Physics of materials

As physicists, we believe that the work we do is very important to technology and also, we naively believe that the industries know, how important physics is to technological development. We are wrong. Politicians and industrial leaders have only a vague idea how physics contributes to technological development. The situation is aggravated by the fact that there is no single "physical" industry in the way that there is an identifiable "chemical" industry. Also, most physicists have a very simplistic view of this role. They tend to see physics as "the" fundamental science, from which technology develops as a next step. In fact, large areas of technology got developed in the past with minimal contributions from physics (civil engineering, much of mechanical engineering, mineral processing). Physicists should recognize that theirs is only one of several disciplines contributing to this process.'

— excerpts from comments of Peter Wedepohl, SAIIP, 2002.

The year 2005 is declared World Year of Physics (WYP 2005) by the United Nations Organization (see box). Although physics has played a crucial and important role in our day-to-day activities, it is noted that 'the perception of physics and its importance in our daily life has decreased in the General Public to such a low level that the number of physics students in high schools and universities has dramatically declined over the past few years'. To physicists and other scientists it may be obvious that even in this century physics would play a central and crucial role in further improving the quality of life in sectors like entertainment, transportation, medical care, communication, etc. and in solving problems associated with energy production, environmental degradation, public health and so on.

'\text{The choice of the year 2005 as “WYP” refers to the 100th anniversary of the “Miraculous Year” of Albert Einstein, when he wrote his legendary articles, which turned out to be the basis of three fundamental fields in physics: theory of relativity, quantum theory, theory of Brownian motion.'}

In this issue

One of the ways that the public awareness of physics can be improved is by publishing reviews of work that has taken place in the recent past in our laboratories and institutions; this may be augmented by publication of original and not-yet-published results of research in front-line areas. Currently, research activities in physics in our country cover a wide spectrum of topics: elementary particle physics, materials science, plasma research, solid state physics, nano-physics, atmospheric aspects, fluid dynamics, nuclear physics, quantum phenomena and so on. Current Science has been publishing original papers in many of these areas and also special sections on selected topics. Some of the special sections related to materials published in the recent past are: Surface characterization (25 June 2000), Soft condensed matter (25 April 2001), Surface characterization using accelerators (25 June 2001), Plasma applications (10 August 2002) and Nanoscience and nanotechnology (25 December 2003). In this issue we carry a few articles on 'Physics of materials'.

Why Physics of materials?

Condensed matter physics and materials science coexist in a single department in many academic institutions, as if they are two sides of one coin. Applications emerge when there is merging of basic, applied, and industrial science. Currently one sees development of functional materials, such as biomaterials, sensors, and other smart systems.

Experiments are being done in our country mostly using independent facilities. But globally the trend is towards 'science at a distance'. People are increasingly communicating by e-mail and videoconference and are 'able to pack a suitcase and go to a facility and do the experiment and then go home'.

A panel, recently constituted, identified a few areas to have high potential for important contributions by theoretical modelling. These are: (i) Biologically inspired physics and materials science, (ii) Materials far from equilibrium, (iii) Integration of materials' properties across length- and time-scales: The micro-macro connection, and (iv) Strongly correlated materials.

It is noteworthy that study of correlated systems has been receiving attention in India at a few centres, addressing issues at the very core of condensed matter physics and materials science. In recent years much of this research has been on the high-temperature superconductors, heavy fermion materials, and quantum Hall systems. Specifically theory of magnetic materials involving study of the cuprates and f-electron intermetallic compounds, the recently discovered borides, germanates, and Mn and Ru-based transition metal oxides come under purview. Interactions in disordered quantum systems assume importance because of the problem of strong correlations in quantum systems, made difficult by the presence of disorder.

Real materials are complex—their composition (number of components) and structure (grain size, morphology, etc.) are not simple. These complexities appear to be necessary to obtain their desired characteristic properties. Research in complex materials is at the interface between condensed matter physics and more traditional materials science; multicom-

### International Year of Physics 2005

1 June 2004

**The General Assembly of United Nations,**
- Recognizing that physics provides a significant basis for the development of the understanding of nature,
- Noting that physics and its applications are the basis of many of today's technological advances,
- Convinced that education in physics provides men and women with the tools to build the scientific infrastructure essential for development,
- Being aware that the year 2005 is the centenary of seminal scientific discoveries by Albert Einstein which are the basis of modern physics,
- Welcomes the proclamation of 2005 as the International Year of Physics by the United Nations Educational, Scientific and Cultural Organization;
- Invites the United Nations Educational, Scientific and Cultural Organization to organize activities celebrating 2005 as the International Year of Physics, collaborating with physics societies and groups throughout the world, including in the developing countries;
- Declares the year 2005 the International Year of Physics.

The resolution was approved by acclamation on the 10th of June 2004.
ponent alloys fall under this category. The properties of these materials are of technological importance.

Remarkable progress has been made in recent years in understanding new phases of vortex matter in Type II superconductors. These phases are particularly important for the magnetic field-temperature phase diagram and proposed applications of high-temperature superconducting materials. A rich variety of regimes and physical phenomena have been revealed by advances in experimental techniques. Many important fundamental problems remain, like in soft condensed matter and self-assembling systems.

Resume of this special section

We have seven articles in this special section. There are several other areas in which research is underway in the country but which are not covered in this special section. Some of them are: Soft condensed matter, nanostructured materials, materials under extreme conditions (temperature, pressure, magnetic and electric fields), Bose–Einstein condensate, advanced scientific computing, etc.

S. R. Banerjee has reviewed (page 54) photoemission studies on quantization of electron states due to confinement in nanostructures, namely Na films on Al(111). He discusses ‘features in the valence band spectra that behave like quantum well resonances in a narrow photon energy range’. He has also discussed electronic structure of Au nano-bubbles embedded in sub-surface region of Al. Amongst other observations, he notes that the Au 2p binding energy varies systematically as functions of Au’ implantation energy and its fluence.

Undoped and doped quantum antiferromagnets (AFMs) in low dimensions exhibit a variety of novel phenomena. Indranil Bose (page 62) deals with a special class of these low-dimensional AFMs, the spin gap (SG) systems. One of the emphases of the review is to motivate research to look for real materials to confirm theoretical predictions. A few examples are dealt with in depth to illustrate the strong interdependence of theory and experiment. Several spin models (for example, spin ladder model) are dealt with in this context. Most of these models are involved with quantum phase transitions (QPTs). She notes ‘One might think that experimental observations of such QPTs is not possible as exchange interaction strengths cannot be changed at will. There is now reason to believe that exchange interaction can be controlled’ and proceeds to discuss a few examples and the implications on future applications.

A class of functionally important materials is in the domain of magnetic materials. Magneto-structural phase transitions are now recognized as important in the behaviour of materials exhibiting colossal magnetoresistance or giant magnetoelastic effect or giant magnetoelasticity etc. S. B. Roy and P. C. Chakraborty, have in their article (page 71), dealt with features associated with magneto-structural phase transitions that are quite general to different types of materials. They have ‘highlighted that the key features associated with such magneto-structural phase transitions are phase coexistence and metastability’ and that ‘these features are actually universal characteristics of a disorder-influenced first order phase transition’. The phase-coexistence phenomenon is also related to vortex solid melting phenomenon.

S. N. Kaushik (page 78) deals with magnetic behaviour of various systems depending on the nature of magnetic inhomogeneities. The systems span a large variety— including ferromagnets, antiferromagnets, soft magnetic alloys, nanostructures and so on. He notes that attempts to understand origin of magnetic inhomogeneities on existing knowledge have had limited success because of conflicting opinions. As a result of detailed analysis of various models and experimental results, it is concluded that ‘the infinite ferromagnetic spin clusters model (originally proposed by Kaushik) is shown to provide a coherent basis for understanding the nature and origin of magnetic inhomogeneities’, in case of amorphous Fe–Zr alloys.

About a decade ago scientists at TIFR, Mumbai had discovered that a quaternary system, namely, (Y–Ni–B–C) exhibited superconductivity at a fairly high temperature (13 K). Since then a whole range of materials derived from this system, referred to as quaternary borocarbides have attracted attention all over the world. Chandan Mazumdar and R. Nagarajan (page 83) have detailed the intense activity in these borocarbides with varying rare earth elements and transition elements. A variety of phenomena including heavy fermion behaviour, valence fluctuation, coexistence of superconductivity and magnetism and so on are observed. The article gives a flavour of the whole range of materials studied with varying phases, properties and still open problems. As the authors note, ‘the review gives a feel for the methods and efforts which nearly represent a piece of classic science that went into the discovery of superconductivity in quaternary borocarbides’. Materials of type RuSiO (R = Dy–Lu and Y) exhibit novel and multiple phase transitions. These phase transitions are subtle and are a result of interplay of charge density waves with superconductivity and magnetism. In addition to discussing these observations, S. Ramakrishnan has presented (page 96) the rich variety and complexity of the phase transitions in a more general class of compounds, namely, RE₁₋ₓTxMₓO₈ (T = Rh, Ir and M = Si, Ge and Sn). He notes ‘unusual multiple phase transitions are realized in this structure depending on the choice of elements. One can observe superconductivity, magnetism, coexistence of superconductivity and magnetism, coexistence of charge density wave with magnetism or superconductivity, giant magnetoresistance and heavy fermion behaviour in these systems’.

Study of manganite alloys, with formula Laₓ₋₁₋ₓAₓMnO₃ (A = Ca, Ba, Sr), has been of interest for several decades but more so, after the discovery of colossal magnetoresistance in these alloys recently. They exhibit coexistence of metallic behaviour with magnetism in certain range of composition. The distortions and vibrations of the MnO₆ octahedra are believed to play an important role in the metal to insulator transition in these systems. M. Premila et al. (page 102) have described infrared absorption measurements of Laₓ₋₁₋ₓCuₓ₋₁₋ₙMnO₃ and based on the analysis of these data, concluded that interaction of the IR active phonons with Jahn–Teller polarons is crucial in the transition to the metallic state.

To conclude, one notices that the contributors to this special section have arrived at important conclusions, based on theoretical models or based on analyses of data obtained by use of a variety of experimental techniques measuring resistivity, susceptibility, specific heat, superlattice structure, magnetoresistance, neutron diffraction, etc. as functions of relevant parameters like temperature or magnetic field. Thereby, they have achieved a coherent and consistent understanding of materials and the physics underlying the behaviour of these materials and their properties. Although this special section contains only a few articles, they are representative of the richness of the activity in materials science in India at the frontiers of current research in this age of materials science. It is hoped that Current Science would carry a few more special sections on Physics in this WPY 2005. I thank all the authors for their contributions to this special section.

K. R. Rao
Guest editor