tape drawing; superconducting quantum interference devices (SQUIDS) and the development and engineering of a superconducting power generator using low-T_c superconducting materials. Some new areas targeted for technology development and demonstration are: passive bearing; low power SMES; MRI/MRS subsystem development; development and demonstration of special applications; low and high-T_c SQUIDS. During this period, financial support was provided to scientists and engineers associated with NSP projects to participate in international conferences. The organization of two workshops and seminars in India were also partially supported.

Some major achievements of the NSP projects were as follows:

(i) Process for 4N (99.99 per cent) purity yttrium oxide developed by Indian Rare Earths Ltd;
(ii) Bulk material 1-2-3 & bismuth-type superconducting quantum interference devices (SQUIDS), developed at the National Physical Laboratory, Delhi and the Central Electronics Engineering Research Institute, Pilani and working at liquid nitrogen temperature (77°), capable of detecting weak radio signals, cracks in metals, weak magnetic fields, etc., in a laboratory.
(iii) Passive microwave high T_c stripline high Q cavity/resonator and band pass filter feasibility demonstration carried out at TIFR/SAMEER.
(iv) Feasibility of small-size batch type High Gradient Ore Separator System (HGMS) using Nb-Ti superconducting (at liquid helium temperature); wire electromagnet demonstrated at

BARC and BHEL, with various types of weak magnetic component ores and system dedication.

(v) Low cost (about Rs. 4 lakhs per system or less) superconducting thin film deposition systems for university laboratory experiments and demonstrations using high oxygen pressure sputtering technique (for *in situ* deposition of HTSC films using a combination diffusion/rotary absorption pumps have been engineered and demonstrated at the Indian Institute of Science, Bangalore.

(vi) Nickelet based alcohol/gas sensors developed at the IISc, Bangalore.

(vii) HTSC material synthesis and characterization using different techniques such as powder (solid-solid, solid-liquid, gaseous phase, solgel, etc.), and thin films fabrication (by excimer laser ablation, sputtering, spinning, MBE/ABE, MOCVD etc., techniques) tried and materials characterized. Peak current density exceeding 17,000 A/cm^2 achieved at 77 K, OT.

The following are highlights of the achievements and capabilities developed under the NSP:

- Upgrading of capabilities for 4N purity yttrium oxide up to 8 tons/year for gem/diamond etc. use, and also for HTSC material synthesis.
- Substrates development for HTSC thin films is in progress.
- Development of epitaxial and good quality HTSC thin films.
- Availability of HTSC sputtering targets.
- Thin HTSC films for microwave applications.
- Passive microwave devices feasibility.
- LTSC and HTSC Josephson junctions and SQUIDs and SQUID based devices/systems/subsystems.
- Improvement of current density (J_c) in short samples of Bismuth HTSC wires/tapes.
- Initiation of project work on semi-industrial LTSC type ore separators at liquid helium temperature with involvement of industry.
- 200 KVA capacity generator testing and generation of up to 100 kw power is in progress.
- Design and fabrication of subsystems of a 5 MVA LTSC generator is in progress.

Superconducting generator model developed

The BHEL's Corporate Research and Development wing has taken up the development of five MVA superconducting generators under the National Superconductivity Programme, coordinated and monitored by the Department of Science and Technology's Programme Management Board. As a forerunner, a 200 KVA laboratory model of the generator has been developed, extensively tested and successfully connected to the State Power Grid. According to a BHEL press release, the model was reviewed by a team of experts led by Dr. P.K. Iyengar, former Chairman of the Atomic Energy Commission, on 5 October 1995 at the Corporate Research and Development Meeting.

Explaining the features of the superconducting generator, the Director of Engineering Research and Development, BHEL, said that the development was a breakthrough in overcoming electrical resistance in conventional generators that result in an enormous loss of energy. It is now possible to conduct electricity with zero resistance at very low temperatures, thereby reducing losses and ensuring optimum efficiency.

2. Ceramics

Glass and ceramics play a significant role in the development and advancement of new materials and technologies. The new ceramic materials have inherent superior properties, such as:

- High hardness;
- High strength at elevated temperature;
- Erosion and corrosion resistance;
- Insulating to superconducting properties, etc.

Table 1 summarizes the properties and applications of these advanced ceramics, while their potential demands are projected in table 2.

Table 1. Properties and applications of advanced ceramics

Function	Property	Application
1. Electromagnetic	Dielectric, electrical conductor, ferroelectric, magnetic devices, piezoelectric, pyroelectric, semiconductor	IC substrates, packaging electrodes, SQUIDS
2. Optical	Optical wave guide, translucent, optical conductor, opto-electronics	Laser diodes, cover for IR lamps, Na-vapour lamps, optical fibre, light valve, wave-guides, connectors
3. Mechanical	Wear resistance, thermostructural	Nozzles, dies, thread guides, cutting tools, pressure sensors, engine components, bearings
4. Chemical and biological	Corrosion resistance, conductivity, radiation, resistance	Pumps, valves, heat exchanger, nuclear moderators, heat sink fuel elements

Table 2. Indian market for advanced ceramics

Area of application	Products	1990		1995	
		Volume	Value (Rs.cr.)	Volume	Value (Rs.cr)
Electronic ceramics	Integrated	3.5	3.5	9.5	9.5
	Circuit substrate	0.15	1.5	0.3	3.0
	Multilayer capacitors	70	70	260	260
	Soft ferrites	375	37.5	700	70
	Hard ferrites	450	22.5	700	35
	Piezoelectrics	1.26	8.3	1.83	12.8
	Thermistor	0.42	4.2	0.68	6.8
	Varistor	0.5	5.0	0.70	7
Structural ceramics	Spark plug	1.26	25.2	1.6	32.2
	Cutting tools	-	-	-	0.3
	Bio-ceramics	-	-	-	2.0
Total			258.9		647.8

Table 3. Programme for ceramic IC engine components

Activities	Ceramics	
	Coating (ZrO_2)	Monolithic (Si_3N_4)
	Piston top, pin & ring, valve stem	Valve guide, VPR Soc. Bush for Support, Sc. with toe
• Product Design Specs	EM, RL & PI (1 month)	EM, RL & MI (1 month)
• Powder Property Specs	PI & RL (1 month)	PI & RL (1 month)
• Powder Preparation Powder Testing	PI & AI (12 months)	RL & AI (14 months)
• Scale Up	PI (12 months)	PI (12 months)
• Consolidation or Coating Tests	RL & AI (4 months)	RL & AI (4 months)
• Product Die Making#	-	RL & MI (12 months)
• Component Prototype# or Coating	RL & AI (8 months)	RL & MI (12 months)
• Testing		
Lab	MI & EM (3 months)	MI & EM (3 months)
Field	EM (max. 12 months)	EM (max. 12 months)

\# Activities in Two Stages:
i. Using imported powder
ii. Using indigenous powder

Legend:

AI : Academic Institution
EM : Engine Manufacturer
MI : Manufacturing Industry
PI : Processing Industry
RL : Research Laboratory

India has the second largest resources in the world for rare earth, using beach sand to derive titania, zirconia and titanate/zirconate ceramics. The utility of zirconia alone ranges from semiconductor zirconates, scissors, knives, dies to costume jewellery.

Structural ceramics is one area where India has abundant resources, capable research groups, and an interested manufacturing and user industry. An exercise carried out over a period of one and a half years has resulted in the formulation of a definite programme for the development of Si_3N_4 and ZrO_2 technology for IC engine components, turbine blades, and missile and rocket parts. As such a programme requires a total engineering approach, specific steps were worked out for the development of each product, and specific groups identified for each activity, to work within a set time frame. An example of the total development programme for some IC engine components is shown in table 3. In order to shorten the time needed for the development of powders, their consolidation and characterization was undertaken in parallel, using imported powders for the design and fabrication of the product.

As this programme was formulated in close consultation with use and manufacturing industries and agencies, both technical and financial cooperation was thereby assured. However, the lead was taken by the Government of India in initiating this programme.

It is also realized that a multidisciplinary approach is needed for the successful development of these advanced materials. Expertise in materials engineering and processing, chemistry and chemical engineering, mechanical engineering and processing, design engineering, stress analysis, systems engineering, characterization and product manufacturing should be integrally linked for total development projects from the synthesis of raw materials to the manufacture of the final product.

Partially stabilized zirconia (PSZ) - is a new variation of the widely-used zirconia, formed by adding Y_2O_3 or Mg.O in sufficient quantities so as to stabilize the high temperature cubic phase. Laboratory scale development of PSZ and SiN is being carried out at the Defence Metallurgical Research Laboratory (DMRL), Hyderabad, and the Central Glass Ceramic Research Institute, (CGCRI), Calcutta. In addition, silicon carbide (SiC), zirconia and sialon are important engineering ceramics under development in India.

Significant activity is taking place, with regard to ceramic superconductors at various institutes in India, namely:

- Indian Institute of Science, Bangalore;
- Indian Institute of Tropical Meteorology, Pune;
- Tata Institute of Fundamental Research (TIFR), Bombay;
- National Physical Laboratory, New Delhi; and
- Bhabha Atomic Research Centre (BARC), Bombay.

2.1 Sensors

The materials used for making sensors are PZT, BaTiO2, ZnO, together with a few other mixed transition metal oxides. As a result of the advances made in India in the area of sensor chemistry and technology, most of the sensors for various industrial and consumer applications are now being made with indigenous know-how available in India.

2.2 Bioceramics

CGCRI, Calcutta, achieved a breakthrough in the field of bio-ceramics, when a ceramic head was developed as a substitute for hip joints for patients suffering from osteoarthritis. Ceramic heads were fabricated with alumina which matched the density of bone samples and are fully bio-compatible and non-toxic. A few patients have been successfully operated upon for the transplantation of these hip joints.

Carbon and clay bonded graphite crucibles have been an important contribution in the area of refractories. These used to be imported, but are now mainly manufactured by a number of units on a commercial scale at Rajamundry, Andhra Pradesh, utilizing the National Metallurgical Laboratory's technology and expertise.

In the development of materials, some important programmes which are under way at the Regional Research Laboratory, Bhopal, include the development of metal matrix composites based on aluminium alloy matrix and fibres/whiskers of aluminium/SiC and particulates of graphite, SiC and Al_2O_3 as dispersoids.

CGCRI, Calcutta, has taken up the development of PZT-polymer composite ceramics for various electro-chemical transducer applications, and the development of ceramic composites based on ceramic and glass ceramic materials etc.

Zirconia-toughened alumina ceramics are promising true materials. Si.N may also serve as an aircraft engine application beyond the year 2000. Also, the Si.N. ceramics are replacing metals in automobiles, thus reducing fuel consumption by 30 per cent and engine weight by 40 per cent. The development of sintered alpha SiC can replace a large proportion of conventional ductile metals in various engine parts, increasing the efficiency of the engine alone by 50 per cent.

3. Glass & glass-based products

CGCRI, Calcutta, has made substantial contributions in the development of products and processes of strategic importance from indigenous materials namely, optical glass. The institute has also developed "Radiation Shielding Window" glasses which are essentially used for the attenuation of harmful high energy radiation in nuclear reactors. The process technologies developed at CGCRI for the production of a variety of optical glasses and radiation shielding glasses are progressively being transferred to Bharat Ophthalmic Glass Ltd., (BOGL), Durgapur, for commercial production. CGCRI has also developed laser glass complying with the stringent defence specifications for instruments such as a range finder. The quality of these laser glasses is comparable to equivalent materials obtained abroad.

In the area of fibre optics and optical communication, CGCRI, along with the Central Scientific & Instrumentation Organization (CSIO) and the Central Marine Research Station (CMRS), has successfully installed an optical fibre communication system in the Malkera colliery, Dhanbad. The 225 m long cable made by CGCRI, was laid from the pit head to pit bottom of the 16th seam. This has been connected to an audio transmission system (a two-way telephone link) and since December 1988 is fully operational.

3.1 Optical fibre materials

Two collaborations have been entered into for the manufacture of fibre and cables i.e.:

(i) Madhya Pradesh State Electronics Development Corporation (MPSEDC), and

(ii) Hindustan Cables Limited (HCL).

Each will have production equipment to draw optical fibre from preforms made by using MCVD (modified chemical vapour deposition) technology. The optical fibre is being made primarily for 1300 mm (1.3 μm) transmission and can also be used for 1550 nm (1.55 μm) transmission. The basic technology for dispersion shifted fibre at 1550 nm (1.55 μm) transmission is also available. With synchronous transmission and WDM (Wavelength Division Multiplex) techniques, the traffic handling capacity of these optical fibres can be substantially increased.

India is now focusing attention on the following aspects:

(a) To prevent optical fibre cable being damaged due to lightning strikes, the cable has to use non-metallic strengthening materials. At present these are imported. These are areas in which India has yet to acquire self-reliance.

(b) While the low loss optical fibre suitable for higher wave length (i.e. greater than 2000 nm) has not been considered an industrial priority, it is worthwhile pursuing their development in R&D laboratories to meet small length requirements used in instruments and as sensors.

4. Polymers and composites

4.1 Polymers

Commodity plastics like LDPE, HDPE, PVC, PP, ABS and LLDPE are being manufactured on a large scale, in India. There is a growing demand for these types of plastics for agricultural purposes, e.g. water conservation, lining of canal and drip culture.

The engineering plastics being manufactured in India are polyethylene terephthalate (PET); polybutylene terephthalate (PBT); nylon; and acrylonitrite butadiene styrene (ABS). India has already established a sophisticated industrial infrastructure for the manufacture of polyester fibres. Recently the Indian Petro-Chemical Complex Ltd. (IPCL), Baroda, acquired technology from the General Electric Company (GEC), USA, for the development and production of engineering plastics, including polycarbonate, in the country.

The National Aerospace Laboratories (NAL), Bangalore, has developed Kevlar-49 type aramid fibres, the production of which on a large scale, will be undertaken by M's Shriram Fibres, New Delhi. IPCL, Baroda, has also acquired technology for the production of high modular carbon fibres based on polyacrylonitrite (PAN) precursors.

4.2 Composites

The technology for the production of FRP (fibre reinforced plastics) already exists in India. The present production of glass fibres amounts to approximately 25 tons per annum, which is just under 3 per cent of the world's production.

The National Aerospace Laboratory, Bangalore, has undertaken considerable work in the field of resin matrix composites, together with the Aeronautical Development Establishment (ARDE), and the Defence Research and Development Laboratory. The NAL has also designed and fabricated a rudder for the MIG and Dornier aircrafts respectively, which has been successfully static tested by Hindustan Aeronautics Ltd., Bangalore.

A technology centre has been set up at the Defence Research and Development Laboratory (DRDL), Hyderabad, for the manufacture of carbon-polymer matrix and carbon-carbon matrix. Laboratory-scale work has been carried out for MMC's (Al-SiC) and CMC's (Al_2O_3-SiC) composites, at the Defence Metallurgical Research laboratory (DMRL), Hyderabad. The Indian Institute of Chemical Technology (IICT), Hyderabad, is planning to manufacture coal tar pitch (500 kg per batch), for C-C composites.

Considering the bulk availability of raw materials such as glass, polyester, rice husk and pitch, as well as the availability of technology for the processing of composites in addition to being labour-intensive, the development of composites as new materials is well-suited to Indian conditions. Academic research in the field of composites is largely carried out at:

- Indian Institutes of Technology, (Delhi, Madras, Kanpur and Bombay);
- Indian Institute of Science (IISc), Bangalore;
- National Aerospace Laboratory (NAL), Bangalore;
- National Physical Laboratory, (NPL), New Delhi; and
- Defence Materials Stores, R&D Establishment (DMS RDE).

The successful development of the all-composite aircraft, "HANSA" at the NAL, and the use of sophisticated composite products in, for example, the Advanced Light Helicopter (HAL), the national missile (DRDL), the INSAT 2 satellite and the satellite launch vehicle (ISRO) programmes, signify the expertise available in the country in the design, analysis, fabrication and testing of new composite products. The advanced technologies developed for aerospace applications have also led to such spin-offs as orthopaedic supports. Similarly, the low-technology, high-volume FRP segment has set an impressive record in terms of the variety of products manufactured in the country. Thus, the capability for the development of primary composite structures as well as complex FRP parts is rapidly being established.

In appreciation of the current situation, research and development laboratories have taken the lead in setting up special centres. The Defence Research and Development Laboratory (DRDL), has a Composite Products Centre (COMPROC) at Hyderabad, and the NAL has a Centre for Composite Product Development and Application (COMPAC). Both have close links with industry. Similarly, a large number of other institutions like the FRP Research Centre at the Indian Institute of Technology, Madras, and the IIT's at Bombay and Kharagpur, have also opened their facilities to private industry. Professional societies such as the Indian Society for the Advancement of Materials and Process Engineering (ISAMPE), the Indian Society for Composite Materials (ISCM), and the All India Reinforced Plastic Moulders Association (AIRPMA), have placed emphasis on composite materials and thus contributed to promoting the industry through a series of national seminars and workshops.

4.2.1 Mission on advanced composites

A Technology Project on Advanced Composites (TPMM-AC) was recently approved by the Government and is a target-oriented activity which will be implemented by the Technology Information Forecasting & Assessment Council (TIFAC), New Delhi, under the guidance of the lead agency, the Department of Science and Technology (DST). This project requires close association with industries and users. The TPMM-AC aims at the indigenous development of composites products and technologies for the domestic as well as export markets, for which nineteen subprojects have been identified in two major categories i.e. (i) Strategic inputs needed for the overall development of composites and (ii) Specific products to be taken up for design, prototype development, technology diffusion and further commercialization.

The strategic inputs include: Prepreg technology, thermoplastic matrix composites; carbon pan fibre production; development of non-destructive evaluation technique for composite structure; design capability development; fibre architecture; development of PEEK resin; and manpower development.

Products identified for development are: Musical instruments; golf club shafts and fishing rods; medical applications; radiography beds, wheelchairs, headrests etc.; aircraft interiors; refill cylinders for CNG; wave guide for microwave communication; carbon-carbon composites brake discs; railway components; automotive components; and bicycle components.

An incremental funding support from the Government for each subproject is to be made available as the seed capital for technology and product development. Industries and users would collaborate with research and development laboratories, with equal financial participation, to develop commercially viable composite products within a targeted time-frame.

5. *Metals and alloys*

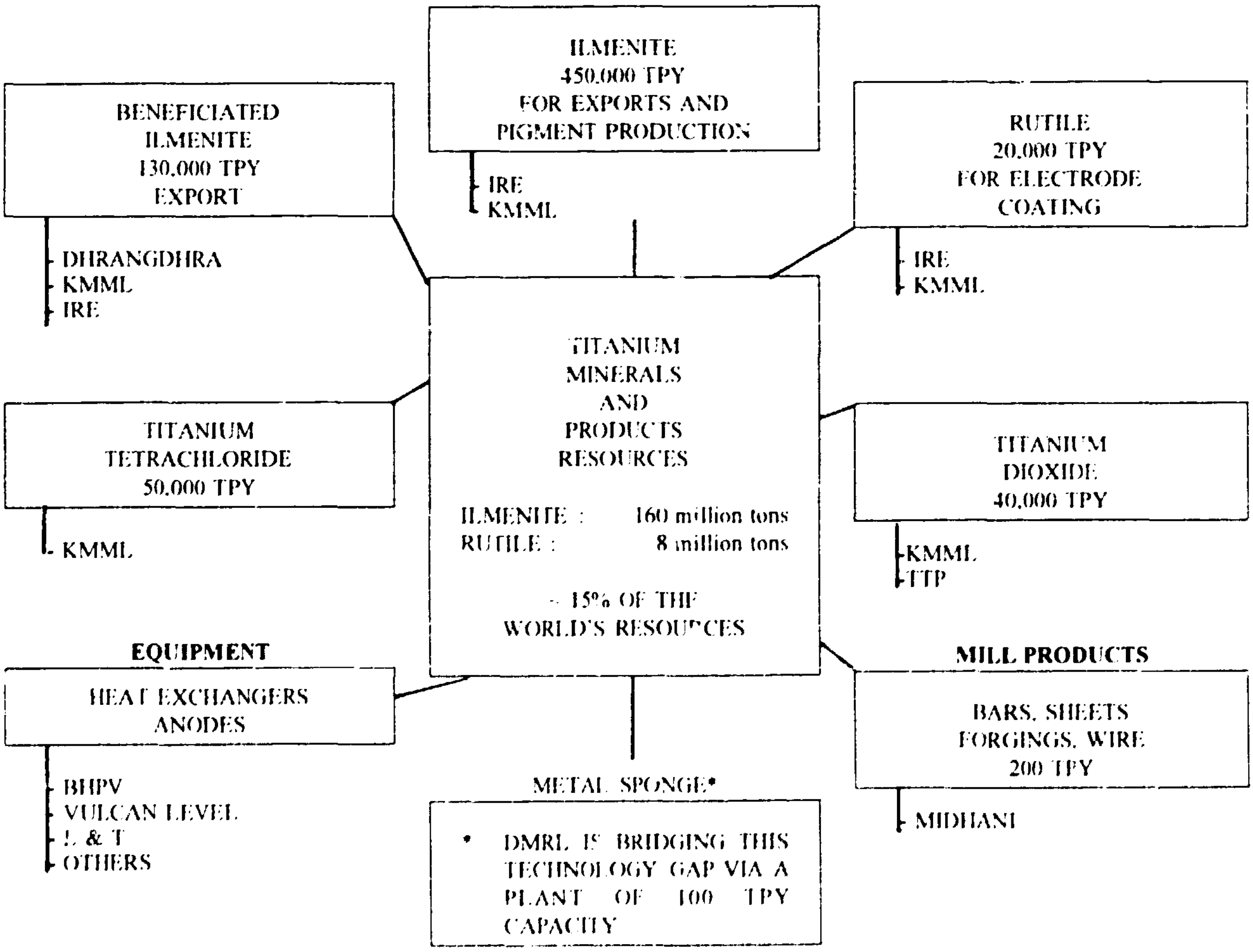
The metals and alloys sector constitutes one of the core sectors of industry. Attention is now being focused on the following:

5.1 Titanium

India has an abundant resource of titanium minerals (more than 20 per cent of the world's resources), therefore titanium has acquired a special significance. With a view to identifying the uses for titanium, TIFAC set up a Titanium Development Advisory Committee in December 1991. Until now, the technology for metal production on an appropriate scale was not available for ready exploitation. This gap has now been bridged with the establishment of a technology development centre at the Defence Metallurgical Research Laboratory (DMRL), Hyderabad. A modern titanium tube plant has been set up at MIDHANI, Hyderabad to produce 25 tons of titanium per annum. It has remarkable corrosion resistance and is very useful as condenser tubing in thermal power plants and in similar applications.

A well established beach sands industry for mineral separation exists in the country at the Dhranghadara

Figure 1. The titanium scene in India



Chemical Works, Kerala Minerals and Metals Limited (KMML) and the Indian Rare Earths (IRE). Large-scale production facilities for synthetic rutile (IRE, KMML), titanium tetrachloride (KMML) and pigment grade titanium dioxide (KMML, TTP) are in operation.

A capacity to design a steam condenser exists at Bharat Heavy Engineering Ltd. (BHEL), that needs to be harnessed. The technology for the fabrication of equipment is available at the Bharat Heavy Plate and Vessel (BHPV) and BHEL, but these need augmentation in respect of applications such as power plant condensers.

5.2 Magnetic materials

The National Metallurgical Laboratory, Jamshedpur, Defence Metallurgical Research Laboratory, Hyderabad, and MIDHANI, Hyderabad, are working on the research and development and design aspects of Fe-Nd-B alloys as permanent magnets both through powder & RSP methods in India. These may replace alnico and smarium-cobalt magnets by the end of the century, bearing in mind the import requirements for nickel and cobalt and the indigenous availability of an excess of monazite ore containing Nd in India.

An Advanced Research Centre for Powder Metallurgy has been set up, with Russian assistance at Hyderabad, to manufacture intricate devices through powder metallurgy methods.

5.3 Steel

The production of steel in India is around 10 million tons per year. It is estimated that the required level of production would be around 22.5 million tons by the year 2000 as per the report of the National Mission for Iron and Steel.

5.4 Aluminium

The production of aluminium is estimated to be around 500,000 tons per year following the commissioning of the National Aluminium Company (NALCO) Ltd., Orissa. With the enormous resources of bauxite in the country, the production of aluminium can be increased in the future.

Aluminium-lithium alloys offer a density (7.12 per cent), higher stiffness (10 per cent), increased fatigue crack growth resistance and broader environmental capability (table 4). They promise up to a 15 per cent reduction in structural weight and are thus poised for a major expansion as aircraft frame materials.

Table 4. Goals for aluminium-lithium alloy development for aerospace application

Ultimate tensile strength	586 MPa
Tensile yield strength	517 MPa
Elongation	10 per cent
K_c	64 MPa m
K_{Ic}	23 MPa m
Elastic modulus	69 GPa
Density	2.49 g/cm^3
SCC classification (ST)	C

Academic and research and development institutions in India have been seriously involved in the design and development of aluminium alloys for the past three decades. This long experience has been used in the development of aluminium-lithium alloys during the past two years, with encouraging results.

Visvesvaraya Iron & Steel Limited, Karnataka, has set up a plant for the production of ferro-vanadium from vanadiferrous ores from Karnataka utilizing the NML's experience; carbon free ferro-alloys which were previously imported are now produced indigenously by using the aluminothermic reaction technology of the NML by a number of firms. The NML has been instrumental in developing distilled grade zinc dust, using both primary zinc as well as waste galvanizers dross as raw materials, a 600 tpa commercial plant for producing high-grade extra-fine zinc dust has been set up at Patna. Another significant achievement, made by the NML and CECRI, has been the development of aluminium- and other alloy-based anodes for cathodic protection, which are now commercially produced for the cathodic protection of ship hulls, harbour structures, and underground pipelines, etc., against corrosion. The NML has also developed highly powerful sintered magnetite anodes which can provide very effective protection. With a view to developing a system to provide 100 per cent cathodic protection, the NML plans to develop an autocontrol system which would have readily usable and directly transferable packages of technological hardware and software.

Developments in the pipeline

India today imports around Rs.1000 crore worth of copper and nickel. The land-based resources of copper and nickel cannot meet India's long term need for these metals. To overcome these impediments, a consortia of laboratories are working on a project to develop an internationally competitive technology for the extraction of copper, nickel and cobalt from poly metallic sea nodules from the Indian Ocean.

In another noteworthy effort, a detailed computer programme has been developed by the RRL, Thiruvananthapuram, for the mathematical modelling of liquid/liquid extraction and separation of individual rare earths from chloride medium. This has been done with the objective of process optimization and the possible use of the programme to develop a computer-controlled process instrumentation system.

Another notable process in the offing, namely, NML's RESINESS (RE-Reduction; SIN-Sintering; and ESS-Electroslag Smelting) technology deserves special mention. This technology has the potential of becoming a novel method for the production of steel in the future. RESINESS produces steel by using inexpensive raw materials which were hitherto considered unsuitable, such as: blue dust, the fines of iron ore and the fines of non-coking coal, all of which are abundantly available in India. The charge mixture, consisting of non-coking coal fines and iron ore fines is charged into the retort, which is externally heated in the RESIN furnace. The heat is supplied either by coal, oil or gas and the charge mixture is pushed down through the retort. As a result the iron ore in the charge mixture is reduced and sintered, emerging at the end of the retort in the form of a directly reduced iron (DRI) rod (or a slab), in a red hot condition. The DRI rod (or slab) is then fed into a slag bath, which is kept in a molten condition through passing of a high electrical current through the ESS furnace. As a result, the rod is smelted to directly produce high quality steel. In the conventional process, the steel is at first produced by reducing the iron ore to produce pig iron and then reoxidizing the pig iron. The

RESINESS process is based on a continuous decrease of the partial pressure of oxygen to directly produce steel. The experiments and trials conducted at the NML show that if and when the RESINESS process is used, the capital and operational cost can be substantially reduced. The energy consumption can be reduced to less than half, with liquid and gaseous pollutants and wastes being decreased by about one-fifth.

The process would be technically and economically viable at a much lower plant capacity, making it possible to disperse the iron and steel industry to wider locations. The process does not require atmospheric oxygen and consumes very little refractory material. In the RESINESS process it is expected that redundant chemical and metallurgical work can be avoided. The process uses concepts and techniques which are entirely new and have not hitherto been tried.

6. *Mining and minerals*

India is endowed with rich minerals resources such as coal, iron ore, bauxite, manganese, copper, chromium, lead, zinc, fluorspar, pyrites, phosphates, etc., which form the basic wealth of the nation. The economic development of a country depends to a large extent on its capacity to exploit these resources effectively and efficiently. To be able to utilize even low-grade ores cost effectively is thus a challenge. The CSIR laboratories, particularly NML, Jamshedpur and RRL, Bhubaneswar, have been pioneers in conducting studies and developing methods and techniques for the agglomeration and beneficiation of low-grade ores to make them suitable as industrial raw materials.

CSIR's efforts have resulted in the commissioning of a number of plants in the country. For example: a 50 tons per day (tpd) manganese pan sintering plant at Shreeramnagar, and a 2x30 tpd iron ore sintering plant at Barbil set up based on the RRL, Bhubaneswar Design; copper concentrators of 6000 tpd at Malanjkhand and 1000 tpd at Rakha were designed based on the investigations and flowsheet developed at the NML; iron ore washing and sintering plants set up at Noamundi for TISCO, Dalli-Rajhara for the Bhilai Steel Plant, Barsua for the Rourkela Steel Plant, Bolani Mines for the Durgapur Steel Plant and Kiriburu for the Bokaro Steel Plant, were based on detailed technical know-how developed by the NML; low grade fluorspar beneficiation plants of 500 tpd by the Gujarat Mineral Development Corporation and 50 tpd by the Madhya Pradesh and Maharashtra Minerals and Chemicals (Pvt) Limited were also based on the NML flowsheet; the 100 tpd graphite beneficiation plant set up in Tamil Nadu was again based on NML designs.

The NML has now developed a project of strategic importance, i.e., to produce tungsten from Indian tungsten ores, which are lean, the deposits are embedded in hard graphite rock. Even though the extraction of tungsten from such ores may not be economical, the process to extract tungsten needs to be developed for purely strategic reasons and at the lowest possible cost. The NML has critically examined and assessed the flow-sheets developed for the Degana and Sirohi deposits of tungsten ores and upgraded the product quality of the Degana plant to meet the stringent specifications of defence requirements for tungsten. The NML laboratory has been working on the development of flow sheets to beneficiate the low grade trench-loaded ore of Degana deposits.

Nickel and cobalt are totally imported at present. The RRL, Bhubaneswar has been requested by the Government of India to coordinate with other agencies, a project for beneficiating chromite over-burden to recover nickel and cobalt so that an industrial plant to manufacture these could be established in the country.

RRL, Thiruvanathapuram, is ideally placed to work on minerals which are generally categorized as "rare earth". They have been working on the development of a process to manufacture synthetic rutile by a catalytic process method. Laboratory investigations have shown encouraging results and they are now upscaling the process to the level of a demonstration plant with the participation of industry.

Education and Research - Microelectronics

The Department of Electronics (DOE), Government of India, and the University Grants Commission (UGC), have jointly identified 11 universities where two-year postgraduate courses in "Electronic Science" have been started. The objective is to make available trained manpower in the country to undertake research and development activities in specific areas of electronics, such as LSI/VLSI design, fibre optics, artificial intelligence robotics, advanced signal processing, instrumentation and high power devices. These universities are:

1. Delhi University
2. Poona University
3. Calcutta University
4. Cochin University of Science and Technology
5. Kurukshetra University
6. Bihar University
7. Devi Ahilya Vishwa Vidyalaya
8. Sardar Patel University
9. Behrampur University
10. Guwahati University
11. Bangalore University

This programme is now being extended to five other universities. Similarly, the programme on the generation of special staff for computers and to bridge the gap between the supply and demand for trained computer staff was started by the DOE. The emphasis has been on multiple effect programmes, such as the cross-migration programme and the teachers training programme. A postgraduate course leading to the degree, Master of Computer Application (MCA), is running at thirty-six universities or institutes. Another one-year postgraduate diploma in computer applications (DCA), running in collaboration with the UGC is being conducted at fifty-four centres. One more post-polytechnic DCA programme meant for engineering diploma holders, has been introduced in fifty-two polytechnics in collaboration with the Ministry of Human Resource Development.

In addition, several other laboratories and R&D centres are engaged in activities which would facilitate microelectronic device processing. The Central Scientific Instruments Organization (CSIO), Chandigarh, is running a comprehensive programme on the development of capital instruments which typically constitute a fabrication line. CAT, Indore, is developing a synchrotron radiation source, whose miniature version could be tapped for submicron lithography. Work on plasma polymerization, dry resists and e-beam writing is being carried out at the University of Pune. NPL, Delhi has also recently been active, through some of its programmes on the characterization of microelectronic materials, collaborative programmes and the assembly of process equipment. Several other institutions such as the IISc, Bangalore; TIFR, Bombay; and NCL, Pune have also contributed to specific sectors of the entire fabrication process, either directly or through their collaboration with other institutions.

The activity on microelectronics can be considered in various levels of integration such as printed circuit boards (PCB), hybrid circuits, discrete circuits, integrated circuits (IC), small- and medium-scale integrated circuits (SSI, MSI) and large and very large scale integrated circuits (LSI, VLSI). These activities are being undertaken at academic or educational institutions, research and development (R&D) institutions, or in industry. Some research and development centres are part of an educational institution, where they concentrate on academic or open-ended research. Others are at industrial sites, where the main aim could be technology or product upgrading. Some others are exclusively research and development institutions, which concentrate on specific applications, such as telecommunications, defence, or industrial sectors. Research and development institutions generally welcome trainees and exchange visitors from within and outside their national boundaries on pre-agreed terms. A few research and development establishments also have complete fabrication-cum-testing lines for a particular process to enable them to perfect a technology and produce devices in small numbers for specific purposes (tables 7 and 8).

Analogous to the establishment of the National Radar council (NRC) and the Technology Development Council (TDC), a National Microelectronics Council (NMC), was set up in India in 1985. Its responsibilities included the coordination and implementation of the national research and development programmes, technology development and manufacture in the area of microelectronics. It is giving thrust to proliferating the computer aided design (CAD) culture in the country at academic institutions, research and development laboratories and electronic equipment manufacturers; setting up prototype foundries for MOS ICs and updating existing technology and manufacturing capabilities for bipolar ICs. A clear plan to establish design centres at increasing levels of competence has been followed.

Future perspectives

The development of new materials in India has been carried out in clear relation to the advances that have taken place in science and technology abroad, and to the needs of Indian society. These efforts have led to capacity building in many areas leading towards achieving self-reliance in the country. The requisite expertise for the development of the newer and special purpose materials for hi-tech applications, is available in the country at educational and research institutions. Sophisticated research facilities and complex processing techniques are now needed for the development and production of new materials, which are required for all the new and emerging fields of engineering and technology.

Although few inputs from industry in this direction until the beginning of this decade were made, industry has increasingly taken on the responsibility of participating in the country's development plan programmes, and broadened its base to absorb the new technologies. Materials such as micro-alloyed steels, dual-phase steels, and zinc aluminium bronzes, which are cost-effective and offer better performance are being developed. For any developing economy to be successful in such endeavours, there has to be an active collaboration effort by both government and industry. A number of programmes for the development of advanced new materials have, therefore, been initiated by the Government in collaboration with manufacturing and user industries.

Special materials have now gained a particular significance in present-day scientific and technological activities, as well as in industry, because much of the instrumentation for laboratory work and process and quality control in industry would not have been possible without these materials. Bearing in mind that there is a continuous development of advanced materials with novel and unique characteristics abroad, an apex science advisory body (i.e. SAC-PM) recommended, in 1990, that:

(a) A national plan on new materials, keeping clearly in mind not only the future materials needs of our technologies, but also the natural resources position, the indigenous situation in the area of materials processing, a near lack of sophisticated manufacturing infrastructure and the constraints imposed by the funds position. Thus arises a paramount need for selecting a few advanced materials for concentrated research and development.

(b) Setting up a National Advanced Materials Research and Development Board (NAM-R&DB) with a view to developing a strategy or programme to forge links among relevant academic and R&D institutions, including production centres in India where sufficient expertise has been developed in order to consolidate the strength in this vital field of high technology.

The Board should focus its attention on the development of the following advanced materials:

(i) Metals and alloys : Titanium
(ii) Electronic materials : Silicon-based microelectronics and III-V semiconductor compounds.
(iii) Magnetic materials : Permanent magnetic materials based on rare-earth materials (RE-Co and Nd-Fe-B)
(iv) Other selected materials : Nirconia ceramics, ceramics raw materials like high purity zirconia and yetria, reinforcement materials like kevlar and carbon fibres and advanced composites.

In this context, a recent report by the Joint Scientific Committee (JSC) of the Department of Electronics (DoE), Government of India, is relevant. Their suggestions in respect of the following, deserve serious consideration:

Development of process techniques to fabricate multi-layer, advanced printed circuit boards; establishment of remote design centres to increase the availability of design software and hardware for the design of computers; development of Application Specific Integrated Chips (ASIC).

A summary of recommendations concerning new materials by SAC-PM are listed in table 5. Thus, this article covers a brief overview on India's experience in the development of research and development facilities, scattered all over India, for the promotion of new materials.

Table 5. Summary of recommendations on new materials
(Science Advisory Council to the Prime Minister, 1990)

Materials	Area of projected applications	Current status and support recommended
I. Electronics Sector		
1. Amorphous silicon	"Slow" electronic devices: reprography (also relevant for energy sector: Photovoltaics)	Very low key and largely academic activities; 20-25 times the present level of funding should be invested.
2. Gallium arsenide and related III-V semiconductors	Fast electronic devices computers: specialized photovoltaic applications, light emitting diodes and other solid state applications	Very little effort; A national laboratory fully dedicated for the purpose should be established.
II. Communication Sector		
3. Quartz fibres	Optical transmission	Fibres have only been bought in trial applications; activity should be initiated on a large scale for silica fibre preparation starting from organic silicon by sol-gel route. R&D on oxide and halid fibres should be simultaneously emphasized.
4. III-VI semiconductors	Phosphors for TV industry	Virtually fully imported; entire gamut of II-VI semiconductors to be developed in a dedicated laboratory.
5. A-Magnetic material of Fe-Si-V-C; opto-electronic crystals	Recording heads transforms cores, etc.	Fast quenched alloys are only an academic activity at a few centres.
6. Fe-Nd-B permanent magnet	Motors	Isolated effort; R&D on rapid solidification of these alloys can be initiated.
7. KDP, ADP, BANANA, PZT, PLZT, KLN, LN, etc.	Signal modulation and control electronics	Rather isolated efforts and mostly imported; a national single crystal facility to be established to meet the entire gamut of single crystal materials.
III. Transportation Sector		
8. Aluminium alloys	Mopeds, automobiles, trains, aircraft	Well developed systems are available; necessary to intensify research on aluminium-lithium alloys.
9. Intermetallic compounds	Engine material	New technology needs to be developed.
10. Toughened zirconia, silicon nitride	Automobile engines; tools	Intensive programmes have to be initiated.
11. Kevlar and carbon-carbon composites	Advanced composites for initial deployment in aircraft and later expansion into less strategic areas	Expertise in fibre reinforced plastics exists in the country: activity on advanced composites needs to be strengthened.
12. YAG and glass matrix rare earth ion lasers	Laser machining, laser annealing, laser cutting, etc.	Virtually non-existent, even its use appears to be very limited; a crash programme for the development of industrial lasers is recommended.

Materials	Area of projected applications	Current status and support recommended
13. Super-conductors: Novel valence fluctuating oxide	Levitation transport (also relevant to other sectors like in energy for magnetio-hydrodynamics) and in health sector for magnets used in whole body scanners.	Scientific know-how for the preparation available in the country but no action in the direction of exploiting it for definitive industrial applications; highly recommended as an area which promises leadership opportunities.
IV. Energy Sector		
(1a) Amorphous silicon	Referred to earlier in electronic sector	Heavy investment recommended.
14. Hydrides	Hydrogen from photo electrochemical cell used in direct burning and in fuel cells	Many photo electrochemical cell materials investigated and developed in the country, hydrogen storage particularly in LaFe type of alloy not being investigated; R&D programmes to be intensified with much larger level of funding than now.
V. Other Industrial Sectors		
15. Sensors semiconducting oxides transition metal oxides and zirconia	Oxygen, humidity, toxic gases, etc. detection, monitoring and measurement	Know-how available in the country and scattered in a variety of research centres; all types of sensors to be developed in small scale industries like in Japan.

Table 6. Materials research in selected academic institutes in India

Academic Institutions	**Field(s) of Study**
Tata Institute of Fundamental Research, Bombay	Submicron CMOS structure in Ga AsP alloys
Indian Institute of Technology Bombay	Oxidation of silicon S_iO_2 thin films MOS technology, HCL oxidation RNO films Pyrogenic oxides
Indian Institute of Technology Kharagpur	In. P In & Ga As SiN (PE-CVD) SiN4, GaAs
Indian Institute of Technology, Kanpur	Si - Photodiodes H-Si QWS - In Ga As/Al GaAs
Indian Institute of Technology, Delhi	Ga As hetrostructure Silicon on insulators EiS structure Photo CVD S_iO_2 thin films CMO - VLSI Polysilicon SOI mosfet
IISc + TIFR	MBE grown Al Ga A S
IIT(D) + CEERI + NPL	Materials for VLSi application
BAnaras Hindu University	Ga AS, Mesfet Cu In Se
Jadavpur University &	a-Si thin films
Indian Association for Cultivation of Science, Calcutta	Narrow gap semiconductors Porous silicon
Behrampur University	Ga Sb and Al Sb
University of Pune	Al Si samples RTF process RPT techniques for Si Opto-electronic gates
Delhi University	Shotky Barrier GeSe, GeSbSe, HgCdTe, CdSe
M.D. University, Rohtak	Ge-Chalcogenides
Meerut University, Meerut	Thick Film Cds.
Jamia University, Delhi	GeSe
Indian Institute of Science, Bangalore	DLTS Al GaAs Al In Si Ga Sb. E12 in GaAs, MOS devices
Indian Institute of Technology, Madras	In Sb film GaAs - Ga Al As superlattice structure
University of Burdwan	I-III-VI compounds
University of Delhi	Sb-Te System, Ge Sb Se, a-Si
Anna University, Madras	In As. (LPE)
BARC, Bombay	MBE - GaAs/In Ga Al As
University of Calcutta	Ga As/Si (epitaxial layers)

Table 7. Materials research in selected research and development laboratories in India

Research and development laboratories	Field(s) of Study
CEERI + BITS, Pilani	C-MOS Process
CEERI + NPL, Delhi	EPR study of BF_2 implantation in Si
Central Electronic Engg. Research Institute, Pilani	Junction transistor LDD transistor High Tc super conductor CMOS, MoSFET, LV-BSE In P, Al Si alloys Submicron technology
National Physical Laboratory New Delhi	Polycrystalline silicon Silicon (impurity diffusion) GA As single crystal
Solid state physics lab New Delhi	Gunn diodes Impatt diodes III-V compounds Hetrostructure solar cells HEMT MBE grown films Silicon wafers In Ga As layers Ga As devices Si impatt diodes Si pin diodes Hg Te, Hg Cd Te, thin films Porous silicon

Table 8. Organizations engaged in development of materials for HMCs in India

S. No.	Organization
1.	Nuclear Fuels Complex, Hyderabad
2.	M/s Eltech Corporation, Peenya, Bangalore
3.	M/s Jyoti Refinery, Bombay
4.	M/s Kerala State Electronics Development Corporation (KELTRON), Trivandrum
5.	Centre for development of materials, Pune
6.	Central Glass and Ceramic Research Institute (CGCRI), Calcutta
7.	Indian Institute of Science, Bangalore
8.	Indian Institute of Technology (IIT), Kharagpur

Table 9. Major industrial units producing HMCs in India

S. No.	Industry
1.	Bharat Electronics Limited (BEL), Bangalore
2.	Bharat Electronics Limited (BEL), Ghaziabad
3.	Indian Telephone Industries (ITI), Bangalore
4.	Indian Telephone Industries (ITI), Naini, Allahabad
5.	Indian Telephone Industries (ITI), Mankapur, Gonda
6.	Hindustan Aeronautics Limited (HAL), Hyderabad
7.	Electronics Corporation of India Limited (ECIL), Hyderabad
8.	Gujarat Communications and electronics Limited (GCEL), Vadodara
9.	Western Indian Enterprises Limited, Pune
10.	Mini-circuits Limited, Bangalore
11.	Vikas Hybrids and Electronics Limited, New Delhi
12.	Film Electronics, Meerut
13.	Anvi Electronics, Valsad
14.	Usha Rectifiers Corporation India (P) Limited, Shimla

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B. MATERIALS POLICY DEVELOPMENT IN INDIA:
EMERGING ISSUES

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1. Introduction

The National Materials Policy Project is an inter-institutional effort to develop long-term strategies to enable India to become more competitive in materials. Some key materials important to the economy at the present time, and for the near future, have been selected for policy development. Various issues like raw material potential, sustainability of production, technological developments (global as well as Indian), R&D capabilities, demand and supply, economics of substitution, etc. are studied in depth. The project also aims to develop a consensus among different stakeholders in materials about the strategies to be adopted in the future. As a part of the project, a database on the research carried out in India for various materials is also being created.

The project, to date, has identified several common policy issues across materials. This report outlines some of the key issues and strategic options along with an action plan for the country. Many of these findings are being discussed extensively with various stakeholders in different forums.

The raw material situation in the country (in terms of resource endowment and production capacity) for most materials is quite satisfactory. However, there are quality problems and a lack of appropriate technology to utilize them more efficiently. Technological developments for the processing and the production of materials are not yet fully developed within the country. The dependence on the import of technology, in spite of our capabilities, is very high. Many of the R&D efforts remain at the laboratory level and the transfer of technology to industry is not very effective. Human resource development by academic institutions is not always in line with what the materials-based industry needs, leading to the poor utilization of these resources, in spite of a high potential.

The structure of industry in some materials is conducive for employing high technology and mechanization. Some changes, however, are needed to promote innovation and competition. Similarly, the role of the Government will have to be redefined. The Government in future will have to play a positive, promotional and facilitative role, and less of a regulatory one. Given the right kind of policy environment, India can be an important player in the world of materials.

This paper explores the relevant policy issues, outlines the interim findings of the research carried out and identifies tentative strategies in a comprehensive framework. It is intended as a basis for discussion and feedback.

2. Background

The future of materials crucial to the economy is the main concern of the National Materials Policy Project. As the name suggests, the Project's objectives are to prepare a long-term perspective and a framework of policies and strategies for the development, production and use of key materials of relevance to the country in alternative socio-economic scenarios. In addition, the Project has the task of building up a consensus among major stakeholders concerning strategies for the total management of the materials cycle to facilitate optimum gain for the economy.

The materials chosen for a detailed study by the Project, on the basis of their importance to the economy at present, and in the near future, are:

- wood
- leather
- iron and steel
- aluminium
- ceramics
- light alloys
- polymers
- composites
- electronic materials
- coatings

The Project builds upon earlier specific studies and ongoing efforts in materials science, technology and industrial development.

As an inter-institutional effort involving industry, the Government and S&T institutions, the Project commenced its work in April 1990 and concluded its work in March 1992. Major funding came from the Steel Authority of India (SAIL), while the Technology Information and Forecasting Council (TIFAC), of the Department of Science & Technology, provided the administrative infrastructure and technical inputs through studies, surveys and extensive technical literature. The Confederation of Engineering Industry and the Defence Research & Development Organization also supported this effort. The Project was overseen by a Steering Committee consisting of eminent professionals.

2.1 Activities

Building the database

The Project undertook an extensive review of literature towards building up a database on key materials that have been identified, to include developments in technology, industry and applications in India and abroad. This was a significant contribution to the development of a Materials Information System in the country and is closely linked with the national interaction Technology Information System, called the TIFACLINE, developed by TIFAC.

Analysis

Detailed analysis and assessment of the following aspects of each material was carried out by the Project:

- Demand and supply;
- Materials intensity and the efficiency of economic activities;
- Management of the material cycle;
- Synergy between R&D, production and use;
- Interdependence (substitution, conservation, etc.);
- Technology development and diffusion;
- Comparative advantage and competitive positioning of India;
- Restructuring of institutions.

Studies/papers

The Project prepared studies, papers and reports on the basis of analytical work and participation in workshops, etc. and disseminated them widely among industry, Government and S&T institutions to elicit views on policy options presented by it. The Project's aim was to promote knowledge-based policy development and reform in the area of materials.

Workshops/seminars

The Project organized the following workshops:

(a) Materials policy issues;
(b) Management of high tech programmes;
(c) The future of iron and steel in the world of materials;
(d) Strategies for materials research;
(e) Strategies for leather;
(f) Strategies for wood;
(g) Strategies for aluminium;
(h) Development of standards for advanced materials: strategic issues.

Commissioned papers

Besides carrying out studies and preparing papers on its own, the Project also commissioned outside agencies and experts to undertake studies and prepare papers. Some of the topics on which papers have been commissioned were:

1. Strategies for packaging materials;
2. Strategies for copper;
3. Strategic alliances for development of materials.

International links

To keep abreast of world developments in the whole spectrum of materials, their technology and applications, the Project established contacts for the exchange of information with agencies in Japan, the United States, the United Kingdom, Germany and China, besides international organizations.

Related endeavours

The Project was also closely linked with other ongoing efforts related to materials, and participated actively in the conduct of research and seminars organized by other agencies in the field. Among such groups or activities were:

1. Technomarket and forecasting studies of TIFAC;
2. Science and Technology Advisory Committees of various ministries;
3. Policy Group on Wood Substitution of the Ministry of Environment and Forests;
4. Production of a series of 10 video films for educational broadcasting on the theme "Materials and Society" based on the Project's knowledge base, by the Mass Communications Research Centre, Jamia Millia Islamia, New Delhi.

2.2 A unique initiative

The National Materials Policy Project was a unique initiative in the area of policy development for key material resources anywhere in the world. The concept of a policy for materials being itself new, the demands of an exercise to formulate such a policy were onerous. The methodology of the Project was diverse and it sought to work with and through industry, S&T institutions and Government, to achieve synergy and cumulativeness. Despite several data and institutional limitations, this modest first attempt to build up a knowledge base and use it for policy development began to yield interesting results. While the dimensions of an overall materials policy are yet to emerge from the various efforts undertaken, many common policy questions relating to different materials have already been raised. These relate to substitution, interdependence, comparative advantage, technology development, inter-policy coordination, and India's possible global role in this area.

Since the Project began, the complex process of policy development has brought home some lessons, and crystallized some important aspects of the design and conduct of the exercise. The Project quickly accomplished to a good extent some of the objectives through building up a consensus about goals and strategies among key stakeholders of some materials, and also by producing diverse reports to elicit the views of Government, S&T institutions and industry which led to a clearer definition and formulation of policy options and strategies for the development, production and use of key materials in the years to come.

3. *Strategy formulation*

This part outlines some of the strategies that India should adopt in future to manage the materials cycle effectively. The strategies are based on the issues that emerged from the analyses of the major materials issues.

3.1 Raw materials

India has a large resource base for producing major economically important materials. Raw materials, in general, suffer from a poor quality and a lack of homogeneity. However, India does not have the adequate technology to pre-treat these raw materials on a large scale, so as to improve their quality. The efficient use of raw materials is also not widespread. Instead of stepping up value-added production, we tend to export some raw materials which are in excess supply, even if it is due to a low capacity utilization of production units. Issues related to raw materials availability and utilization specific to some key materials are discussed below.

An improvement in mining technology is necessary to produce more and better quality iron ores. There is a need to reduce the ash content in coal and iron ore. To improve the quality of steel, pre-treatment will have to be done more efficiently before raw materials are fed into the furnace. Stockpiling of raw materials will have to be minimized since it creates artificial shortages.

In the case of ceramics, India is yet to develop the use of advanced ceramics in many emerging areas. To achieve this, it is essential to identify the raw material potential. In the case of aluminium, there is a need to allow the import of coal tar pitch and CP coke to exploit the vast resources of bauxite (2,600 million tons). This, along with changes in the priorities of locational decisions, can make India strong in aluminium production.

Raw material availability for wood is crisis-ridden. A supply of wood from non-conventional sources is required. There is a need to enhance the supply of industrial wood from plantations and private farms and firewood from community and social forestry through biotechnology and improved tree farming. In addition, the wastage from logging needs to be reduced to improve effective yields.

In leather, there is a tremendous amount of loss caused by poor flaying, collection and transportation methods, which needs to be avoided. There is a need to develop and innovate technology to recover more leather from the available hides and skins to obtain a uniform quality.

In the case of polymers, there is a need to concentrate more on natural gas as a feedstock. India has a relatively better advantage there, since the other source, naphtha, is recovered from oil, a considerable amount of which is imported. This will help to avoid supply problems arising from fluctuations in the availability and price of oil in the international market.

For composites, many of the raw materials are not produced in India. It is necessary to estimate the requirements of various raw materials for the future to meet domestic demand. Natural fibres and fibres which are abundantly available in India will have to be promoted. While the import of technology to process these raw materials and to convert them in the required form is essential (e.g. carbon fibre as a reinforcement material is synthesized at IPCL through technology imported from the United Kingdom), there is a need to place an emphasis on the indigenous production of matrix resins in the future.

3.2 Demand and supply

Demand-supply disequilibrium (across space and time) is common in most materials in India.

Conventional planning techniques for meeting demand by increasing the supply have proved to be very costly for many materials. Hence, it is essential to direct demand in a desirable pattern. Therefore, the planning strategy called for both demand and supply management, so as to avoid any adverse impact on prices. This can be achieved only with the consensus of all stakeholders. Several policy options will have to be used to achieve this objective.

International substitution is a dynamic process, depending on comparative advantage (supply, cost, savings, performance, environment friendliness, etc.). "Penetration"—a measure of the relative share of various materials used (in terms of weights) in a particular application or industry—often describes the degree of substitution, or international competition. Substitution occurs slowly when applications demand unique or high performance.

Steel continues to play a dominant role in the transport sector. At the same time, aluminium, being a light metal, would help in weight reduction and is being increasingly used in this sector throughout the world (60 kg/vehicle in developed countries versus 20 kg by Maurti automobiles in India). Looking at these advantages, it is necessary to increase the use of aluminium in the transport sector. The involvement of vehicle manufacturers in achieving this is necessary. Norms can be developed after a detailed study. Similarly, inside vehicles, there is a need to reduce the use of steel and replace it with polymers.

The annual increment of wood is estimated to be 52 million m^3 (12 million m^3 of industrial wood and 40 million m^3 firewood against a demand of 263 million m^3 (27.58 million m^3 for industrial wood and 235 million m^3 for firewood). Looking at these supply constraints and the grave environmental consequences of extracting wood from forests, there is a need to conserve wood by using it more efficiently, both as a fuel and as a material (gross wastage at present is about 60 per cent) and to generate wood from non-forest sources. Substitutes like plastics and aluminium should be encouraged. The economic costs involved in substitution are high and therefore wood continues to have a comparative advantage in some applications. This calls for a need to improve the quality and properties of wood through technology.

Composites, though used in the defence sector at present, offer high-strength low-weight materials, ideal for the transport sector. They can substitute conventional materials, especially engine components and other parts which are subjected to high friction. Due to their light weight and high performance, they can replace steel bodies in automotive vehicles, leading to energy savings. The TIFAC study on Performance Materials identifies several important priority areas for action.

As far as steel is concerned, the dominant role it played in the development of core sectors will continue to remain the same. India has abundant raw material reserves. What is required is quality and value-added steel, besides an improvement in demand. This pattern is common throughout the world. In industrialized countries, steel even now plays a dominant role and the emphasis is to alter consumption by decreasing the material intensity with the help of high quality steel. India too has to aim in this direction. In the future, the supply-led demand pattern will change, in response to market forces.

In the case of leather, the estimated demand for finished leather (1,334 million $ft.^2$ in 1990) is far more than the availability (1,238 million $ft.^2$ in 1990) of finished leather. However, there is an immense potential of raw materials, which at present are underutilized. Therefore, the efficiency of recovery and provision of a better supply of quality leather has to be increased. More capacity has to be created in the leather processing industry to produce more finished leather.

In the case of polymers, the raw material constraint will continue to be important. However, the shortage can be reduced to a large extent by substituting gas for naphtha as the feed stock and by placing emphasis on the recycling of used polymer products.

Demand can be altered through price mechanisms. First of all, the price of all materials should reflect the real costs of production (including environmental costs). Certain hard wood species like teak and rosewood should cost more. Panel products like wood composites, flake board, etc., should be promoted. To encourage the use of aluminium in sectors like transport and electrical engineering, the prices of the types required for these end uses should become lower. Fiscal measures can help substituting leather products (especially footwear) by polymers in the domestic market so that enough surplus leather can be used for exporting value-added fashionable items to the international market. In a period of foreign resource crunch, this is relevant. Actual mechanisms to do this will have to be decided by the stakeholders. Prices, when they reflect market realities, will ensure the efficient use of materials. Subsidies or reliefs should be targeted, explicit and only for a short time.

The choice of material by users is often governed by current cost considerations. A life cycle costing approach looks at costs all along the materials cycle and will result in a more efficient material choice.

A look at supply strategies is now required. In the case of wood, conventional sources of timber cannot be relied upon. Hence end-users of wood should be encouraged to generate their requirements from industrial plantations and community or social forestry. Technology can assist in improving the performance of low-grade wood, cellulosic and agricultural material and hence supply. In the case of ceramics, a programme for the development of raw materials for advanced ceramics, would be required.

At the production level, changes are required in the quality of steel, quality of leather, quality of polymers and energy efficiency in the production of aluminium. The promotion of demonstration production facilities for advanced ceramics, engineering plastics and composites, wood-based panel products, etc., are also needed.

Two major materials that will have to be conserved are steel and wood. It is imperative that the use of steel in the transport sector is reduced by substituting aluminium and plastics for steel. In other sectors the material intensity of steel will have to be reduced by using high performance steel and its alloys. A similar strategy is applicable for wood where there is a need to reduce the material intensity in general, and particularly in buildings and construction. Substitutes are required for plastics or non-petroleum-based raw materials for plastics as oil resources will be depleted in the next few decades.

To reduce the pressure on raw materials and to maintain the quality of the environment, it is essential to promote the recycling of materials, wherever possible. The recycling of materials is less energy-intensive. Looking at the pattern of consumption in India, aluminium, polymers and steel provide immense potential for recycling. This can be accomplished through changes in collection practices for discarded materials. Recycling can increase supply in an energy-efficient way; the recent growth of secondary steel and secondary aluminium industries bears out the economics of this.

No change in the demand or supply structure can be done overnight. There will be a gestation period which is bound to be long, since the existing pattern has evolved over a long period of time. There will be transitional problems which can only be taken care of with the co-operation of all the interested parties. The strategy should be to address, in a coordinated way, all the activities of the management of the materials cycle. The problems at the raw material stage are acute for leather and steel. In leather and steel India needs a greater recovery rate. Iron ore and coal in India contain impurities which are higner than the norms elsewhere. Hence, treatment to eliminate the impurities before they are processed is required. This is crucial if India is to be competitive in producing high quality steel.

3.3 Technology development

Looking at the status of technology internationally, Indian technology to produce materials lags behind considerably. At the same time the Indian capability to develop technology (e.g. infrastructural facilities) seems to be adequate. However, these capabilities are not being fully used. The major problem seems to be the inability to assimilate imported technologies and an inhibition to get out of the "import syndrome". This is reflected in the case of many materials. Most of the technologies developed at the laboratory-level remain there without being transferred to industry. Thus, India is not able to obtain the full benefit of its capabilities and is therefore less competitive in the domestic and international markets.

Technology development for the better utilization of wood is mainly in sawmilling techniques and technology to produce wood composites and panel products. To suit Indian conditions, technology innovations are required to peel small girth, fast growing plantation species. There is a need to develop and improve tools and implements, as well as their maintenance, to achieve a higher quality and less wastage. Similarly, there is a need to develop more efficient firewood burning cooking stoves (efficiency at present is only 10 per cent).

Technological development and the adaptation of modern techniques for processing remain low in the leather industry, partly because of the industrial structure. There is a need to import technology to improve the quality of processed materials, and to make the necessary modifications to suit Indian conditions. This would help to produce more value-added, fashionable, quality products with a high export potential. CAD-CAM technology innovations in the leather product industry, especially for export-oriented large firms, should be encouraged.

For the iron and steel sectors, a long-term strategy seems to be of the utmost necessity, to restructure the plants and to develop more advanced technology for processes and value-added products. The recently completed TIFAC studies on Modernization of Steel Industry provide valuable guidance in this regard. The Steel Authority of India Ltd. has also prepared a long-term corporate plan (including a technology plan). Technology is required mainly for the production of high-quality steel and alloys by integrated and secondary steel processing plants, pre-treatment of raw materials, automation, modelling of processes to avoid wastage and new processes such as continuous casting, ladle refining, electromagnetic separation, etc. At present, mini steel plants in India lack alternative technologies to produce high quality, value-added special steels. They need substantial technological upgrading before they can achieve this objective.

There is a need to immediately increase the capacity to produce more aluminium. Instead of relying on freshly imported technology, India should assimilate the technology that has already been imported and develop its own capabilities to design and construct plants independently. Power consumption to produce aluminium should be reduced to a stage comparable to MALCO's. The technology needed to reduce the import of aluminium foil should be developed. India also needs to work on aluminium alloys and other value-added products.

Although some new plants with modern technologies have come to the ceramics market, lower productivity, outdated and highly labour-intensive technologies are the main obstacles to increasing the production of ceramics. Therefore, there is an urgent need to improve design engineering to strengthen machine-building capabilities. Quality control and better testing facilities for the major raw materials suppliers should be given due importance. The outstanding work of the Centre for Materials for Electronics Technology (C-MET) in collaboration with industry needs a special mention here. However, research and development on advanced ceramics should be diverse enough to concentrate not only on electronic use, but also on structural ones.

The Indian Institute of Management-Indian Petrochemical Corporation Ltd. study on "Technology planning for petrochemicals", identifie priority areas and strategies (R&D, import and investment) for petrochemical technology development. In polymers, there are quite a few plants operating in the country, using imported technology. These imported technologies must be assimilated and improved and at the same time indigenous technologies should be developed. There is a need for technology development to carry out process design and engineering commodity plastics. An endeavour should be made in technology development of engineering plastics and polymer blends and alloys. The recycling of polymers in a safe and environmentally benign way is also another priority area.

The production of commercial composites in India is restricted to small units, and the technology adopted is quite conventional. The level of technology here should be improved. Resin transfer moulding and reinforced reaction injection moulding needs to be introduced in composite processing units. Pultrusion technology should be developed to produce sports goods. The recently initiated collaborative arrangement between TIFAC and the Research Centre Imarat, Hyderabad, for the development and production of a variety of composites, along with the participation of industry, is a major organizational innovation and is potentially promising. The space research and defence research programmes have advanced capabilities in composites design and production, which need to be adopted and transferred to industry.

3.4 Human resources development

Basic formal training capabilities in material science and technology in India seem to be adequate. More specialized, long duration courses in some of the specific materials will lead to more unemployment. At the same time, specific short duration courses for each of the materials are required. This should be done carefully by identifying the needs. At the present time academic institutions are not exactly catering to the needs of industry. A proper understanding of these needs and the reorientation of courses offered at academic institutions has been identified as one of the important policies for any country to be competitive (Zwilsky, 1987).

In the case of aluminium, at present there is some duplication of efforts since the training programmes are undertaken by producers.

In India, the training facilities for forest management seem to be inadequate. There is a need to start academic and continuing education programmes to develop manpower in the field of wood science and technology. There is also a need for specialized training programmes for various industries which should be done by industry associations or within firms.

For the leather industry, training would be necessary to create the skilled manpower to design and produce fashionable leather products. Here emphasis should be on the automation of processes and quality control. The skilled manpower required for computer aided design and manufacturing (CAD-CAM) will have to be developed. Moreover, there is a need to go in for upgrading through on-the-job training and short courses for skilled workers.

In the polymer and composite industries, some training is being done in-house by industry. However, this training is inadequate. India needs to increase its continuing education programmes and training within industry to upgrade the manpower, as human resources are crucial to the development of this industry. Many of the research and development personnel are not adequately informed of the latest developments. This calls for more continuing education and information services (Sivaram, 1991).

3.5 Trade

It is essential to export materials in which a comparative advantage exists. While formulating export strategies, it is essential to keep in mind the "sustainability" question. Exporting materials which are only temporarily in excess supply will not help in obtaining a long-term committed market. A long-term perspective is essential.

In the case of aluminium, exports for a longer duration can be done only at the cost of domestic demand, unless the supply increases. Hence, the decision to export should be taken carefully. In policy formulation, more thrust should be given to the export of more value-added items.

Materials in which we have some comparative advantage are aluminium and leather. Their quality will have to be improved to a level for the more value-added fashionable leather products which are acceptable on the international market. This has already been achieved in the aluminium field. What is now needed is additional production of the same quality aluminium, using cheaper power and value-added products.

Over the last three decades, an extremely haphazard and patchy scenario has existed in the export of iron and steel, because of uncompetitive prices and quality. The slump in world steel trade in recent years has also adversely affected the prospects. As a result, the possibility of exporting iron and steel in large quantities is remote in the near future.

The export of polymers should be confined to high value-added products. Markets for these will have to be carefully developed, since world-wide polymer uses are being restricted due to a shortage of raw materials and the biodegradability problem.

Ceramics offer a good potential for export, if the cost of production can be reduced through more capacity utilization. In developed countries, due to high and rising labour costs, conventional ceramics are becoming more expensive and the prospect of increasing exports appears to be favourable.

3.6 Industrial structure

The structure of a particular industry plays a crucial role in determining the performance of that industry. This can also determine the ability to innovate, adopt high technology and modernize different processes. In India, the structure of industry across and within materials shows a large variation.

In the case of the aluminium industry, it is presently oligopolistic in nature. Export is done by NALCO. Looking at the pattern of growth of demand and supply, it is clear that an additional capacity needs to be installed and more emphasis should be given to a higher capacity utilization. Private sector investment towards this is required in order to increase competition.

The case with steel is slightly different. Large-scale units still dominate production and the share of the public sector is very high. Mini steel plants elsewhere cater to high quality special steel, but in India the quality of steel produced by them is not very good. A quality improvement in this sector is required. Simultaneous to the modernization and expansion plans of the existing large-scale units, it is necessary to promote mini steel plants which can produce high quality steel. This is important since the gestation period of such units is low. Because of the comparative advantages of such plants, which enable them to locate in different parts of the country, the establishment of these plants will ensure the easy availability of steel. Secondary steel units within this sector need to be encouraged.

As far as wood is concerned, a major change in the industrial structure is required. It is necessary to organize the small-scale and unorganized sector units into co-operatives, so as to enable them to use efficient technology and mechanization to reduce wastage. The same is applicable to the leather industry (collection and tanning). Cooperatives can be easily formed since most of these units are concentrated in a few areas.

The polymer industry in India is relatively new and technology changes rapidly in this field. While bulk polymers are produced by large-scale units, the production of polymer durables through processes such as extruding, moulding and forming are undertaken by small-scale units. Hence, in the end-use industry, technological innovation is limited and diffused. The organization of these small-scale units into cooperatives for the promotion and adoption of quality technology is thus needed. Since the small-scale sector is labour-intensive, they should be assisted to enable them to become more viable and competitive. Such a strategy will also promote entrepreneurship within the country.

The composites industry presently consists of specialized small units, apart from large-scale absorption and defence programmes. Glass and fibre reinforced plastics are important areas of growth.

3.7 Financing

Financing is an important factor for the development of materials-based industries. The requirements and types of finance differ from one material to another. Financing in India generally takes place from one of the following sources: budgetary support, financial institutions and internal sources. Of the corporate sources, equity, risk venture capital, long-term and short- or medium-run loans are the major sources of finance. While systematic financial planning (sources, types, uses, incentives, regulations, etc.) has not been attempted for all material cycle activities, important trends are evident and discussed below.

In the world-wide mining industry, the major source of financing since World War II has shifted from equity investment to debt financing. In India, there are two major trends:

(a) After independence, almost all essential mining has only been undertaken by the Government, with proportionately less debt;

(b) As large-scale mining has started growing, mining and processing have become capital-intensive.

Over the last two decades, new, advanced materials have been developed which require a higher initial capital outlay for research and development. As we have seen, for major materials, research and development takes place in government laboratories and academic institutions. Budgetary support, and to some extent internal sources (surplus, etc.), have remained the major sources of material financing. Industry, both public and private, invest relatively less on research and development, due to a lack of competition and innovative tradition and protectionism. However, banks and other major financial institutions (mostly under the direct control of the Government), provide financial assistance for investment in plant and machinery as well as working capital. In the last few years, few venture capital firms have come into existence which finance the development, engineering and commercialization of new improved technologies.

It is clear that forests cannot sustain the supply of wood which is required in India. Wastelands can be utilized to grow trees. However, private agencies and individuals are not willing to invest in developing wastelands. Hence, Government initiatives and incentives to improve production and to develop wood utilization technology are required. Similarly, a new initiative to invest in research and development to develop substitutes for wood is also necessary.

Financing is an important instrument for the development of the leather industry, which is dominated by small firms. One of the major problems of the leather processing industry is its environmental pollution. However, for small firms, it is difficult to invest in pollution control due to a lack of finance. The product industry, on the other hand, is not able to be internationally competitive mainly because of poor design and inadequate automation (CAD/CAM technology). Financing should play a major role in this respect, especially for products which have large international demand (i.e. leather fashion goods, leather garments, etc.).

In the case of aluminium, investment is required in setting up new plants. Similarly, plants to produce secondary aluminium are also required. Investment for such production should come primarily from private sectors. More use of aluminium in the transport sector is required. Research and development activities to identify end uses in this sector using aluminium will have to be undertaken. Incentives and venture capital for promoting new aluminium-based technologies are necessary.

In the case of polymers, investment is required to set up natural gas-based cracker plants and to expand the capacity of existing naphtha crackers. The private sector should consider making investment in the various downstream projects which are to be implemented in the near future. Financing is important for development of the technology required for small-scale processing units. Investment to set up recycling plants is also necessary.

A similar trend is seen in the ceramics industry, especially for conventional ceramics. The productivity of this industry (especially in crockery, sanitary-ware, glazed tiles) is very low. This calls for the modernization of small firms. Better financing facilities would be required to meet the high initial investment needs for this. For advanced ceramics, which do not have any immediate market, the industrial houses in related business should initiate in-house development and engineering to produce export-oriented goods. However, without the commercialization of government technologies, it is very unlikely that private firms will promote research and development in an appropriate manner unless suitable financing facilities are available. The absence of competition also inhibits innovations by firms.

3.8 Institutional structure

Although in India a hierarchial pattern is observed in the institutional structure in relation to material development, with the Government holding the apex position in most cases, the linkages between different institutions in the overall materials cycle is problematic. For the effective utilization of the resources available there is a need to improve the linkages in the existing institutional structure. The changes required are mainly the reorientation of existing institutions, and in some cases the creation of new organizations or agencies. Our analysis also shows that a major flaw in the existing structure is a very weak sharing of information and knowledge. This has been observed in the case of all materials.

Research and development efforts from various centres in the country have to be coordinated, in the case of aluminium, with an identification of the priority areas. In the application of aluminium in the transport sector, alloys have to be developed, with the coordination of research and development agencies, with the Defence Research and Development Organization and with vehicle manufacturers. Coordination is also needed in training. The Aluminium Development and Promotion Council and/or the Aluminium Association of India can undertake this coordinating role. Similarly, this Council should establish an information centre.

In the case of wood, product development, manpower development and product utilization take place in a fragmented manner under the present structure. Research and development and technology development should be coordinated between government institutions such as IWST, IPIRI, industry and academic organizations. A National Wood Information Centre, to develop and provide data relating to the wood industry on an on-line basis, is needed.

This will have to be done on coordination with all interested parties. Training facilities for human resources development should be established in consultation with industrial associations.

In the light of the new industrial policy, it is essential to reorganize the existing structure for the iron and steel industry. Some of the existing organizations could be wound up, or merged with other organizations. Research and development activities are undertaken by SAIL and TISCO. Considering the role mini steel plants can play, it is vital to involve them, through a nodal agency, to facilitate the smooth transfer of technology from research and development laboratories to industry. Besides internal diffusion mechanisms, there is also a need for an information centre, for external dissemination. It would be better to set up such a centre within an industrial association, with the involvement of all stakeholders.

In leather, small-scale units do not have access to information regarding technology or market trends, etc. Organizing them into cooperatives and the involvement of different cooperatives in research and development activities are necessary to create a linkage between them. Information regarding technology, environmental degradation and remedies, the mechanization of processes, the importance of quality assurance, market trends, etc., should be shared by all producers.

In the case of ceramics the same trend is observed. At the present time conventional ceramics are mostly manufactured by small-scale units, but advanced ceramics are produced by government organizations for specific applications. The identification of the sectoral potential to use advanced ceramics and the involvement of industries in these sectors for research and development and technology transfer are, therefore, called for.

Presently, the polymer technology in the country's enterprises is largely imported. Research at academic and research and development institutions is largely unrelated to industrial production. The promotion of more collaboration between industry and research/academic institutions as well as the promotion of application-oriented research in industry itself is needed. The creation of an awareness of choices among users and coordination of various research and development application efforts is urgently needed.

3.9 Energy and environment

The production of materials, especially metals, consumes large quantities of energy of various forms. In India, where energy is in short supply, it is vital to decrease energy consumption in the production of materials. It is essential to ensure an uninterrupted supply of power to materials production, as erratic supply results in a loss of production and large-scale waste, arising out of loss of heat and other associated problems. Loss, due to power shortage, which is one major reason for low capacity utilization, has to be avoided. For the manufacturing of advanced materials and structures, the cost of energy is generally 1-2 per cent of the cost of the finished product. Moreover, the energy cost savings obtained over the service life of the product is a major potential advantage in using these new materials.

Energy-efficient technology for aluminium production and changes in location decisions is required. Since power constitutes 40 per cent of the input costs, consideration should be given to setting up aluminium plants in States where hydro-electric power is abundantly available (e.g., north-east). A similar strategy is relevant to the ceramic industry, which is energy-intensive. However, a shift of location is not easy, as the conventional ceramics industry is dominated by small firms which are spatially dispersed. Similarly, changing location is not feasible for steel, as raw materials constitute a major element in the inputs (in terms of quantity). What is required is a power-efficient technology.

Environmental problems associated with materials production have to be taken care of by reducing harmful effects on animal and plant life. The degree of environmental effects created varies with each material. In the case of aluminium, two major problems to be tackled are fluoride emissions and the reclamation of disposal grounds. Strict control on filtration to check fluoride emissions is required. To reclaim the land used for the disposal of red mud, it is essential to identify species which can grow on this ground. HINDALCO is already making efforts towards this; it should be extended to other manufacturers. Red mud contains many valuable materials like vanadium, gallium, titanium and aluminium. Hence, it is essential to convert this red mud into a valuable resource base by recovering these materials.

The leather industry (especially the processing industry) is a highly polluting industry and the harmful effects are quite serious. It would be necessary to encourage the small-scale units to adopt modern treatment technologies. One pilot project in Tamil Nadu (under the aegis of the Central Leather Research Institute) is providing positive results. Since the scale of operation is not sufficient to adopt these measures throughout the industry, changes in the industrial structure to have common facilities, establish cooperatives, etc., are needed.

In the case of the iron and steel industry, the pollution created at various stages is quite high, owing to the sheer volume of activities. It offers a good recycling potential. Presently in India the recyling rate is very low, compared to international practice. The import of technology and investment in recycling is required. For the ceramics industry, dust created at the processing stage is harmful for the workers. There is a need to take care of this problem.

For polymers, air pollution control through atomizer, furnace and burner design can be adopted. Water treatment through biological and chemical treatment is necessary. Such treatments will have to be made mandatory. Most of the polymers are recyclable. Better incentives to recycle used materials are required to tackle the problem at the disposal stage.

3.10 Industrial policy

Industrial policies determine the performance of industries in general. This is also applicable in the case of materials. Industrial policy determines foreign investment, export/import, productivity, innovation, etc. While an open-door policy, facilitating foreign investment with an objective to increase competition, is a good sign, it has other implications. Domestic producers may not be able to cope with the competition and may be completely excluded from the market. This is obviously not desirable. Hence, such an attempt should be on a selective and gradual basis. Policies should be formulated for managing a transitional phase. Such a role, by Government intervention, should be multidimensional so that industry can become competitive and innovative. Market forces should be given enough freedom to direct the trends. At the same time, Government intervention is needed to orchestrate these trends from a materials perspective.

Some of the strategies that should be adopted in modifying the industrial policy with respect to materials are outlined below.

With regard to aluminium, the present open-door policy will not affect Indian technology since India still operates mainly with foreign technology. What is required are the necessary conditions in the terms of agreement which facilitate the horizontal transfer of production technology within the country. Simultaneously, India should develop its capability to design and construct new plants independently. This is relevant to application-oriented technology too; Indian technology for alloys is adequate. At the same time, technology to produce foils required for the electronics industry remains inadequate. Hence, selective participation of foreign collaboration is called for.

In the case of wood, the import of technology to produce wood composites and other wood panel products is necessary. This technology should be modified to suit the Indian industrial structure. A similar approach is required for the leather industry, where the emphasis should be placed on the mechanization of processing and the improvement of the quality of products produced by small- and medium-scale units.

For polymers, the present policy of increasing naphtha-based ethylene production is not desirable. Adequate incentives should be given to industry to set up plants to product gas-based bulk polymers.

The indiscriminate export of all raw materials will have to be curtailed, since such a policy will deplete the resources available at a fast rate. Incentives should be given to produce value-added items. The export of bauxite, alumina and iron ore will have to be curtailed. Similarly, the export of raw leather should not be encouraged. Incentives in the form of tax benefits should be applicable to all value-added items. To increase domestic competition, the import of technology should be allowed, but the import of materials (except special category materials required for strategic purposes) should not be encouraged.

To alter the industrial structure, incentives of various kinds should be given. For example, in the case of materials where cooperatives are called for, incentives should be applicable only to enable them to achieve results at a faster rate. Disincentives are necessary to curtail the use of certain materials as discussed in the section on demand and supply in this chapter. However, extensive subsidies or prolonged protection will be counter-productive. This needs to be done on a selective basis.

In the case of advanced materials, which are engineered to perform better, the technology requirements are either imported or developed by high technology sectors like defence and aerospace. The international trade of these materials is vital so as to make use of the comparative advantages of other countries. This calls for an over-emphasis on the standardization of these materials. Standardization can lead to a wider application as the properties of the materials will be well known. Linkages with research and development centres in this effort are vital to avoid a lack of innovation due to unacceptable standards. Certification to internationally acceptable standards, such as ISO 9000, is desirable since they are quality standards, not product standards.

4. Action plan

In this part, an action plan for implementation of the strategies is outlined. These are specific plans for implementation by the year 2000, to reach the policy goals discussed earlier.

Wood

Technology development should be aimed at increasing the efficiency of sawmilling equipment, logging and extraction of wood, flake boards, oriented standard board and mineral bonded products to produce wood composites, panel products like particle or fibre boards, based on the short rotation plantation wood of fast-growing species and agricultural and wood residues. To suit the Indian industrial structure, machines should be designed for small-capacity plants of 25-30 m^3 per day. Equipment for the maintenance of tools also needs to be developed.

Changes in industrial structure, with manufacturers generating their supply of wood from industrial plantations and wastelands and organizing small-scale producers and processing units into cooperatives, are required.

The tax structure should be such that the price of wood reflects the true costs, e.g. higher taxes for rare species like teak and rosewood, and lower taxes for wood from fast-growing species. Fiscal incentives to farm-forestry through firms or cooperatives to cultivate fast-growing species on wastelands should be given.

Amendment to the Forest Policy of 1988 to enable the removal of dead trees from forests, protection of some forest areas as reserved (for biodiversity) and the exploitation of forests in an environmentally benign way is required. Use of wood in buildings above specified norms should be penalized. Only preserved and treated wood should be allowed for use.

Institutional changes needed are research and development coordination through a proposed Wood Development Council and a Wood Information Centre to collect, collate, analyse and disseminate information regarding the wood industry on an on-line basis.

Human Resources Development—in the wood sector this needs to be in terms of specialized training programmes for various industries, to be carried out by industrial associations, or within firms or academic organizations.

Studies are required to understand the exact sector-wise end-use demand pattern and supply changes. These will facilitate both demand management and supply augmentation. Wood as a material cannot be considered separately from wood as a fuel. Hence the need exists for an integrated approach.

Leather

There is a need to establish "district carcass centres" as producer cooperative ventures to collect raw hides and skins in an efficient manner. This is expected to reduce the loss incurred in the collection and transport of raw materials to tanneries (200 million sq.ft. of finished leather in 1986).

As the auxiliary and leather machinery industry is not well developed, more encouragement is needed through awareness-creation and financing. The role of Government should only be promotional.

To substitute leather by polymer items in the domestic leather footwear market, the high import and excise duty on polypropylene should be reduced. This would help to generate surplus finished leather which can be used for making exportable value-added items.

There is a need to provide incentives to promote mechanization in the leather tanning industry with a capacity to process hides and skins up to the finished leather stage. Standardization of finished leather should be ensured (perhaps through the Bureau of Indian Standards). Preferably, these initiatives should be started in Tamil Nadu, West Bengal and Uttar Pradesh, where 88.4 per cent (in 1989) of the tanneries are concentrated.

Relocation of tanneries in some particular areas, away from towns, can be undertaken as a long-term action plan. This helps the firms to establish "pollution removal and waste disposal plants" on a cooperative basis.

Some firms may be given licences to import CAD/CAM technology and they are to be assigned a 100 per cent export obligation for their products.

There should be encouragement for the dissemination of new technology from the research institutions (CLRI) to small firms, so that the commercialization of indigenous technology and innovation can take place.

More formal and continuing education courses on leather technology are required in the near future. Presently, there are only two institutes offering undergraduate courses. Academic institutions, like IITs and universities, as well as industry and user institutions, should take the initiative. The need for a diploma or certificate programme by polytechnics and trade schools can hardly be overemphasized.

Iron and steel

Technology development is needed for an improvement in the quality of iron and steel, production of special quality steels and value-added products, pre-treatment of raw materials, automation, energy conservation, new processes like continuous casting, ladle refining, electromagnetic separation, etc., waste recovery and pollution abatement, modelling of processes, etc. Technologies like ladle refining and electromagnetic separation can be imported and adopted. As the steel industry is a large industry, cooperative and partnership arrangements among research and development, educational and industrial enterprises is needed. If in industry, users undertake the funding of research and development, the relevance and utilization of research will considerably improve.

The price of steel in the domestic market should be decontrolled to encourage competition, innovation and remove entry barriers.

Formation of a mechanism to facilitate the transfer of technology from research and development laboratories to industry is required. The flow of information should also be smooth, which in turn calls for an information centre, comprising members from industry, government and research/academic institutions. This is in addition to the internal information dissemination efforts in legal firms such as SAIL.

Aluminium

Technology development should be focused on the following areas: the production of aluminium foils, alloys required for the transport sector through rapid solidification and powder metallurgy, using efficient energy, tools to evaluate the texture of alloys, the assimilation of imported production technology, the development of design and engineering capabilities for new plants and the recovery of gallium, vanadium, titanium, etc., from red mud.

Investment incentives are needed for new plants to increase the production capacity, research and development to develop alloys for the transport sector and the production of secondary aluminium.

Import/export policy should be flexible to protect domestic industry, keeping in mind global price trends, quality and supply.

Human resource development is required for the automation of various activities and computerized control systems. Programmes of short duration are required. An Aluminium Promotion Council can set up an Aluminium Information Centre.

Location decisions for new plants should be based on their availability and cost of power. Locations such as the north-east will have to be considered due to the potential hydro-electric power. Transport of bauxite will be cheaper than the transportation of power.

Polymers

Technology development to produce ethylene from natural gas, and to assimilate imported technology for the production of polymer blends, alloys and composites, is needed. To conserve energy, techniques to produce different grades of polymer in the same reactor will have to be developed. Development of three-phase fluid bed polymerization for polyethylene, slurry process for production of polypropylene/LLDPE and bulk polymerization for PVC are vitally needed.

Changes in the institutional structure should be made in order to create mechanisms for the coordination of research and development at different centres like NCL, IPCL, NICT, industry, research and development laboratories, etc.

Training programmes for the computer control of various activities is also required. These could be undertaken by industry associations, or within firms themselves.

Export policy should permit only value-added items such as specialized and engineering plastic products to be exported.

Market development for new applications in transport, machine building and construction should be undertaken by industry.

Ceramics

There is an urgent need to estimate the potential of raw materials required for advanced ceramics. This should be done by taking into consideration the potential demand for advanced ceramics in various sectors like transport, electronics and aerospace.

As the production of conventional ceramics shifts to the developing countries (because of the high standard of living and hence the high cost of production in developed countries), India should import the required technology, especially in the areas of tiles and insulators.

There is a need for the creation of a Ceramics Development Council with the following functions:

(a) To identify promising technologies and their applications for dissemination;
(b) To plan for the commercialization of the technologies identified;
(c) To provide finances for these projects;
(d) To identify groups to implement such projects;
(e) To monitor progress and coordinate the related activities of each project.

A ceramics technology centre can be established for the compilation and maintenance of a database, which is widely and easily accessible, establishment of standards of performance, testing and composition of ceramics, etc.

More thrust should be given to structural ceramics in the short term, especially in areas of thread guides, seals and nozzles, etc. These products have a good export potential in the near future. Optical communication fibres, high purity silica by the sol-gel process, zirconia and ultra-fine active powders for precursers, zirconia nozzles for continuous casting of steel are other priority areas for technology development. Research and development laboratories, institutes and universities should be guided to facilitate work in these areas.

Composites

There is a need to identify, sector-wise, the potential demand for composites and their scope in substituting other materials. Also, an application and market development programme in association with users should be launched by the industry.

Technology development is required in the areas of the production of epoxy and polyimides bismaleimide resins. Long-term production of carbon fibre should be assured. Resin transfer moulding for better quality composites needs to be imported and developed.

Research and development activities, in coordination with the defence sector and automotive manufacturers, to develop application-oriented technology products are needed.

Emphasis should be placed on the export of composite sports goods and aircraft sub-assemblies based on pultrusion technologies. This could be both in the private and public sectors, or as joint ventures together with foreign partners.

Manpower development is required at different levels such as design, plant engineering, processing and operational problem-solving.

6. Conclusion

The analysis of various materials indicates that India can have a fast-growing, viable, materials technology-based industrial development. This report outlines the interim findings of the project and the emerging strategic options. It is clear that multi-level strategic intervention is needed in order to achieve this objective. This ought to be an orchestrated effort in which government, industry and scientific and technological institutions come together with shared goals, complementary programmes and collaboration.

The National Materials Policy Project will articulate more specific strategies based on research findings and ongoing analyses. International dimensions, technology strategies, intersectoral linkages and structural changes will form a part of the final recommendations. The future of materials, it is clear, will be very different from the past. How we perceive it and formulate strategies to respond to the changing world of materials in a global economy is a challenge this project seeks to address. Readers are invited to send their comments and reactions.

C. TESTING AND EVALUATION OF MATERIALS:
INDIAN EXPERIENCE

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Abstract

Research and development in the area of materials science is being pursued in a variety of institutions all over the country. These R&D groups are part of national laboratories, Indian Institutes of Technology, Indian Institute of Science, Tata Institute for Fundamental Research and Universities. In the industrial sector, the activities confined to a limited number of materials. Both for understanding of the behaviour of materials on a fundamental level as well as for control of properties so that these can be employed in different devices, a strict control is required over basic materials characteristics and properties. There is considerable infrastructure in the country for characterization of materials regarding all aspects, namely: composition, purity, crystallographic structure and lattice imperfections. Also, a number of properties can be measured at a high level of accuracy. Centralized facilities are available to common users in: 19 R&D laboratories of the Council of Scientific and Industrial Research; 7 Regional Sophisticated Instrumentation Centres and 6 special Centres of the Department of Science and Technology; about 20 University Science Instrumentation Centres of the University Grants commission and a few industrial laboratories. At the author's laboratory, a comprehensive Centre for Characterization of Materials has been established. This centre provides facilities for characterization of advanced materials regarding all aspects. In addition to the commercially available facilities, a series of multicrystal X-ray diffractometers including a Five-crystal X-ray Diffractometer have been developed in the laboratory. These facilities are available not only to scientists in India but also to foreign users. In the recent past, guest scientists from USA, Germany and Russia have come to work in the group. The NPL infrastructure for material characterization is being used to prepare Indian Reference Materials to ensure quality of measurements in testing laboratories all over the country. For quality enhancement of Indian industrial products, the Department of Science and Technology is running a programme: National Coordination for Testing and Calibration Facilities. More than 90 test laboratories have been accredited.

While supporting the idea of setting up an International Centre for Materials Evaluation Technology, it is proposed that regional collaboration and resource sharing may be encouraged. Also, attempts may be made to ensure compatibility in the measurements made in the region.

I. Introduction

In modern industrialized societies, huge quantities of a wide variety of materials are used in innumerable devices, equipment and machinery. Indeed, one can say that the state of the development of a nation can well be judged by the number, quantity and quality of materials that are being produced and used by it. The materials required are very diverse in nature ranging from gases, liquid chemicals, polymers, ceramics, metals/alloys and amorphous materials to nearly perfect single crystals. For advanced applications, these materials have to conform to very strict specifications in terms of their physical and chemical properties. The stringency in specifications increases with the level of sophistication of a particular application. The methods of production have to ensure that these materials have the desired properties even when produced on a very large scale. Further, in any one sector of science and technology, materials of widely different types and properties are utilized. In the microelectronics industry, for example, one requires metals and alloys, a variety of ceramics, different types of polymers, thin dielectrics, passivating oxides and a number of ultra-pure gases and chemicals, besides the basic single crystals of semiconductors. To ensure that the materials conform to pre-decided specifications one requires the infrastructure to measure a number of properties. These measurements must yield numbers which must be compatible with the results of measurements made at different locations within a country or across national borders. To ensure the traceability of measurements to the national level, one has to take recourse to using Certified Reference Materials. To ensure international compatibility at the bilateral and multilateral level, intercomparisons need to be carried out periodically.

For the utilization of materials in advanced devices, it is necessary to have a basic understanding of the parameters which control their properties. Also, for fundamental understanding of materials and their properties, it is necessary to know why different materials behave in their characteristic way and what are the basic variables which control the properties of materials. Therefore, for applications of materials as well as for their understanding, one requires measurements at two levels. The first level is user-oriented and is concerned with the measurement of essential properties and parameters. The next level of the evaluation of materials is concerned with the determination of materials characteristics which influence the properties of materials.

In the present paper we shall consider first the basic concepts and then the Indian experience in this area. Some suggestions resulting from the personal experience of the author are also presented.

II. Basic considerations

The scientific experience of the past hundred years or so has established that the properties of materials are controlled by the following four basic characteristics:

(i) Composition;
(ii) Purity;
(iii) Crystallographic structure; and
(iv) Perfection of structure at atomic level or crystal defects.

The first two characteristics are concerned with the determination of the major and minor constituents of a material. These characteristics are common to all materials, be they solids, liquids or gases. The third characteristic defines the spatial location of constituent atoms, ions or molecules of a solid material. In any real crystalline material, the atomic arrangement broadly remains the same in all regions of a material, yet it varies from region to region in detail. In some parts, the normal periodic arrangement totally breaks down. These regions are known as crystal defects or lattice imperfections. One can see that the last two characteristics define the spatial locations of constituent atoms, ions or molecules of a material. For the complete characterization of materials, it is necessary to have information on all the four basic characteristics listed above.

From the foregoing, one would conclude that a complete characterization of a material would require the identification of all its constituent atoms, the determination of their quantities and spatial locations at the atomic level. Such complete information is not feasible experimentally. In real life, one has to be content with modest goals, which are limited to only those essential parameters which control the desired properties, or a process for the preparation of materials, or for the application of a given material. The generally accepted definition of the Characterization of Materials is [1-3]:

Characterization describes those features of composition and structure (including defects) of a material that are significant for a particular preparation, study of properties and/or suffice for the reproduction of the material.

For the determination of material characteristics, one has to keep in mind that the techniques to be employed should be as far as possible specific. There is a tendency to measure the properties of materials to "characterize". For examples, in semiconducting materials one is deeply concerned with electrical resistivity and the mobility of minority carriers if microelectronic devices are to be fabricated. These properties are crucial for device fabrication purposes but these do not "characterize" these materials. The properties are essentially controlled by traces of impurities and the presence of defects. To keep control of these properties, one has to keep a track of the material characteristics.

There are a large number of properties of materials, one or more of which are very crucial for a given application of a material. For example, materials to be used for magnetic recording or other magnetic applications would need to have a desired level of magnetic properties. Similarly, thermal, optical, mechanical, electrical, electronic, and other properties are of interest in different applications of materials. It is not possible to have one comprehensive centre which can adequately measure all possible properties of materials. One has to limit one's goals to specific properties and materials which are necessary for that application. In each of these measurements, it is necessary to ensure that the level of accuracy and precision is adequate to meet the required specifications. Also, the measurements should be cost-effective, in terms of time and money. Measurements should be traceable to national standards and be compatible with international measurement practices.

III. Basic infrastructure

As mentioned above the basic infrastructure required for the measurement of the properties of materials will essentially depend on the materials under consideration. Optical materials need to be characterized for optical properties, electronics materials would require that electronic properties are measured in detail. Therefore, this type of infrastructure is best utilized in the research group concerned with either the preparation or application of a given material. There are exceptional situations when detailed studies of some of the properties are necessary, and an extensive infrastructure is required. One such example is the measurement of the fatigue of metals and alloys, or creep testing at different temperatures. Such facilities can be centralized.

For the characterization of materials, there are certain basic facilities which can cover a wide variety of materials. One has to ensure facilities for the elemental analysis of gases, liquids and solids. For solids, additional consideration is required whether the measurement is to be made on the surface of a material, or if it is to be concerned with the bulk of the material. Sometimes, the material itself is in the form of a thin film. In the microelectronics area particularly, such situations are often encountered. Also, in certain applications one prefers a non-destructive technique whereas destructive techniques can be used in many others. Here we shall describe some of the most important techniques for material characterization.

Trace impurity analysis

For the determination of impurity concentration in the bulk of materials, some destructive techniques have a very high sensitivity. These include ICP mass spectrometry [4], ICP emission spectrometry [5] and atomic absorption spectrometry. [6] For non-destructive characterization, neutron activation analysis, [7] electron probe micro analysis [8] and X-ray fluorescence [9] methods are very useful. For the determination of impurities and their location in crystal lattice techniques like Rutherford back scattering [10] and X-ray fluorescence electron emission associated with dynamical diffraction of X-rays from single crystals are very useful. [11] Electron spin resonance spectrometry is an important tool for the determination of traces of paramagnetic impurities and their environment in crystal lattices. Other important techniques include Raman spectroscopy, Fourier transform infrared spectroscopy, and nuclear magnetic resonance spectroscopy. For the study of solid surfaces, low energy electron spectroscopy methods like Auger electron spectrometry, photoelectron spectroscopy (XPS and UPS) and secondary ion mass spectrometry (SIMS) [12] are to be used.

It is not possible for any one technique to give high sensitivity for all impurities. Table 1 gives a comparison of the limits of detection for a few impurities of the three important techniques mentioned above. [13] These values should be treated as indicative only. Matrix effects are very important and specific cases are to be considered separately as general statements cannot be made.

Part per million sensitivity is achieved with Auger electron spectroscopy. Spatial variation in impurity concentration on solid surfaces or variations in impurity concentrations as a function of depth from the surface can also be analysed. The depth profiling is done on layer by layer removal of surface atoms.

Structural characterization of materials

Crystallographic structure defines the spatial arrangement of constituent atoms, ions or molecules of a material. In crystallography, this is achieved by defining the crystal system (which defines the external symmetry of the crystal); space group (which defines the internal symmetry); atomic positions in the unit cell and the distribution of electron density inside the unit cell. For a material which has been synthesized for the first time, all this information needs to be generated. However, this effort would be a part of structural crystallography and not of materials science. For structural characterization, one is required to identify the structure of a given material with one of the known structures already documented. A large volume of data in this respect is available in the form of books, magnetic tapes, hard disks and CD ROMs.

For the structural characterization of materials, powder X-ray diffractometry is the most widely used technique. [14] In modern powder X-ray diffractometers, experimental data on angular positions and intensities of diffraction maxima is collected and automatically processed to match the structure of a given specimen with one of the known structures. If the specimen contains more than one material, relative proportions of various phases can also be determined. Powder X-ray diffractometry is also used to determine the direction and degree of preferred orientation. For submicrometer particles, powder X-ray diffraction techniques can also be utilized for particle size measurements. Electron diffraction [15] and neutron diffraction [16] techniques are also very valuable in selected cases.

Electron optical methods employing conventional transmission electron microscopes (CTEM) and modern scanning transmission electron microscopes (STEM) are extensively used for the characterization of materials with small dimensions. In the recent past, electron microscopy under defocus conditions has been used for direct imaging of lattice planes. [17] With modern equipment, it is possible to achieve a lattice resolution of 0.15 nm or even less. Attempts are being made to locate individual atoms in the crystal lattices. Analytical electron microscopy is one of the recent advances in electron microscopy. An electron energy loss spectrometer (EELS) when attached with an electron microscope, enables a comprehensive characterization of thin materials. One can observe the structure, composition and purity of a material at the same time. [19]

For the structural characterization of solid surfaces, low energy electron diffraction (LEED) has been used for quite some time. Recently invented scanning tunnelling electron microscopy [20] and atomic force microscopy [21] are

Table 1. Minimum detection limits (in ppb) attainable with major techniques of elemental analysis in the case of few selected impurities [13]

Element	Graphite Furnace Atomic Absorption Spectrometry	ICP-Mass Spectrometry	ICP-Emission Spectrometry	Spark Source Mass Spectrometry
Mercury	0.001	0.01	12	300
Manganese	0.005	0.06	1	10
Silver	0.01	0.02	3	60
Chromium	0.04	0.2	3	60
Sodium	0.04	0.2	7	30
Gold	0.1	0.04	10	60
Gallium	0.1	0.03	15	1800
Iron	0.1	0.5	2	200
Arsenic	0.8	0.02	30	80
Thallium	0.3	0.3	1	20

powerful methods for revealing the atomic structure of solid surfaces. These techniques have considerable advantage over LEED.

Characterization of single crystals regarding perfection

For the determination of real structure of crystals knowledge about the ideal structure and the nature and number of defects present in a given specimen is required. Major crystal defects, in order of the decreasing disturbance they produce are: grain boundaries, sub-grain boundaries, dislocations (including stacking faults), clustered and isolated point defects. In addition, the crystal lattice is sometimes disturbed by non-localized deformations, like the mechanical deformation of a semiconducting crystal caused by stress at its interface with a thin film deposited on it or with a base to which it needs to be attached after the fabrication of devices. The evaluation of crystallographic perfection, in general, would also include information about non-localized defects like stress. Information on crystallographic perfection is required in: (i) as grown crystals or crystals used as starting materials for the fabrication of various devices such as integrated circuits, lasers, optical components; (ii) crystals subjected to various external disturbances such as processing steps for the fabrication of devices like ion implantation in semiconductors; and (iii) the effect of externally applied fields such as electric fields on the real structure of semiconductors and insulating crystals.

The following major techniques are used for the evaluation of perfection of single crystals: (i) etching; (ii) transmission electron microscopy; (iii) field ion microscopy; (iv) decoration; (v) birefringence; and (vi) high resolution X-ray diffraction techniques—diffractometry, topography and diffuse X-ray scattering. All these techniques are useful for the observation and characterization of discrete defects. For a study of stress in crystals, X-ray diffraction methods are particularly well-suited.

There are various constraints posed by the sizes and shapes of the specimen crystals which should be borne in mind when selecting a method for characterization. On one extreme, we have bulk crystals of semiconducting materials such as silicon wafers of 125-300 mm diameter (volume ~ 35 cm^3). On the other extreme are thin epitaxial films or small whisker crystals with very small volumes of 10″ cm^3. In some applications, the defect structure in crystals which are part of a device is analysed in a non-destructive fashion.

Etching techniques are relatively simple to use and have been extensively used for a quick, but destructive, examination of crystal surfaces.[22] When very thin specimens are examined, electron microscopy can be used with great advantage. All types of defects can be investigated using atomic resolution.[18] However, only very small volumes of materials can be characterized and the technique is destructive in nature. Bulk samples can also be examined, but these have to be thinned down by techniques like ion milling. Field ion microscopy can be used directly to photograph an atomic arrangement in selected cases, but it requires a special needle-shaped specimen, and therefore, its application is very restricted. Birefringence can be used with optically transparent materials exhibiting appreciable birefringence like gadolinium gallium garnet crystals.[23] If applicable, this method can be used to examine large volumes very efficiently in a non-destructive manner, even dislocations can be directly observed and characterized. High resolution X-ray diffraction methods are non-destructive and can be used for direct observation of defects like boundaries and dislocations.[25] Point defect clusters in otherwise dislocation free crystals can also be investigated by diffuse X-ray scattering (DXS) measurements.[26-28] These can also be used for study of non-discrete disturbances in the lattice like stress in crystals.[29-30]

IV. Indian experience

In India R&D work in materials science is being pursued in national laboratories of the Council of Scientific and Industrial Research (CSIR), academic institutions (universities, Indian Institutes of Technology, Indian Institute of Science and Tata Institute of Fundamental Research), as well as in some industrial laboratories. The Department of Science and Technology, besides sponsoring R&D work in this area, has also set up Regional Instrumentation Centres. Materials science activity is also being pursued in the Atomic Energy Establishments and Defence Research and Development Organizations. In addition, activities in some establishments of the Department of Electronics are noteworthy. Here, we consider in some detail, only those agencies which have a large infrastructure for materials testing and evaluation. In particular we consider the CSIR laboratories, the Regional Sophisticated Instrumentation Centres of the Department of Science and Technology and the Sophisticated Instruments Centres of the UGC.

Laboratories of the Council of Scientific and Industrial Research

The range of materials on which R&D work is being carried out is very wide. It includes building materials, refractories, minerals, glasses, ceramics, semiconductors, metals alloys, polymers, catalysts etc. Facilities for the characterization of materials and measurement of their properties are necessary to support this R&D effort. Therefore, 23 out of 41 CSIR laboratories, including the author's laboratory, have fairly elaborate facilities for the testing and evaluation of materials. Besides in-house utilization, most of these institutes offer their infrastructure to outside users against a test fee or consultancy.

As expected, facilities for elemental analysis are available with a large number of laboratories. Structural characterization facilities are available at relatively few places. The expertise and infrastructure for the evaluation of perfection of single crystals is available at only three places. Among these, only the author's laboratory can carry out the characterization of all types of lattice imperfections in bulk single crystals. Indeed, high resolution X-ray diffraction facilities of the author's research group are unique, not only in our country, but in many ways globally. The special features of these will be described separately.

Several laboratories of the CSIR have high quality expertise and infrastructure for the measurement of materials properties. Notable among these are: mechanical testing of metals and alloys (creep, tensile bending, fatigue test etc.); trisonic aerodynamic facility for the testing of aerospace materials; coal quality evaluation and acoustic testing.

Regional Sophisticated Instrumentation Centres of the Department of Science and Technology

In the early 1970s, it was realized that there had been a substantial expansion in the academic sector, industrial growth and in national R&D laboratories. However, due to the high cost and the limited availability of foreign exchange, it was not possible to equip all the laboratories in these three sectors with facilities having state-of-the-art level performance capabilities. Moreover, the pace of development in instrumentation had increased and it was not possible for any one institution to keep itself up to date with its own resources. In the universities, and other academic institutions, the lack of advanced facilities affected the quality of education and research. The National Committee on Science and Technology examined this issue and recommended the establishment of Regional Instrumentation Centres in different parts of the country. These Centres were proposed to promote an instrumentation culture, besides providing facilities to a number of scientists and technologists. Additionally, these Centres were expected to promote R&D work in multidisciplinary areas. The Department of Science and Technology, Government of India, New Delhi gave this programme practical shape. Four "Regional Sophisticated Instrumentation Centres" (RSICs) were established during 1975-1980 at the following locations:

(i) Indian Institute of Technology, Madras
(ii) Indian Institute of Technology, Bombay
(iii) Central Drug Research Institute, Lucknow; and
(iv) Bose Institute, Calcutta

In addition to these four the following two specialized instrumentation facilities were also set up:

(i) High Field Fourier Transform Nuclear Magnetic Resonance Spectrometer at the Indian Institute of Science, Bangalore; and
(ii) Liquid Helium Production Facility at the Indian Association for the Cultivation of Science, Calcutta

Besides providing facilities to various users at nominal charges, the Centres aimed at (i) developing a capability for preventive maintenance and repair of instruments; (ii) organizing training courses for scientists and engineers on the application of major facilities; (iii) training of technicians for the maintenance and operation of sophisticated equipment; and (iv) development of prototypes of selected instruments, or enhancement of facilities.

All these Centres received funds from the Central Government. The host institutions provided the basic infrastructural facilities and heads of the centres.

The activities of the RSICs and specialized facilities were reviewed at the end of the first phase, during 1979-1980. As a result, the facilities of the existing establishments were strengthened. Also, keeping in view the requirements of the Northern, North-Eastern and Central regions, it was decided to establish three new RSICs at:

(i) Punjab University, Chandigarh
(ii) North-Eastern Hill University, Shillong; and
(iii) Nagpur University, Nagpur.

The following new facilities were created:

(i) Electron Microscopy Facility,
All Indian Institute of Medical Sciences, New Delhi;
(ii) X-ray Diffraction and X-ray Fluorescence Facilities, Guahati University, Guahati;
(iii) High Field 500 MHz FT-NMR Spectrometer, Tata Institute of Fundamental Research, Bombay.
(iv) National Electron Microscopy Facility,
Centre of Advanced Study in Metallurgy,
Banaras Hindu University, Varanasi.

While establishing these new Centres and facilities, the Department of Science and Technology kept in view the plans of the University Grants Commission (also described in this paper) to avoid any duplication of effort. The Review Committee laid considerable stress on the full utilization of these major facilities. Even today this is a major concern of the sponsors and management. Utilization targets have to be indicated by RSICs. While strengthening the facilities, preference was given to replacing obsolete equipment. At present, the emphasis is on the consolidation of the facilities and their greater utilization.

The RSICs have some very good facilities for the testing and evaluation of new materials. For the characterization of materials regarding composition and purity, the following equipment is available:

(a) Atomic absorption spectrophotometers;
(b) Mass spectrometers;
(c) Scanning electron microscopes with EDAX attachments;
(d) F T Infrared spectrometers;
(e) ESCA/Auger electron spectrometers (surface analysis);
(f) High pressure liquid chromatographs;
(g) EPR spectrometers; and
(h) FT-NMR spectrometers (for specialized purposes)

In addition, a number of UV-Visible spectrophotometers and Laser Raman spectrophotometers are available.

X-ray diffractometers and electron microscopes are used for structural characterization. Some centres also have equipment for property measurement.

University Science Instrumentation Centres (USICs)

The University Grants Commission of India had realized that it was necessary to provide continuously highly reliable sophisticated instruments for teaching and advanced research. It has encouraged universities to establish Scientific Instrumentation Centres for the use of different departments. In this manner, limited resources could be made available to a large number of active scientists and scholars. Funds were also provided to establish mechanical workshops to assist in the maintenance of and development of equipment activities. It was hoped that these Centres would promote instrumentation activities. Training of manpower has also been one of the activities of these Centres.

Some of the active USICs are functioning at the following Universities:

(i) Jawaharlal Nehru University, New Delhi;
(ii) University of Delhi, Delhi;
(iii) Kanpur University, Kanpur;
(iv) Devi Ahilya Vishwavidyalaya, Indore;
(v) Punjab University, Chandigarh;
(vi) Punjabi University, Patiala;
(vii) Guru Nanak Dev University, Amritsar;
(viii) Rajasthan University, Jaipur;
(ix) Poona University, Pune;
(x) Cochin University, Cochin;
(xi) Madurai Kamraj University, Madurai;
(xii) Osmania University, Hyderabad;
(xiii) North-Bengal University;
(xiv) Kalyani University, Kalyani;
(xv) Nagpur University, Nagpur;

Several of these USICs have very elaborate facilities for the testing and evaluation of advanced materials. However, presently these are mainly being used for fundamental research.

Recently, the UGC has established an Inter-University Centre (IUC) at Devi Ahilya Vishwavidyalaya, Indore. It has some excellent modern facilities for testing and evaluation of materials. It is planning to develop two beam lines on the synchrotron source being established at the Centre for Advanced Technology, Indore. One of these lines will be used for high resolution X-ray diffraction experiments to evaluate perfection of single crystals.

Other major R&D centres

Facilities for the testing and evaluation of materials have also been established at the laboratories of the Department of Atomic Energy, most of these are for in-house use. However, several of these are available to outside users. A notable major facility is that of neutron diffraction and scattering experiments at the Bhabha Atomic Research Centre, Trombay.

Major public sector industries like the Bharat Heavy Electricals Ltd. (BHEL), Bharat Electronics Ltd. (BEL), Indian Telephone Industries (ITI), Semiconductor Complex Ltd. (SCL), Hindustan Machine Tools Ltd. (HMT) and Steel Authority of India Ltd. (SAIL) have a high quality infrastructure for in-house materials evaluation and testing. These facilities are meant to satisfy the day-to-day requirements of the industry. Private sector industries also have well equipped in-house laboratories. As an example, mention may be made of Tata Iron and Steel Company.

V. National Physical Laboratory (NPL), New Delhi

We shall consider the experience of the National Physical Laboratory in some detail as this is perhaps the only laboratory which has a coherent group for the characterization of solid materials in all the four aspects. This was the first laboratory in the country to initiate research and development work on industrially important materials: carbons and ceramics. Also, materials analysis was visualized as an essential activity, right from the planning stage. In this connection, an interesting and very relevant piece of correspondence will be reproduced here. Dr. S.S. Bhatnagar, the founder of the chain of CSIR laboratories, wrote in the 1940s to the Directors of national standards laboratories of advanced countries, like the USA, to seek their opinion on the plan for the National Physical Laboratory. In response to this request, the then Director of National Bureau of Standards, Washington, Dr. Lymann J. Briggs wrote back:

...*"I am not quite clear in regard to your plans for chemistry. I can only say that we have found our Chemistry Division indispensable. Your Physicists should know exactly what they are working with otherwise their careful measurements become indeterminate. The value of a great deal of the work which has been done in past years has been seriously impaired because of the failure to recognize this fact"*...

It can be seen that the importance of materials characterization had been quite well realized even at that time, though the term "Characterization of Materials" was adopted much later.

At present, the National Physical Laboratory has fairly comprehensive facilities for the characterization of bulk materials, as well as solid surfaces. Several physical properties can be measured with a high level of accuracy. The laboratory occupies an important place in the national quality assurance programme. Besides providing services to outside users, the laboratory undertakes consultancy assignments and sponsored projects. In some areas strong international linkages have been established. Also, in the area of high resolution X-ray diffraction a wide variety of sophisticated equipment has been developed indigenously. This infrastructure is being used to prepare and supply Indian Reference Materials in collaboration with 15 R&D laboratories. In this section we shall briefly describe the activities of the NPL covering these aspects.

Infrastructure

During the last decade or so, the focus of activities in the area of materials characterization has been on materials for electronics. Besides improving the infrastructure to meet the requirements of this area, collaborative R&D work was pursued with the Microelectronics Division of the Central Electronics Engineering Research Insitute, Pilani.

The following major facilities are available for determination of composition and purity:

(i) Atomic absorption spectrophotometers, including one with a graphite furnace and Zeeman correction facility;
(ii) ICP Emission spectrophotometer;
(iii) Fourier Transform Infrared Spectrophotometer;
(iv) X-ray fluorescence spectrometer;
(v) Microprobe analysis facility with SEM;
(vi) Gas chromatographs with different detectors; and
(vii) Ion chromatograph

In addition, there are the conventional facilities like UV-visible-infrared spectrophotometers. An indigenous facility for the preparation of ultra high purity water and acids by a sub-boiling technique has been developed.

For the structural characterization of materials, powder X-ray diffractometry (XRD) and transmission electron microscopy (STEM, CTEM) are employed. With the XRD facilities, we are able to carry out automatic phase identification. Temperature variation facilities from liquid nitrogen to ~1000° C, are available in a Guinier-Lenne camera. Several powder diffraction patterns recorded as a part of a research programme are now included in the standard powder X-ray diffraction data used internationally. [13]

A 200 keV electron microscope (Jeol) with a lattice resolution of 0.14 nm and point-to-point resolution of 0.35 nm (TEM mode) is used for the structural characterization of thin films and fine particles. Besides this, the surface morphology and topography of specimens can be investigated. Specimens can be heated up to 1000° C, with preparation facilities also being available. Defects in thin materials can be characterized at high spatial resolution.

For the evaluation of perfection of bulk single crystal materials high resolution X-ray diffraction methods—diffractometry, topography and diffuse X-ray scattering are employed. A special feature of these facilities is that all major equipment has been developed in the author's research group. [28] These include:

(i) Double crystal X-ray diffractometers with symmetrical and asymmetrical monochromators;
(ii) Triple crystal X-ray diffractometers (two types);
(iii) Multicrystal X-ray diffractometer (four crystal system); and
(iv) Five crystal X-ray diffractomer.

A small angle X-ray scattering facility has been developed for the evaluation of quality of non-crystalline materials.

For surface morphological studies, scanning electron microscopy facilities are available. Surface area and porosity measurements can be made by using adsorption measurements.

For the study of solid surfaces, an Auger electron spectrometer and a secondary ion mass spectrometer have been established as a part of a UNDP sponsored project.

These enable the compositional analysis of surfaces. Also, a scanning tunnelling microscope is available in the laboratory.

A variety of techniques are available to outside users for the measurement of physical properties. These include: electrical, thermal, optical, acoustic, electronic, magnetic, luminescent and mechanical properties. Temperature and pressure variations can be made in many measurements.

Indigenous development of techniques and equipment

The rate of growth of knowledge and technology in the materials science area is very fast. It is necessary to make continuous efforts to keep the levels of expertise and infrastructure up to date. The capability of the development of equipment and techniques is one area which can help in this direction. Some of these are briefly described here.

Techniques

(i) Multicrystal X-ray diffractometry and topography

By using the Five Crystal X-ray Diffractometer briefly described below, it has been possible to improve the quality of diffraction curves in a remarkable manner. The uncertainty in the half width has been reduced to about 1/10th of the theoretical value. Traverse topographs can be recorded when diffraction curve widths are about 3 arc sec.

(ii) High resolution diffuse X-ray scattering

Measurement of X-ray scattering has been made possible, very close to the reciprocal lattice points which enables one to get information about point defects and their clusters in otherwise dislocation free device quality crystals of semiconductors and other materials.

(iii) Measurement of curvature of single crystal wafers

Biaxial stress induced by thin deposits in single crystal wafers can be deduced from the bending or curvature of wafers. Radii of curvature of about 30 km can be measured.

(iv) Accurate determination of crystallographic orientation

Two new techniques have been developed for the determination of crystallographic orientation:

- Surface of wafers/blocks/boules; [34]
- Straight edges of wafers used for fabrication of microelectronic devices. [35]

(v) Measurements of anomalous transmission of X-rays through "thick" and "thin" crystals

A new technique has been developed which enables the direct observation of forward diffracted beam and anomalous transmission of X-rays through thin crystals of varying degrees of perfection. [33] Till now this was not considered possible.

Interaction with industry

Industries have been provided with infrastructural support either through regular testing or through consultancy services. Some of these services helped industry to solve critical problems of failure analysis. In one case, an industry producing heavy chemicals, Gujarat Heavy Chemicals, Verawal, had occasional boiler tube failures which led to a loss in production. This problem was analysed by using our infrastructure and helped the company find a solution.

International collaboration

We have the following collaborative projects with institutions in different advanced countries:

(a) Indo-US
- Preparation, Characterization and Precision Measurements of Semiconducting Materials with NIST, Gaithersburg and University of Arizona, Tucson - just completed
- High Resolution X-ray Diffraction Imaging for Advanced Materials Characterization
  NIST, Gaithersburg and University of Maryland

(b) Indo-German
- High Resolution X-ray Diffraction Studies on Gallium Arsenide Single Crystal
  Technische Hochschule, Darmstadt, Germany

(c) Indo-Russian
- Growth of Nearly Perfect Crystals of Oxides like Lithium Niobate.
  Institute of Inorganic Chemistry, Novosibirk, Russia

Presently, we have a request from the University of Waterloo, Canada, for some work to be done against a fee.

VI. Quality assurance system

For the testing and evaluation of materials, a wide variety of measurements are necessary as is clear from the foregoing. To ensure the high quality of measurements in terms of accuracy, it is necessary that all measurements are traceable to the National System of Measurements. This national system should ensure compatibility with similar systems in other countries. In India, the Department of Science and Technology had established a system which had been known as National Coordination of Testing and Calibration Facilities (NCTCF). Under this system testing as well as calibration laboratories are accredited through assessment. The work on accreditation of calibration laboratories is being coordinated by the author's laboratory. The testing laboratories' accreditation is coordinated by the Department of Science and Technology itself. At present 91 testing laboratories have been accredited and some more are in the process. The number of tests for which accreditation has been granted is approximately 150. This system is presently under review and a new system under a National Quality Council is being established. This Council will have three boards including one on Testing and Calibration (NABL).

VII. Indian reference materials

To transfer high level accuracy achieved in measurements, made with the help of an elaborate infrastructure at a national laboratory, to shop floor level in industry or laboratories in R&D institutions, certified reference materials are necessary. The author's laboratory has initiated a programme on the preparation of Indian Reference Materials or Bhartiya Nirdeshak Dravya (BNDs). Fifteen national laboratories are participating in this programme. The following reference materials have already been prepared and supplied to consumers, a few of which are outside India.

1.	BND 101.02	Lead solution	Concentration	1.04 ± 0.03 ppm
2.	BND 102.02	Lead solution	Concentration	2.04 ± 0.02 ppm
3.	BND 201.02	Cadmium solution	Concentration	0.96 ± 0.02 ppm
4.	BND 301	Arsenic solution	Concentration	0.99 ± 0.02 ppm
5.	BND 401	Chromium solution	Concentration	0.98 ± 0.02 ppm
6.	BND 402	Chromium solution	Concentration	1.98 ± 0.02 ppm

The following BNDs are ready for release in the near future:

1. Solution of mercury
2. Solution of selenium
3. Silicon powder for X-ray diffraction.

Participation in international programmes

Recently, we participated in an international intercomparison of five samples of certified reference materials. The Institute for Certified Reference Materials, Beijing coordinated this activity. Eight countries were invited to participate in this activity.

At present, we are analysing two solution samples containing: (i) magnesium, calcium and lead and (ii) lithium, molybdenum and iron. The Working Group on Metrology in Chemistry of CIPM is coordinating this activity designed to assess the international compatibility of a wide range of methods and reference materials.

VIII. Funding

As mentioned above, most of the centralized facilities for testing and evaluation of materials are in national laboratories, IITs and universities. Their main source of funding is the Government of India, through its various departments and agencies. A limited amount of funding has also been obtained from international agencies, like the UNDP. The NPL's facilities for surface characterization were established in this mode. For some of the projects in bilateral cooperation, like Indo-US activities, the funding comes from non-Indian sources.

Industrial sector laboratories have their own funding for supporting testing and evaluation activities.

IX. Some suggestions

The establishment of an International Centre for Materials Evaluation Technology is a welcome step. This is an area, though not very visible and not giving concrete products directly, which has a strong influence on total activity in scientific and technological spheres. It essentially has a multiplier effect on industrial growth. Since major facilities are very expensive and require highly trained manpower, it may be desirable to share expertise and facilities. The strong points of the major institutions in the region could be taken advantage of, even though the countries of the region are separated by long distances. Modern communication facilities help in efficient contacts and distance is not an unsurmountable hurdle.

X. Concluding remarks

In this paper, an attempt has been made to present the overall picture of the activities in India in the area of testing and evaluation of advanced materials. At times, the paper may appear to have unconventional ideas. These have emerged out of the author's experience in this field. Further, this report is not claimed to be an exhaustive account of all the Indian expertise.

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UNIDO NEWS

ESTABLISHMENT OF THE INTERNATIONAL CENTRE FOR MATERIALS EVALUATION TECHNOLOGY (ICMET) IN TAEJON, REPUBLIC OF KOREA

One of the latest achievements of the UNIDO programme in the area of new materials is the establishment of the International Centre for Materials Evaluation Technology (ICMET) on the premises of the Korea Research Institute of Standards and Science (KRISS) in Taejon, the Republic of Korea. The preparatory and pilot activities phase has just started and is planned to be implemented from 1996-1998. The following information about the mission, objectives, functions and the work programme of ICMET will give the opportunity to our readers to know more about this new institution which is planned to provide a framework for developing countries to cooperate in this vital area for materials science and engineering.

As stated in the Feasibility Study on the Establishment of an International Centre for Materials Evaluation Technology: "...It is also worldwide recognized that reliable methods of testing and evaluation of new and advanced materials are crucial for their successful development and efficient incorporation into competitive industrial products. The standardization of testing procedures is a key principle in materials science and engineering, vital for a wide range of industrial sectors and, thus, will have a major influence on economic and industrial competitiveness in the future. Since markets and their competitive and regulatory forces have become global, worldwide standards development and deployment are essential for the survival of an enterprise, a sector of industry and the economy of any country and for being competitive in the international trade."

MISSION

The mission of the International Centre for Materials Evaluation Technology (ICMET) is to develop international guidelines, codes of practice, standards on testing and characterization for new materials which can be accepted across national boundaries. It is also to bridge the gap between research and development organizations, innovative enterprises and the market place within developing countries to stimulate the diffusion of new materials and processing technologies and their application in materials related sectors of industry.

OBJECTIVES AND FUNCTIONS

The objectives of the ICMET is to respond to demand from the developing countries for building-up/strengthening technological capabilities in testing and evaluation of new materials and to act as the focus point for promoting international cooperation in this field.

The ICMET is operating under auspices of the United Nations Industrial Development Organization (UNIDO) and will focus on the following functions:

(a) AWARENESS BUILDING:

Gather, monitor and disseminate information from both developing and developed countries in the field of testing and evaluation of new materials, including on-going work of important standards committees and standards issues.

(b) COOPERATIVE R&D:

Identify industrially important areas for developing or improving new materials evaluation and characterization techniques through cooperative R&D programmes. Generate validated and widely acceptable techniques which can form the basis for the development of regional and international standards. Intercomparisons of laboratories and development of key reference materials.

(c) ADVISORY SERVICES:

Help industry and R&D institutions in the developing countries build up/strengthen their technological capacity in the area of testing and evaluation of new materials. Deliver the service provided by a network of organizations and locally wherever possible.

(d) TRAINING:

Make a valuable and sought-after contribution by organizing training programmes which offer practical experience to participants in key and developing fields of materials characterization and evaluation. Provide the scientists and technologists access to state-of-the-art instrumentation and testing facilities which are relevant and important to industry. Place emphasis in seeking industrial views in the design of the courses and making them attractive to participants from industry in developing countries.

(e) PROMOTION:

Promote international/regional cooperation in the field of testing and characterization of new materials in order to eliminate barriers in international trade.

WORK PROGRAMME

ICMET will work in close cooperation with existing research and testing centres and institutions, especially in the Asia and Pacific region at the initial stage.

Taking into consideration the novel nature of the Centre and the complexities of arrangements for international collaboration, the task is planned to be tackled in two phases

(a) Preparatory and Pilot Activity Phase (1996-1998):

The initial three year work programme started in January 1996 and includes the following key activities:

(i) establishment of a Technical Advisory Group and holding three annual meetings to provide guidance for the ICMET, advise on the selection of work programmes and assist in formulating a long-term plan for the operational phase of the Centre;

(ii) creation of an international network of institutions and individuals dealing with materials evaluation issues in policy making agencies, professional societies, enterprises, R&D centres and universities;

(iii) design of appropriate database system and its networking with the existing information system in the area of materials testing and evaluation;

(iv) organization of and conducting workshops and training courses on specific issues and problems in the area of testing and characterization of new materials;

(v) formulation of and launching collaborative projects involving intercomparison and validation exercises to demonstrate the basis on which the future R&D programmes can be developed and supported;

(vi) further promotion of the concept and work programme of ICMET;

(vii) development and approval of a long-term work programme for the next operational phase of the ICMET project.

(b) Operational Phase (starting from 1999):

Based on the experience of the pilot activity phase, a fully fledged work programme for ICMET will be put into operation. This is expected to cover all important categories of new materials and an extensive range of activities related to the functions of the Centre. The long-term structure and administrative arrangements for ICMET will be completed and functioning.

FUNDING ARRANGEMENTS

The international dimension of the Centre and the need for its efficient management and innovative methods of work require a kind of pump priming fund which will help the nucleus to grow to a stable size and demonstrate the value of such a cooperative programme. Once this is achieved, the Centre should be expected to raise sufficient additional amounts from other sources for carrying out its activities.

The Government of the Republic of Korea expressed its interest in hosting the Centre and made the decision to allocate initial funding to start the project. Funds for the Centre's programmes are currently being sought from a range of organizations. These include: international aid and development funding organizations, national government development programmes, non government aid organizations, organizations sponsoring research, private industry and industrial organizations.

The ICMET provides a unique opportunity for funding organizations to "leverage" scarce financial resources. Funding organizations can direct funds towards specific programmes. This ensures that a high ratio of programme funds are effectively applied for maximum benefits of the target communities. Appropriate management procedures ensure a high level of financial accountability.

The Centre also seeks to consolidate funds from a variety of sources to undertake programmes for the benefit of developing countries.

INVITATION TO PARTICIPATE

Opportunities now exist, at a number of levels, for participation in the realization of the ICMET concept.

(i) Government organizations, R&D centres and enterprises from both public and private sectors of industry, and funding agencies active in new materials design, development, production and application are invited to submit project proposals and suggestions for areas of cooperation.

(ii) Research, manufacturing, marketing, financing, aid and policy development organizations and trade organizations are invited to make general operational suggestions and specific project recommendations. Discussions focused on identifying joint project opportunities involving the ICMET are also welcome.

(iii) Relevant international organizations are invited to seek formal links with the ICMET. In this manner, as the proposal develops, their additions and participation can be considered from the start.

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