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

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Abstract

Development of new materials has been an integral part of the industrial expansion in economically developed countries, resulting thereby, apart from improving the efficiency of production and quality of products, in revolutionising the nature of certain industries.

Certain raw materials of which India has the largest deposits in the world were till recently exported only, to be imported back as the finished products, and that too, at a high cost to satisfy the needs of certain industries. This necessitated the need for materials development within the country for 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 been progressing well in many academic and R&D laboratories in India. Most programmes geared towards developing indigenous technology would invariably culminate in the further

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growth of new industries in the emerging high-tech areas, for manufacturing special materials.

The author has described in detail the current scene with future plans of the R&D activities in the fields of materials science & technology progressing in India. Though there exists no single national facility, as such, in the country, and the projects are being executed at many academic and R&D laboratories, yet there is a recommendation for the setting up of a National Materials Research and Development Board, for coordinating and concentrating the developmental activities of materials programme in India.

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

Dr. Pawan Sikka*

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

Information technologies, telecommunication, micro-electronics, lasers, fibre optics, advanced materials and biotechnology are the new fields where industrial revolution is taking place in the developed countries. While the developed countries are progressing very well on this front, the developing countries are faced with the urgency of having to mobilise their scientific, technical and other resources to develop related technologies in order to reduce the ever growing gap between them and the developed countries and to accomplish their own overall socio-economic and technological development. And, 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 the availability of her natural resources, trained manpower and vast S&T infrastructure. With a view to promoting the indigenous development of technology of the performance materials, Technology Information, Forecasting and Assessment Council has recently brought out Techno-Market survey in four volumes, clearly indicating the research status in India, technology gap, supply and demand scenario, environmental issues, applications in India and abroad, and action plan. A detailed market analysis 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 (R&D) capacities coupled with some of the production aspects being carried out in India are described here in respect of the followings:

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

4. Polymers and Composites

4.1 Polymers

4.2 Composites

4.2.1 Mission on Advanced Composites Metals and Alloys

5. Titanium

5.1 Titanium

5.2 Magnetic Materials

5.3 Steel

5.4 Aluminium

6. Mining and Minerals

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 is at Semiconductor Complex Limited (SCL), Chandigarh. The present feature size is around 5 um and will decrease to 1 um in the near future. Thus, our capability is upto LSI. Recently, major facilities like silicon MBE, reduced vapour phase epitaxy and electron beam lithography have been set up within Defence Research & Development Organisation. With 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 Solid State Physics Laboratory (SPL), New Delhi - where facilities have been established for synthesis and growth of single crystals, epitaxial processing facilities like 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 Gunn diodes, Millimeter wave devices and MMICs, and new devices such as HEMT (high electron mobility transistors) and InGaAs devices. Several sophisticated diagnostic facilities like EPMA, SIMS, SEM, DLTS, (deep level transient spectroscopy) have been installed. Solid State Physics Laboratory, New Delhi has recently taken the challenging initiative of setting up India's first (and 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 Central Electrical and Electronics Research Institute (CEERI), Pilani with the emphasis on device design and development.

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

As regards 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, in terms of contained gallium, Indian bauxite is among the best in the world. Central Electrochemical Research (CEERI), Pilani and Bhabha Atomic Research Centre (BARC), Bombay have developed processes for gallium recovery which have been respectively adopted by Madras Aluminium Company (MALCO) and Hindustan Aluminium Company (HINDALCO). 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 is launched at Defence Science Centre (DSC), New Delhi. The work would be intensified in this area of great importance, since the success of MOCVD technology ultimately depends upon the availability of high purity metal alkyls.

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

The Department of Electronics of the Govt. of India, is giving considerable importance to the development of materials for electronics. In addition to support through R&D (C-DOME), it is establishing Electronics Materials Development Agency (EMDA) under which materials Development Centre (MDC) (C-METS) have been set up for 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 been perhaps one of the first attempts to develop an emerging high technology in a planned manner leading to 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, Department of Science and Technology, New Delhi.

Later a nationally coordinated project was formulated involving the following organisations/industries:

1) Academic & R&D Organisations

* 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 of developing 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 R&D organizations was approximately Rs.1.5 crore. IACS was given the major responsibility for the development of materials and fabrication technology for a-Si solar cells.

The most important feature of a-Si solar cell technology development programme in India is that within a year of first fabrication of a-Si solar cell in USA, a formal project was submitted to the Department of Science & Technology by IACS in

1978. This has helped to a large extent in keeping the technology gap between developed countries and India within a manageable limit.

In 1985, the Department of Non-Conventional Energy Sources (DNES) decided to set up a Pilot Plant for the production of a-Si solar cells for power applications. Accordingly, a global tender was floated by DNES for the setting up of a Pilot Plant together with basic know-how for process. The decision of importing the Pilot Plant was taken to reduce the time required for the setting up of highly sophisticated plant. Indian R&D was to provide the process know-how to upgrade the product.

In 1986, Government of India identified the development of a-Si solar cells as one of the eight Science & Technology Projects to be implemented in the mission mode during the Seventh Plan period (1985-90). The target of the mission was to set up a plant of capacity of about 1MW/year. The initial efficiency to be achieved in the production line was 6%, which was to be upgraded to 8%. M/s Bharat Heavy Electricals Ltd. was entrusted with the task of installation and commissioning of the plant, which was set up in the campus of Solar Energy Centre, Gwalpahari, Haryana.

In 1987, United Nations Development Programme (UNDP) provided 2.6 million US $ for upgradation of the facilities at IACS. Ministry of Non-Conventional Energy Sources (MNES) provided rupee component support of Rs.1.41 crore, with an objective to set up a lead centre for the Development of Amorphous Silicon Solar Cell, which was to be very closely linked with BHEL/MNES Amorphous Silicon Solar Cell Plant.

Considerable efforts has been made to stabilise the Plant and Process by BHEL/IACS teams after the commissioning of the plant (1990). The National Physical laboratory has been providing engineering support. The Plant and the Process has been stabilised and has passed the criteria set by MNES to be achieved by March 31, 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 the transparent conducting oxide coated glass substrates. This is one of the few facilities in the world for this type of product available in India.

The plant is at present producing single junction a-Si modules having conversion efficiencies comparable to the best available in the world for this type of modules. The present cost/pW (at low level of production) is close to the Indian single crystal silicon solar cell cost. However, plans have been made to modify hardware and upgrade process (in collaboration with IACS) so that the cost will come down by 15-20%. A major plan has been drawn up for the introduction of multijunction a-Si solar cell technology and set up a large size plant (5-10 MW/year). This will bring down the cost to 1-2 US $/pW with modules of conversion efficiency of about 8% (stabilised), for power applications.

1.3 Superconducting Materials

Recently, a National Superconductivity Programme (NSP) was launched by the Ministry of Science and Technology i.e. Department of Science & Technology, New Delhi for developing high temperature superconductors in India. A high powered apex body (i.e. Project Management Board) with an allocation of substantial funds has been set up to guide and coordinate the activities of various R&D labs 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 the various research groups engaged in basic and applied fields, at -

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 so far and as a matter of policy, only those projects on basic research are being supported, or are being considered for support, which will lead to significant addition to knowledge in the area and may lead to major break-throughs. Financial support of the Government for national Superconductivity Fellowships and Superconductivity Technical Staff positions also continued.

In the second phase of NSP, R&D and activities related to technology development are being focussed in areas such as: improvement in critical temperature (T_c) and critical current density (J_c); workability of Yttrium, Bismuth and Thallium based compounds superconducting around liquid N_2 temperature; 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 development and engineering of 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 sub-system development; development and demonstration of special applications low and high-T_c SQUIDS; etc. During the year, financial support was provided to scientists and engineers associated with NSP projects for participating in international conferences. Organisation of two workshops/discussion meetings in India were also partially supported.

Major achievements of some of the NSP projects were as follows:

i) Process for 4N (99.99%) 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 field etc. in laboratory.

iii) Passive microwave high T_c stripline high Q cavity/resonator and band pass filter feasibility demonstration done 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 the system dedicated.

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 diffusion / rotary / absorption pumps combination) have been engineered and demonstrated at the Indian Institute of Science, Bangalore.

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

vii) HTSC material sysnthesis and characterisation using different techniques like 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.

Following are the highlights of the achievements/ capabilities developed under NSP.

- Upgradation of capabilities for 4N purity Yttrium Oxide upto 8 Tons/year for gem/diamond etc. uses 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 (Jc) in short samples of Bismuth HTSC wires/tapes.

- Initiation of project work on semi-industrial LTSC type Ore Separators at Lqd Helium temp with involvement of industry.
- 200 KVA capacity Generator testing and generation of upto 100 Kw power is in progress.
- Design / fabrication of sub-systems of 5 MVA LTSC generator is in progress.

SUPERCONDUCTING GENERATOR MODEL DEVELOPED - The BHEL's Corporate Research and Development wing has taken up 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 lab model of the generator has been developed, tested extensively and successfully synchronised 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 October 5, 1995 at the Corporate R and D.

Explaining the features of the superconducting generator, Director (Engineering, R and D) BHEL, said the development was a breakthrough in overcoming the electrical resistance in the conventional generators that result in enormous loss of energy. It was now possible to conduct electricity with zero resistance at very low temperature, thereby reducing losses and ensuing optimum efficiency.

2. CERAMICS

Glass and Ceramics are playing a significant role in the development/advancement of new materials and technologies. The new ceramic materials have inherent superior properties, like -

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

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

India is the second largest source in the world for rare earth available from beach sand for deriving Titania, Zirconia and Titanate/Zirconate ceramics. The utility of zirconia alone has extended from semiconductor zirconates, scissors, knives, dies to artificial jewellery.

Structural ceramics is one area where India has abundant resources, capable research groups, and an interested manufacturing and user inudstry. An exercise carried out over a one-and-a-half year period has resulted in the formulation of a definite programme for development of $Si_3 N_4$ and ZrO_2 technology for IC engine components, turbine blades, and missile/rocket parts. Because such a programme will require a total engineering approach, specific steps were worked out for the development of each product, and specific groups identified for each activity, within a set time frame. An example of the total development programme for some IC engine components is illustrated in Table 3. In order to cut short the project time, development of powders, their consolidation and characterisation would be taken up in parallel, with the design and fabrication of the product using imported powders.

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

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

Partially stabilized zirconia (PSZ) - is a new variation of widely used zirconia formed by adding Y_2O_3 or Mg.O in quantities sufficient to stabilize the high temp cubic phase. Lab scale development of PSZ and SiN is being done at Defence Metallurgical Research Laboratory (DMRL), Hyderabad and Central Glass Ceramic Research Institute, [CGCRI] Calcutta. Besides, silicon carbide (SiC), Zirconia and Sialon are important engineering ceramics under development in India.

A significant activity is taking place, in regards to ceramic super conductors at -

* Indian Institute of Science, Bangalore,
* Indian Institute of Tropical Meteorology, Pune,
* Tata Institute of Fundamental Research (TIFR), Bombay,

* National Physical Laboratory, New Delhi.
* Bhabha Atomic Research Centre (BARC), Bombay.

2.1 <u>Sensors</u> : The materials in use for making sensors are PZT, BaTiO2, ZnO. and 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 being made with indigenous how-how available in India.

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

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

In the development of materials, some important programmes which are in hand at Regional Research Laboratory, Bhopal are 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 development of PZT-Polymer Composite ceramics for various electrochemical transducer applications, 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 aircraft engine application in the year beyond 2000 AD. Also, the Si.N. Ceramics are replacing metals in automobile, thus dispensing with 30% fuel and 40% excess engine weight. The development of sintered alpha SiC can replace a large proportion of conventional ductile metals in various engines-parts, raising the efficiency of engine alone by 50 per cent.

Table 1 - Properties and applications of advanced ceramics

Function	Property	Application
1. Electro-magnetic	Dielectric, electrical conductor, ferroelectric, magnetic devices, piezoelectric, pyroelectric, semi-conductor	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 Volume	1990 Value (Rs.cr.)	1995 Volume	1995 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

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 'Radition Shielding Window' glasses which are essentially used for attenuation of harmful high energy radiations in nuclear reactors. The process technologies developed at CGCRI for the production of varieties of optical glasses and radiation shielding glasses are being progressively transferred to Bharat Ophthalmic Glass Ltd., (BOGL), Durgapur for

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

commercial production. CGCRI has also developed LASER glass as per the stringent defence specifications for instruments like range finder. The quality of these LASER glasses is comparable to equivalent materials obtained from abroad.

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

3.1 **Optical Fibre Materials** :

Two collaborations have been entered into for 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 basically for 1300 mm (1.3 um) transmission and can be used also for 1550 nm (1.55 um) transmission. the basic technology for dispersion shifted fibre at 1550 nm (1.55 um) transmission would also be 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 focussing attention on the following aspects -

a) To prevent optical fibre cable getting damaged to due to lighting strikes, the cable has to use nonmetallic strengthening materials. At present these are imported. These are areas of industrial secrets in which India is 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 on 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. And, there is a growing demand for these type of plastics for agricultural purposes e.g. water conservation, canal lining and drip culture.

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

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

4.2 Composites

The technology for the production of FRP (fibre reinforced plastics) already exist in India, with the present production of glass fibres is about 25 tonnes per year which is just less than 3% of the world production.

The National Aerospace Laboratory, Bangalore has done considerable work in the field of resin matrix composites, along with Aeronautical Development Establishment (ARDE), and Defence Research and Development Laboratory. NAL has also designed and fabricated 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 Defence R&D Laboratory (DRDL), Hyderabad for the manufacture of carbon-polymer matrix and carbon-carbon matrix. lab scale work has been carried out for MMC's (Al-SiC) and CMC's (Al_2O_3-Si.C) composites, at Defence Metallurgical Research laboratory (DMRL), Hyderabad. Indian Institute of Chemical Technology (IICT), Hyderabad is planning to manufacture coal tar pitch (500 Kg per batch) for the C-C composites.

Keeping in view the bulk availability of raw materials like glass, polyster, rice husk and pitch as well as the availability of nature of technology for processing of composites as labour intensive, the development of composites as new materials is best 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 Labs (NAL), Bangalore.
- National Physical laboratory, (NPL), New Delhi.
- Defence Materials Stores, R&D Establishment (DMS RDE);

The successful development of the all-composite aircraft 'HANSA' at NAL, and the use of sophisticated composite products in 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 design, analysis, fabrication and testing of new composite products. The advanced technologies developed for aerospace applications have also led to such spin-offs as orthotic 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 development of primary composite structures as well as complex FRP parts is being rapidly built up.

Appreciating the current situation, R&D laboratories have taken the lead in setting up special centres. The Defence Research & Development Laboratory (DRDL) has a Composite Products Centre (COMPROC) at Hyderabad, and 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 like the Indian Society for the Advancement of Materials and Process Engineering (ISAMPE), the Indian Society for Composite Materials (ISCM), the All India Reinforced Plastic Moulders Association (AIRPMA), etc., have laid emphasis on composite materials and contributed to promoting the industry through a series of national seminars and workshops.

4.2.1 Mission on Advanced Composites

A Technology Project in Mission Mode on Advanced Composites (TPMM-AC) approved recently by the Government is one of the target oriented activity which will be implemented by Technology Information Forecasting & Assessment Council (TIFAC), New Delhi under the guidance of lead agency - Department of Science & Technology (DST) in which close association is required with the industries / users. The TPMM-AC aims at indigenous development of composites products and technologies for domesting as well as export markets, for which nineteen sub-projects have been identified in two major categories viz., **Strategic Inputs** needed for overall development of composites and **Specific Products** to be taken up for designs, prototype development, technology diffusion and further commercialisation.

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.

Identified Products for Development are -

Musical Instrument; Violin, etc.; Golf Shaft and Fishing Rods; Medical Applications; Radiography Beds, Wheel Chairs, Headrest, etc.; Aircraft Interiors; Refill Cylinders for CNG; Wave Guides for Micro Wave Communication; Carbon-Carbon Composites Brake Disc; Railway Components; Automotive Components; and Bicycle Components.

An incremental funding support from the Government for each sub-projects, would be made available as the seed capital for technology and product development. The industries/users would collaborate with R&D laboratories with equal financial participation basis to develop commercialisable composite products within a targeted time frame.

5. METALS AND ALLOYS

Metals and alloys sector constitutes one of the core sectors of industry. Attention is now being focussed on the followings -

5.1 **Titanium** - India has an abundant resource of titanium minerals (more than 20% of world resources) and so titanium acquires a special significance. With a view to identify use of Titanium, TIFAC had set up a Titanium Development Advisory Committee in December 1991. Till now, the technology for metal production on an appropriate scale was not available for ready exploitation. This gap has been bridged with the establishment of the technology development centre at the Defence Metallurgical Research Laboratory (DMRL), Hyderabad. A modern Titanium Tube Plant has been set up at MIDHANI, Hyderabad for producing 25 tons of titanium per annum. It has got remarkable corrosion resistance and is very useful as a condenser tubing in thermal power plants and in similar other applications.

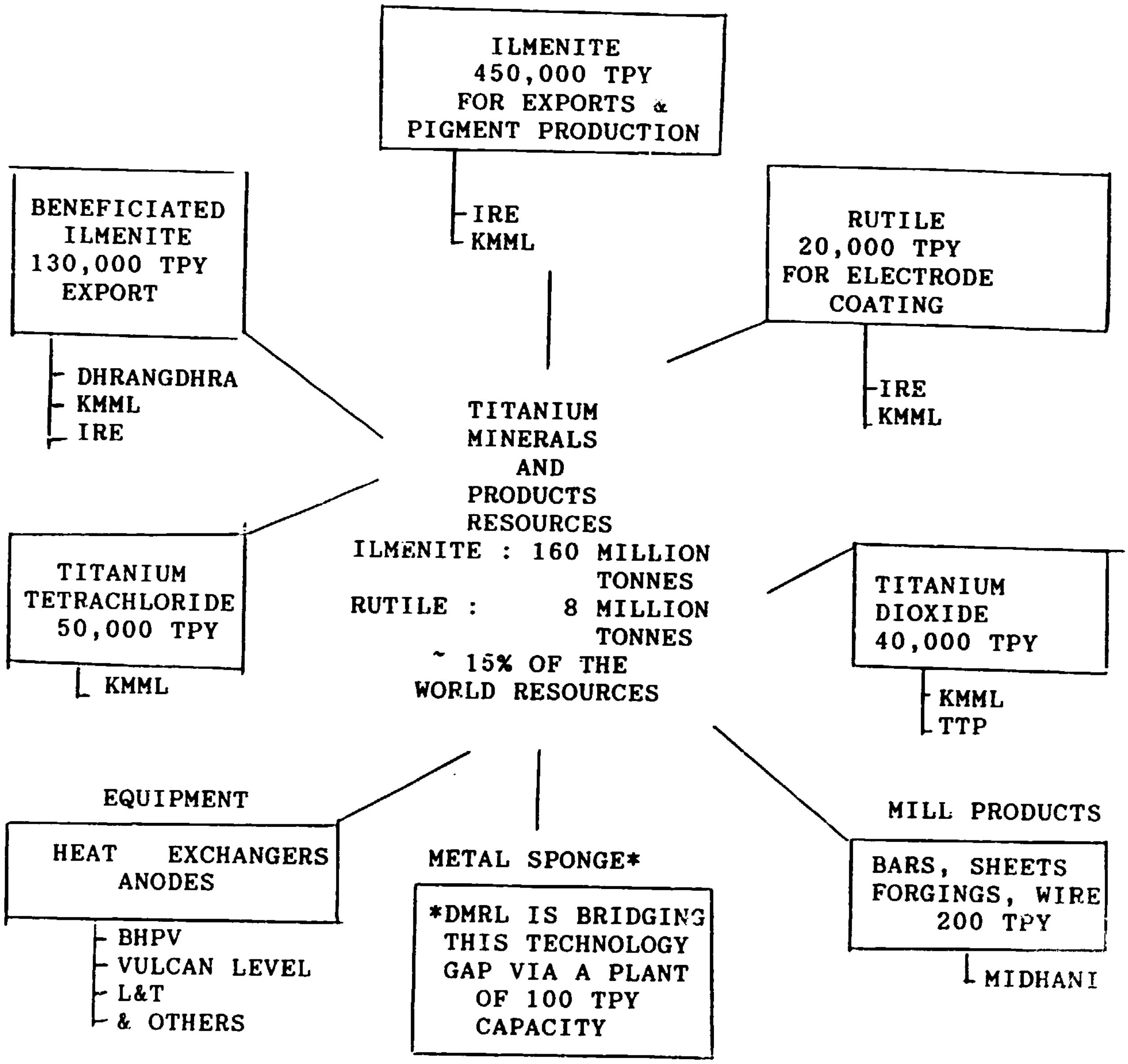

Fig. 1 : The Titanium Scene in India

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

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

5.2 <u>Magnetic Materials</u> : National Metallurgical Laboratory, Jamshedpur, Defence Metallurgical Research Laboratory, Hyderabad and MIDHANI, Hyderabad are working on the R&D and design aspects of Fe-Nd-B alloys as permanent magnets both through powder & RSP routes in India. These may replace Alnico and Smarium - Cobalt magnets by the end of century, keeping in view the import component of nickel and cobalt and indigenous availability of excess of Nd containing monazite ore in India.

An Advanced Research Centre for Powder Metallurgy has been set up with Russian assistance, at Hyderabad for manufacturing intricate devices through powder metallurgy route, in India.

5.3 <u>Steel</u> : The production of steel in India is around 10 million tons per year. It is estimated that the desired production would be around 22.5 million tons by 2000 AD as per the report of the National Mission for Iron and Steel.

5.4 **Aluminium** : Also, the production of aluminium estimated to be 500,000 tonnes per year with the commissioning of the National Aluminium Company (NALCO) Ltd., Orissa. With the enormous resources of bauxite, the production of Al can be increased in the future.

Aluminium-lithium alloys offer a density (7.12%) higher stiffness (10%), increased fatigue crack growth resistance and broader environmental capability (Table 4). They promise upto 15% reduction in structural weight and are thus poised for a major expansion as airframe materials.

Academic and R&D 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 brought to bear on the development of aluminium-lithium alloys during the past two years with encouraging results.

Table 4 : GOALS FOR ALUMINIUM-LITHIUM ALLOY DEVELOPMENT FOR AEROSPACE APPLICATION

Ultimate tensile strength	586 MPa
Tensile yield strength	517 MPa
Elongation	10%
K_c	64 MPa m
K_{1c}	23 MPa m
Elastic modulus	69 GPa
Density	2.49 g/cm^3
SCC classification (ST)	C

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

Developments in the Pipeline

India imports today 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 is working on a project to develop internationally competitive technology for extraction of copper, nickel and cobalt from Poly metallic Sea Nodules from India Ocean.

In another worth-noting effort, a detailed computer programme has been developed by RRL, Thiruvananthapuram for mathematical modelling of liquid/liquid extraction and separation of individual rare earths from chloride medium. This has been done with the objective of process optimisation and possible use of the programme for developing 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 route for production of steel in future. Resiness produces steel by using inexpensive raw materials which are hitherto considered un-utilisable, such as: blue dust, and/or the fines of iron ore and the fines of non-coking coal all of which are abundantly available in India. The basic approach of the process is illustrated in the bar chart. The charge mixture consisting of non coking coal fines and iron ore fines are charged into the retort, which is heated externally in the RESIN furnace. The heat can be supplied 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 and it emerges at the end of retort in the form of directly reduced iron (DRI) rod (or a slab) in a red hot condition. The DRI rod (or slab) is fed into a slag bath which is kept in the molten condition through passage of high electrical current in the ESS furnace. As a result, the rod is smelted to produce high quality steel directly. While in the conventional process, the steel is produced at first by reducing the iron ore to produce pig iron and then reoxidizing the pig iron thereafter, 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 NML show that if and when Resiness process is used the capital and operational cost can be brought down substantially. The energy consumption can be reduced to less than half the generation of the solid, liquid and gaseous pollutants and wastes can be brought down to about one fifth of its current value.

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

6. MINING AND MINERALS

India is endowed with rich minerals resources like coal, iron ore, bauxite, manganese, copper, chromium, lead, zinc, fluorspar, pyrites, phosphates etc., which are the basic wealth of the nation. The economic development of a country depends in a large measure on its capacity to exploit these resources effectively and efficiently. To be able to utilise even low grade ores cost-effectively is thus a challenge. CSIR laboratories, particularly NML, Jamshedpur and RRL, Bhubaneswar have been pioneers in conducting studies and developing methods and techniques for 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 tpd manganese pan sintering plant at Shreeramnagar, and a 2x30 tpd iron ore sintering plant at Barbil set up based on 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 NML; iron ore washing and sintering plants set up at Noamundi for TISCO, Dalli-Rajhara for Bhilai Steel Plant, Barsua for Rourkela Steel Plant, Bolani Mines for Durgapur Steel Plant and Kiriburu for Bokaro Steel Plant were based on the detailed technical know-how developed by NML; low grade fluorspar beneficiation plants of 500 tpd by Gujarat Mineral Development Corporation and 50 tpd by Madhya Pradesh and Maharashtra Minerals and Chemicals (Pvt) Limited were also based on NML flowsheet; 100 tpd graphite beneficiation plant set up in Tamil Nadu was again based on NML designs.

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

Nickel and cobalt are totally imported at present. RRL, Bhubaneswar has been entrusted 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, Thiruvananthapuram is ideally placed to work on minerals which are generally categorized as 'rare earth'. They have been working on development of process for manufacture of synthetic rutile by catalytic process route. The laboratory investigations have shown encouraging results and they are now upscaling the process to a level of a demonstration plant with industry's participation.

EDUCATION & RESEARCH
(Micro-electronics)

The Department of Electronics (DOE), Government of India and the University Grants commission (UGC) have jointly identified 11 universities where a two-year postgraduate course in "Electronic Science" has been started. The objective is to make available the trained manpower to take up R&D activities in specific areas of electronics such as LSI/VLSI design, fibre optics, artificial intelligence/robotics, advanced signal processing, instrumentation and high power devices. The 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 generation of special manpower for computers and for bridging the gap between supply and demand of trained manpower for computers was started by DOE. The emphasis has been on multiple effect programmes like the cross migration programme and teachers training programme etc. A postgraduate course leading to the degree Master of Computer Application (MCA) is identified to be running at thirty six universities/institutes. Another one year postgraduate diploma in computer application (DCA) running in collaboration with UGC is identified for 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.

Besides, several other laboratories and R&D centres are engaged in activities which would facilitate microelectronic device processing. Central Scientific Instruments Organisation (CSIO), Chandigarh is running a comprehensive programme on the development of capital instruments which typically constitute a fabrication line. CAT, Indore is developing Synchrotron Radiation Source whose miniature version could be tapped for submicron lithography. Work on plasma polymerisation, dry resists and e-beam writing is going on at University of Pune. NPL, Delhi has also been active recently though some of its programmes on characterisation of microelectronic materials, collaborative programmes and assembly of process equipments. Several other institutions such as IISc., Bangalore; TIFR, Bombay; NC, Pune etc. have also been contributing to specific sectors of the entire fabrication process either directly or through their collaboration with other institutions.

The entire 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 & medium scale integrated circuits (SSI, MSI) and Large & very Large scale Integrated Circuits (LSI, VLSI). These activities are being undertaken at academic or educational institutions, Research & Development (R&D) institutions or in industries. Some R&D centres are part of an educational institution, where they concentrate on academic or open ended research. Some others are at industrial site where the main aim could be technology/product upgradation. Some others are exclusively R&D institutions which concentrate on specific applications such as telecommunication, defence, industrial sector etc. R&D institutions generally welcome trainees and exchange visitors from within and outside their national boundaries on pre-agreed terms. A few R&D establishments also have complete fabrication-cum-testing line for a particular process to enable them perfect a technology and produce devices in small numbers for specific purposes (Table 7 & 8).

Analogous to the establishment of National Radar Council (NRC) and Technology Development Council (TDC), national Microelectronics Council (NMC) was set up in India as early as 1985. Its responsibilities included overseeing, coordinating and implementing the national programmes of R&D, technology development and manufacture in the area of microelectronics. It is giving thrust to proliferating computer Aid Design (CAD) culture in the country at academic institutions, R&D laboratories and electronic equipment manufacture; setting up prototype foundries for MOS ICs and updating existing technology and manufacturing capability for bipolar ICs. A clear plan to establish design centres of increasing levels of competence has been followed.

FUTURE PERSPECTIVES

The development of new materials in India has been in relation to the great advances that have taken place in S&T abroad and to the needs of Indian society. These efforts led to the capacity building in many areas towards achieving self-reliance in the country. The requisite expertise for the development of the newer and special purpose materials for the hi-tech applications is available in the country at the 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 inputs from industry in this direction till beginning of this decade were few, increasingly the industry has taken on the responsibility of participating in the country's plan programmes and broadened its base to absorb the new technologies. Materials like micro-alloyed steels, dual phase steels, and zinc aluminium bronzes, which are cost effective and better performance alternatives are being developed. For any developing economy to be successful in such endeavours, there has to be an active collaborative effort by the government and industry. A number of programmes for 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 peculiar significance in the 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 the industry would not have been possible without these materials. Keeping in view 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/programme of forging linkages among the relevant academic and R&D, institutions including production centres in India where sufficient expertise has been developed so as to consolidate the strength in this vital field of high technology.

The Board may focus its attention on the development of 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), Govt. of India, is relevant. Their suggestions in respect of the following, deserve serious consideration:

> Development of process techniques to fabricate multilayer, 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 on new materials by SAC-PM are listed in Table 3. Thus, the article covers a brief overview on India's experience in the development of R&D facilities, scattered all over India, for promoting the new materials.

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SUMMARY OF RECOMMENDATIONSON NEW MATERIALS

Science Advisory Council to the [illegible]

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; [illegible]-25 times the present level of funding should [illegible] invested
2. Gallium arsenide and related III-V semiconductors	fast electronic devices computers: specialised photovoltaic applications, light emitting diodes and other solid state applications	very little effort: A national laboratory fully dedicated for the purpose should be establisned.
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 halide fibres should be simultaneously emphasised.
4. III-VI Semi-conductors	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-B-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 establisned to meet the entire gamut of single crystal materials.

Contd.....

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 in 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.
13. Super-conductros: 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 knowhow 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

(a) Amorphous silicon	referred to earlier in electronic sector	heavy investment is recommended
14. Hydrides	hydrogen from photo electro-chemical cell used in direct burning and in fuel cells.	many photo electro chemical cell material 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.	knowhow 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 5 : 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_2Thin 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

Contd....

Table 5 contd. from prepage

Academic Institutions	Field of Study
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 6 : Materials Research in selected R&D Labs in India

R&D Labs	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 Lab. New Delhi.	Poly crystalline 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 7

Organisations engaged in Development of materials for HMCs in India

S.No.	Organisation
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 8

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 Corportion 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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xxxxx