ADVANCED MATERIALS

Polymers as Advanced Materials

Editorial Essay

By Claus D. Eisenbach* and Dietrich Haarer*

The bottleneck in the development of new technologies is often defined by the limitations of the available materials. Obvious examples for such limitations in materials parameters are a) that charge carrier mobilities can control the maximum frequency in semiconductors or b) that the read/write speeds and signal-to-noise ratios of possible optical stores depend on the sensitivity of the storage media. Progress in these and other fields has been mostly due to interdisciplinary efforts: The improved production of epitaxially grown semiconductor layers has contributed as much to the development of semiconductors as has the art of producing thin, sputtered films to the development of optical storage media, and polymer science is crucial to the success of many device applications. In the semiconductor industry, for instance, polymers play a crucial role as photoresists, dielectric layers, and packaging materials, or in the field of optical data stores, polymeric materials can be used as substrates as well as in the form of thin films as data carriers. In high performance polymers the combination of low weight, moderate thermal stability and high tensile strength, has further improved fiber reinforced materials, and has lead to major breakthroughs in aerospace technology.

Polymer science is a young discipline which has lately made large steps towards innovative materials and processes. This is a consequence of the almost unlimited scope for the molecular design of macromolecules, and of blending polymers with low or high molecular weight components. Polymer processing and molding, not to speak of composites, will also make major contributions to the further development of advanced materials. The field of "materials science" has increased in importance relative to physics and chemistry. This trend is documented by the increase in the representation of the "materials science" research faculty staff in the US program of the Interdisciplinary Laboratories (IDLs)/Materials Laboratories (MRLs) from 19% in 1970 to 35% in 1985.[1]

Polymers are ideal examples of structural and functional materials because of their versatility in practically all areas of modern life and technology. Some of their outstanding properties are high elasticity, stiffness, toughness, strength, good thermal resistance, and high chemical stability. Typical examples of their uses are high impact thermoplasts, thermoplastic elastomers, ultrahigh modulus fibers and temperature resistant polymers. An extension of the potential of engineering plastics beyond the organic multiphase polymer systems is given by the combination of polymers with non-polymeric and/or non-organic materials resulting in high performance composites. Progress in this area is favored by the growing research activity in interface phenomena and thin coatings and films. Finally, the electronic properties of polymers or macromolecular systems open up fascinating prospects for storing, processing and transmitting of data, as has been outlined by recent developments in the area of polymeric light waveguides, non-linear optics or conducting polymers.

It is a primary objective of basic materials science to develop a detailed knowledge of the structure-property relationships in macromolecular systems in order to understand how the molecular architecture of the individual polymer chain influences the morphology and superstructure of the polymeric materials. This goal can only be achieved by an interdisciplinary research and development effort, combining the natural sciences and engineering. As a result of the funding situation in West Germany, these considerations have resulted in an effort by researchers from different fields and from both academic and industrial laboratories to cooperate more closely, to participate in joint research programs and even in the establishment of new institutes supported through governmental and industrial research funds. This is reflected by the natural science activities of central research institutions and of universities such as those in Darmstadt and Kaiserslautern. Polymer materials science is especially strong in Freiburg, Mainz and Bayreuth, emphasized by the recent founding of the Max Planck Institute for Polymer Research (Mainz) and the Institute for Materials Science (Bayreuth).

The situation in Bayreuth, where both authors are working illustrates the general concept of the concerted efforts in materials science. Macromolecular topics have been highly emphasized in both the Chemistry and Physics departments leading to a great deal of interdepartmental research: Our program ranges from the synthesis of new macromolecular and micellar systems, through their extensive characterization to specific investigations, e.g. electronic processes in synthetic and biological macromolecular systems. The newly established Institute of Materials Science was conceived as a place of interaction between basic and applied research and is well situated within this environment to interact with the high temperature-geo scientists in the university as well as the local ceramics and electronics industries.

In order to promote this interdisciplinary approach to materials science a symposium was held in Bayreuth from 10.–12. April at which topics of current interest from the areas of polymeric, structural and functional materials were

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presented and discussed, complemented by contributions from the related fields of inorganic/organic polymers and ceramics. It is planned to integrate the inorganic non-metallic materials into the future symposium programs, corresponding to our wishes for the development of materials science in Bayreuth. A key issue and primary concern of this meeting was to discuss the different facets of fundamental and applied research and thus provide a platform for the dialogue between people working in academia and in industrial research institutions. The symposium focused on strategies and steps towards polymers with new and unusual properties, and experimental results and theoretical concepts of the structure-property relationship of organic polymeric materials. Furthermore, connections, similarities and analogies between polymeric materials, and ceramics or inorganic materials in general became visible. Also in this respect, first signs have become apparent at a recent materials science conference organized by the West German Ministry of Science and Technology (BMFT).[2] Among the subjects which were highlighted at this meeting, polymers have made remarkable progress in high-tech applications such as information technology, where tailor-made photoconductive media dominate the field of electro-photography and are finding application in modern techniques of offset-printing. The impact which non-linar optical polymeric materials will make on the advancement of integrated optics was assessed and without doubt the use of polymers as light fibers is a feasible and interesting application. Research into conductive polymeric materials has recently made progress in terms of an increased understanding of the basic processes, but applications for example, in the field of rechargeable batteries are still at an early stage and can therefore not be fully assessed. Liquid crystalline polymers will probably make significant progress in the near future, although it is not yet clear whether it will be the mechanical aspects, (flow viscosity during processing etc.) or the optical aspects of this new class of polymers which will carry the main impact. The mechanical properties of new polymeric materials like copolymers and polymer blends will, without doubt, be a field of active research, where new synthetic materials will be of eminent importance. A question to be answered is, whether or not reinforced polymeric materials can only be made through macroscopic reinforcement with carbon- or glass-fibers, or whether they can also be made by "molecular reinforcement", i.e. by synthesizing molecularly ordered macromolecules with rod-like elements which form structures with a higher degree of order.

Several of the long-term goals of materials research were compiled at a recent IUPAC-meeting in Japan.[3] One of these goals is the development of "molecular devices", for which the basic questions are still unanswered, namely how to manipulate data at a molecular level, but towards which steps have been taken in laser techniques like hole burning or electric techniques like tunnelling microscopy, where ultra-high frequency resolution or spatial resolution can be achieved. However, we have long to wait before the elegant schemes of dynamic biological systems can be incorporated into technical systems as the difficult task of tailoring macromolecules to mimic self-organization phenomena, and molecular reinforcement of macromolecular systems in synthetic polymeric materials has first to be mastered. Molecular schemes like those in nature also require systems which are far from thermodynamic equilibrium. Here we have to explore the largely unknown field of molecular assembly which is certainly different from most present synthetic procedures. If these and many other materials related problems are to be effectively solved it is clear that an interdisciplinary approach is needed, and we are sure that it is this approach which will lead us to new frontiers to the benefit of all.

[1] P. A. Psaras, H. D. Langford (Eds): *Advancing Materials Research*, National Academy Press, Washington D.C. 1987.
[2] *Symposium Materialforschung 1988 des Bundesministers für Forschung und Technologie (BMFT)*, 12.–14. September 1988, Vorträge und Poster, Band 1 and 2, Hamm/Westfalen 1988, KFA Jülich GmbH, 1988. See also: W. Faul, *Angew. Chem. Adv. Mater. 100* (1988) 1824; *Angew. Chem. Int. Ed. Engl. Adv. Mater. 27* (1988) 1754.
[3] K. Ohsima, K. Saito, M. Hirooka (Eds): *Advanced Materials for Innovations in Energy, Transportation & Communications. Perspectives and Recomendations.* The Chemical Society of Japan, Tokyo 1987.

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