Optoelectronics

Sudhanshu S. Jha

School of Physics, Tata Institute of Fundamental Research, Bombay 400 005, India

The challenge of the new technology of optoelectronics and photonics is examined briefly, emphasizing the role of research and development cycle in condensed matter science. Some suggestions to improve our inadequate effort in this field in India are also discussed.

A discussion on the topic 'Optoelectronics' is particularly appropriate here, because this [Physics] department started its activities with the excellent tradition of doing optics and condensed matter physics at the frontiers of knowledge, and this institute [IISc] is an ideal place for developing future technologies. The study of optical properties of condensed matter indeed forms the main basis for the technology of optoelectronics. Here I examine briefly in a very general way a few important points related to (i) experimental research in condensed matter science and the development cycle for a new technology, (ii) the challenge of photonics and opto-electronics, (iii) the inadequate Indian effort in optics, semiconductor science and optoelectronics, and (iv) the question whether it is possible to change this situation.

The research and development cycle

In condensed matter research, one is concerned with the exploration of diverse physical phenomena occurring in different kinds of materials. One is interested in knowing properties of these materials, whether exotic or otherwise, in response to a variety of external stimulus and physical conditions. Having gained this basic knowledge and understanding one then tries to modify known systems to design new deliberately structured materials with desired and controlled properties (Figure 1). Doped semiconductors and other solids, superconducting layered systems, semiconductor quantum heterostructures, metallic magnetic superlattices, and other types of nanostructure materials are just a few familiar examples of such deliberately designed materials. Such materials with controlled properties are important because they can be used directly to fabricate real devices for particular technological appplications. In turn, successful fabrication of high-technology devices motivates experimental researchers to study and design new materials with higher levels of complexity and precision. The emergence of optoelectronics technology is the most recent important example of this research and development cycle beyond the existing technology of semiconductor microelectronics.

The challenge of photonics and optoelectronics

The basic philosophy behind the new technology is to develop and fabricate photonic devices in which optical photons (light waves) instead of electronic charge-carriers

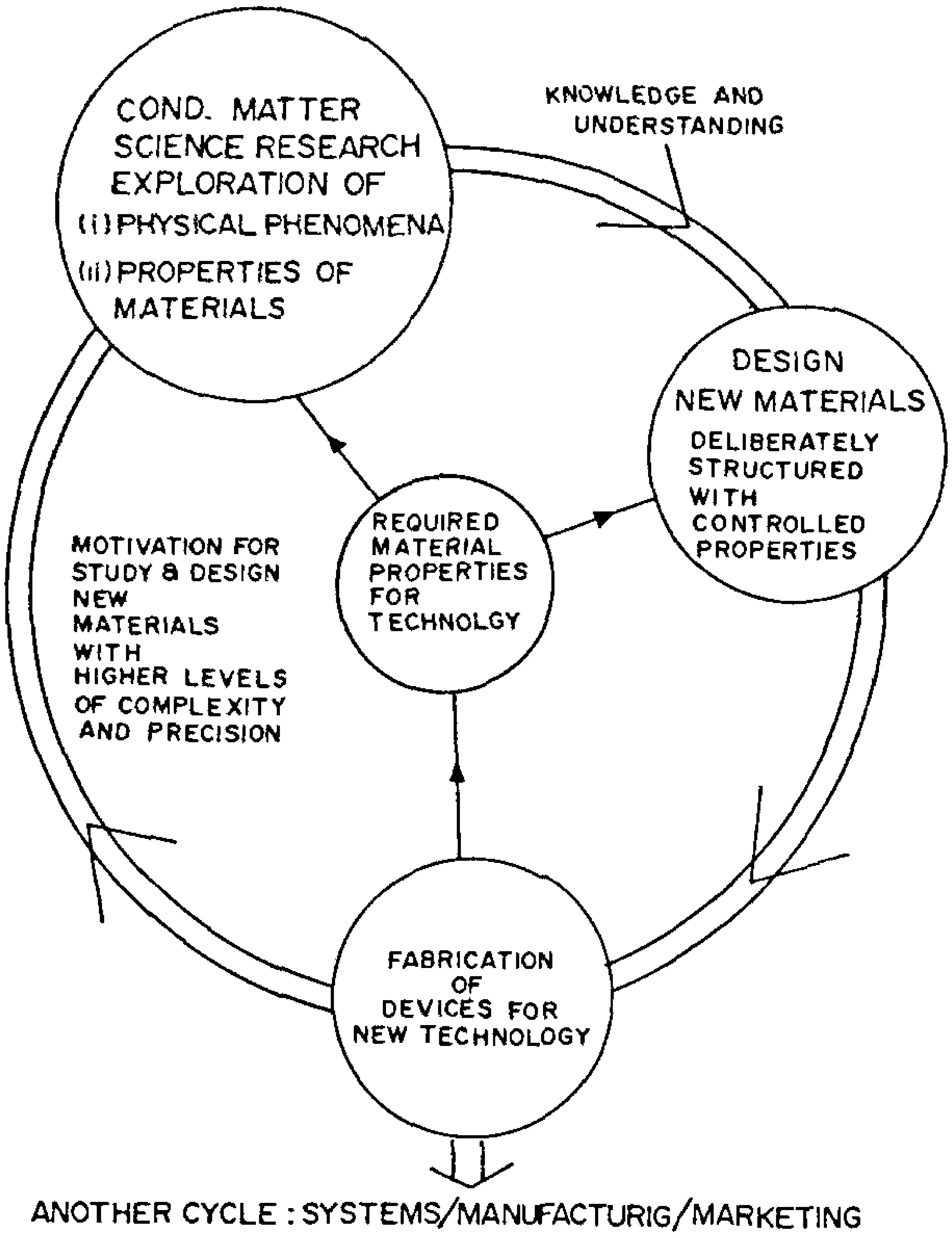

Figure 1. Condensed-matter science and the corresponding research and development cycle.

are controlled and manipulated for the usual task performed by conventional microelectronics. Because of the availability of a very large band-width at optical frequencies and the possibility of ultra-fast two-dimensional optical processing, the field of microelectronics is steadily moving towards this new technology of photonics. In years to come, it is destined to play the prime role in the rapidly growing information industry. Major applications include optical communication, signal and image processing, optical sensors for metrology and control, optical computing, information storage, biomedical devices, industrial and military use, and even important experiments in basic sciences. However, to take full advantage of the large band-width, one needs optical amplifiers, photodetectors, modulators and switching systems with response rate in the range of 10^{13} Hz or more. A large variety of materials is required for different functions in integrated photonic systems. At present, because of the ease in large-scale integration and the possibility of small sizes, the top choice for optical sources and photodetectors is the conventional semiconductor. Development of cheap low-dispersion silica fibers with losses lower than the conventional copper co-axial cables by almost two orders of magnitude has made optical fibers an ideal transmission medium even for existing low-rate electronic communication systems. With the recent fabrication of rare-earth-doped fiber lasers and amplifiers, there will be no longer any need for usual repeaters at the intermediate stations in the long-distance transmission lines. Different types of nonlinear optical materials are also now available for efficient modulation and switching. But the final goal is still far away.

In spite of the tremendous progress made during the last several years in developing very fast single-mode semiconductor diode lasers and amplifiers, erbium-doped fiber amplifiers, vacuum avalanche photo-diode detectors and novel integrated electro-optic modulators, the general speed of operating optical systems still remains below 10^{11} bits/s. In any case, as of now the field of optoelectronics is a hybrid technology in which both the conventional semiconductor microelectronics and new photonic devices are used depending upon their relevant characteristics and suitability in performing specific functions at the current stage of development. The main point to note in this discussion is the fact that the progress made in optoelectronics is the outgrowth of developments in optics, materials science and semiconductor microelectronics. It is the interaction between scientists and engineers working in these fields and the ideas generated by them which have brought the field to the present level. The challenge of developing much faster devices to take advantage of the full potential of photonics still remains one of the most fascinating tasks to be tackled. It will require new ideas and discovery of new materials or new principles.

The Indian scene

Till the end of the second world war, the research activity in optics and optical spectroscopy was being conducted in India at a very high international level. However, with greater emphasis on new fields like nuclear and particle physics and techniques like nuclear magnetic resonance and electron-spin resonance spectroscopies, optics was no longer popular among younger generation of physicists during the fifties. This transition, of course, took place almost everywhere in the world. But, what is surprising is that, even after the advent of lasers in the early sixties, optics remained on the back burner in India for a very long time. This is in spite of the fact that all major new revolutionary concepts establishing the foundations of modern physics to-day owe their origin to experiments involving optics and optical spectroscopy. At present, optics is not only at the top of various emerging technologies at the frontiers of knowledge, its progress is helping to solve the most fundamental problems of science involving precision tests for the validity of quantum mechanics and detection of gravitational waves.

By now, we do have a few good established groups in India working on optoelectronics and related optics, details of which are available in a recent article by Rustagi[1]. Essentially, work involves development of different kinds of lasers, study of nonlinear optical properties of materials, optical fibers and waveguides, design of optical communication systems, optical data processing, holographic storage, optical switching techniques, range finding, and industrial and medical applications. However, most of these activities are either theoretical or at a much lower level of experimental sophistication compared to the international scene. Similarly, we have several groups now which are involved in R & D work in semiconductor science and technology[2]. But till very recently these two types of groups working on optics and semiconductor microelectronics had very little interaction. As a consequence, we do not have significant R & D activity in fabricating the state-of-the-art semiconductor diode lasers and photodetectors even to-day. In experimental optical-fiber research also, we are far behind, with hardly any major group where work on doped-fiber amplifiers is being taken up seriously. Because of very rapid developments taking place on the international scene, and because of our highly inadequate and fragmental experimental efforts in optics, materials science and semiconductor microelectronics, we are faced with an up-hill task to catch up with the rest of the world.

Concluding remarks and suggestions

The story of optics and optoelectronics in India is not unique to these fields. The question one will like to ask is whether it is possible to improve the situation in the near future. Unless we increase the level of experimental activities and upgrade the laboratories in academic and other institutions in India, the catching up with the best in the world will remain only a dream. Can we do it?

It is not possible to answer the above question in a categorical manner. But one has to be an optimist. This is not the occasion to consider in detail more general matters like (i) the level and method of research funding, (ii) immediate structural reform and upgradation of our university system, and (iii) setting up of research and development laboratories in the industrial sector. However, I give below a few specific points particularly related to our subject of discussion:

(i) As emphasized earlier, the culture of doing high class experimental research at least at selected institutions has to be re-established on a high priority. For optics and condensed matter science, it will require upgradation of laboratories and other facilities for preparing different kinds of materials and for characterizing them to very high accuracies. One must be able to study physical phenomena related to these materials, and make precision measurements using either commercial equipments or advanced instruments developed by the laboratory for the required purpose. The success of most experiments at the frontiers depends upon the technology available to set-up such experiments and the ability to make measurements more and more precise. Higher precision must become the keyword for experimental research.

(ii) For the optimal utilization of existing facilities at laboratories set-up outside the university system and expert manpower available in universities, collaborative research between university departments and government laboratories has to be encouraged at all levels.

(iii) The R & D cycle related to optoelectronics involves creation of proper strength and expertise in optics, materials science and semiconductor microelectronics. As far as possible, it is desirable that these activities and groups are established on the same campus or nearby institutions, with close interaction and exchange of ideas and facilities among them. One must create correct atmosphere on the campus of such institutions to emphasize each leg of the development cycle. Since the end product of this cycle is the optoelectronics technology, the interaction (see Figure 1) at the appropriate level with industry and other users is also necessary.

(iv) Even with the best of intentions, the present bottleneck will be the availability of enough motivated and expert manpower for establishing such progammes, apart from the high level of funding. Instead of establishing separate new institutions for optics or microelectronics, I feel that existing institutions like IISc, IITs and some of the universities are capable of training young scientists for this purpose. In a few years, they may also introduce optoelectronics as a separate field of study.

(v) The funding for such an ambitious programme discussed above should be provided by an agency like the Department of Science & Technology (DST). The Department of Electronics (DoE) does not seem to appreciate the important leg of the development cycle involving research in condensed matter science and optics which is vital to meet the real challenge of photonics and optoelectronics. The limited vision of this type is never going to take us to the frontiers.

1. Rustagi, K. C., in *Physics in India* (ed. Jha, S. S.), Indian National Science Academy, New Delhi, 1994, Chapter 13, p. 120, see also, Sirohi, R. S. and Nijhawan, O. P., *ibid*, Chapter 12, p. 109.
2. Arora, B. M., in *Physics in India* (ed. Jha, S. S.), Indian National Science Academy, New Delhi, 1994, Chapter 19, p. 169