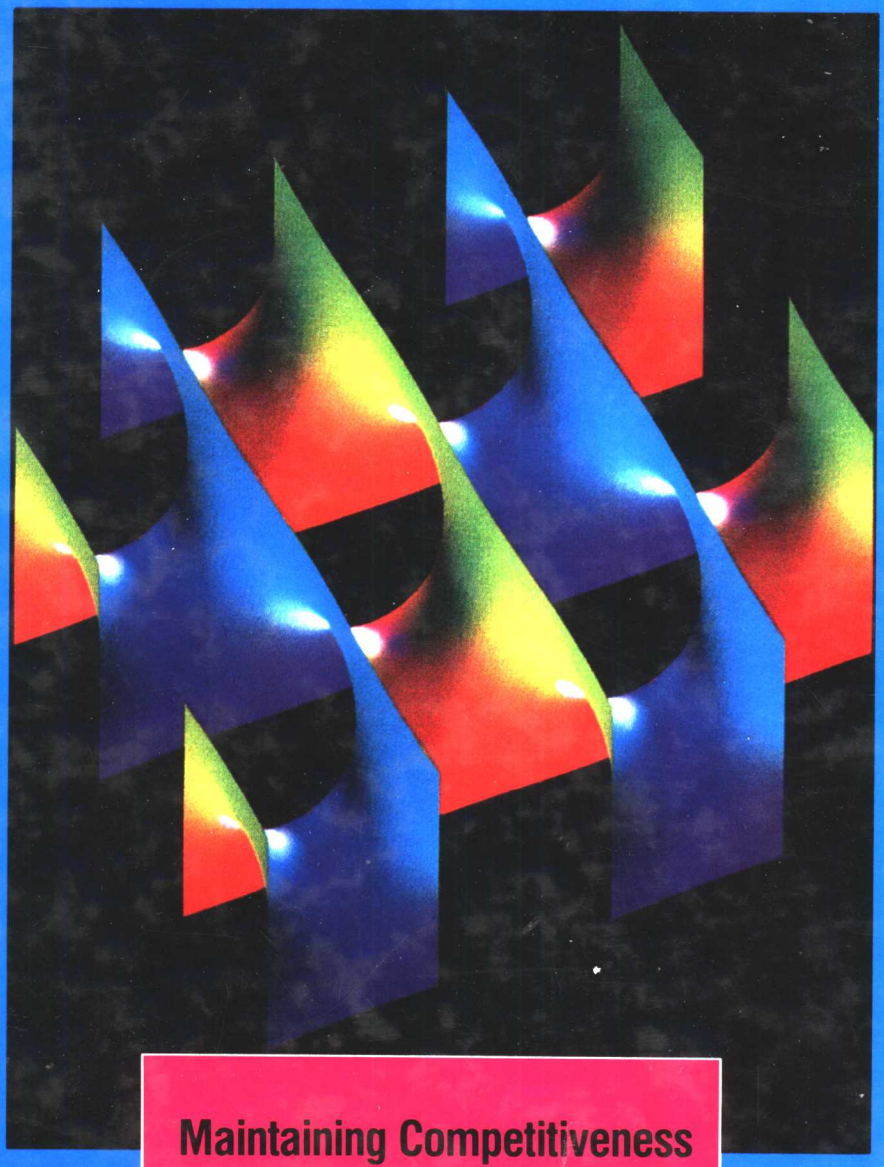
MATERIALS SCIENCE AND ENGINEERING FOR THE 1990s



Maintaining Competitiveness in the Age of Materials

NATIONAL RESEARCH COUNCIL

MATERIALS SCIENCE AND ENGINEERING FOR THE 1990s

Maintaining Competitiveness in the Age of Materials

Committee on Materials Science and Engineering

Solid State Sciences Committee
Board on Physics and Astronomy
Commission on Physical Sciences, Mathematics, and Resources
and
National Materials Advisory Board
Commission on Engineering and Technical Systems

National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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OFFICE OF THE CHAIRMAN

This report, Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials, encompasses a broad enterprise. The field's intellectual content ranges from the quantized Hall effect to dramatic advances in the performance of high-strength structural materials. The vitality and pace of the field are everywhere evident. The Nobel Committee recognized fundamental advances in materials research for three consecutive years -- 1985, 1986, and 1987. Success in translating advances in materials science and engineering into new and improved materials is unparalleled. There have been gratifyingly broad applications of new materials in areas with immediate impact on human welfare such as biomaterials, suitable for artificial organs, biochemical sensors, vascular grafts, and ophthalmological devices.

Despite the diversity of the field, the report points to unifying trends that emphasize the need for scientists and engineers in universities, government laboratories, and industry to work together closely. In particular, the authoring group, the Committee on Materials Science and Engineering, urged greater efforts by the federal government to coalesce these sectors, and endorsed Congressional efforts to strengthen the coordination of federal agencies that support materials science and engineering.

The committee focused its recommendations on synthesis and processing of materials. This is the area that has produced dramatic improvements in superconducting materials, growth in the number of components in integrated circuits, and increases in the strength of structural materials. On the basis of a survey of several key industries, the committee recommended a national initiative in synthesis and processing built on cooperation among universities, industry, and government.

We believe that the field of materials science and engineering offers a special opportunity to act on the growing realization of the need for improved coordination and cooperation in the nation's effort in science and technology. We commend the report to your attention.

Frank Press
Chairman
National Research Council

Robert M. White
Vice Chairman
National Research Council

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The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

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COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS

Preface

In October 1984 Don Fuqua, then chairman of the House Committee on Science and Technology, wrote to the presidents of the National Academy of Sciences and the National Academy of Engineering urging the National Research Council to form a committee "to conduct a comprehensive materials research and technology assessment for the next decade." This direct expression of support from a U.S. congressman, which was further reinforced by the federal agencies with materials-related missions, marked the inception of the survey of materials science and engineering presented here. But the roots of this survey extend much further to include the initial recognition of materials science and engineering as a distinct area of endeavor. There have been earlier comprehensive studies of materials science and engineering, most notably that of the National Research Council's Committee on the Survey of Materials Science and Technology (COSMAT). The publication of COSMAT's 1975 report *Materials and Man's Needs* moved understanding and recognition of the field forward. At that time, national goals were focused on natural resources, energy, and the environment, as well as on defense. *Materials and Man's Needs* dealt with materials issues related to strategic materials, reduction of energy costs in production, biodegradability, recovery and recycling of scrap, and the materials cycle, all in the context of an awakened public awareness of the finiteness of the earth's resources. It also discussed the structure-property-performance relationships that have been so important to development of the field over the last decades. The present report, building on the foundation of that earlier report, stresses the importance of synthesis and processing.

At the inception of this survey, it was clear that materials science and

engineering had changed dramatically since the completion of the COSMAT report. A wealth of new discoveries and technological advances had drawn many new people to the field and had radically altered the field's concerns and methods. At the same time, a number of industries closely associated with materials science and engineering had undergone similarly dramatic changes—and not always for the better. America's mining and metals beneficiation industries, its commodity metals industry, its machine tool industry, its computer industry, and its electronics industry, which had been, and still are, major users of the results of materials science and engineering, were all losing major portions of their market shares to overseas competitors and shutting down research operations.

Prompted by Fuqua's letter, the Solid State Sciences Committee, in collaboration with the National Materials Advisory Board, devoted its spring 1985 forum to the question of whether a new survey of materials science and engineering should be conducted and, if so, how it should be structured. At the forum a remarkable degree of unanimity emerged regarding the potential value of such a study, and forum participants outlined a general statement of task for the project. Shortly thereafter, the National Research Council initiated a joint project under the Solid State Sciences Committee and the National Materials Advisory Board to conduct a survey along the lines suggested, and funding was obtained from the National Science Foundation, the Department of Energy, and the Defense Advanced Research Projects Agency, as well as from the National Aeronautics and Space Administration, the Air Force Office of Scientific Research, the Army Research Office, and the National Research Council.

The National Research Council's principal goal for the study was to present "a unified view of recent progress and new directions in materials science and engineering." Among the specific issues identified in the charge were

- areas of research and development particularly ripe for important advances;
- relationships among the various elements of materials research and development;
- the roles of the federal and private sectors, particularly as they relate to a balanced national materials effort;
- the effectiveness of the materials infrastructure in developing and commercializing new materials technologies;
- the effectiveness of materials research and education at universities; and
- international cooperation and competition in materials science and engineering.

The Committee on Materials Science and Engineering was constituted by the National Research Council with a special focus on the unity of materials science and engineering. The committee was carefully balanced with respect

to several different factors including the range of disciplines that conduct materials science and engineering, the variety of institutions in which these activities take place, and the scope of the field from science to engineering. By the summer of 1986, a committee of 17 eminently qualified individuals representing government, industry, and academia had been formed. In addition, a steering committee was established to provide oversight and guidance throughout the committee's deliberations.

One of the first and most challenging tasks facing the committee was to find a way of breaking down a subject as large and complex as materials science and engineering into manageable parts. The committee formed five panels, each of which examined an important area of the field that cut across all materials classes and ranged from science to engineering to industrial practice. The Panel on Research Opportunities and Needs in Materials Science and Engineering identified research areas of national importance in materials science and engineering and evaluated opportunities and needs in the field. The Panel on Exploitation of Materials Science and Technology for the National Welfare examined the links between scientific advances and economically competitive products and processes and other ways in which materials science and engineering affects the national well-being. The Panel on International Cooperation and Competition in Materials Science and Engineering outlined the global dimensions of the field, particularly as it affects industrial competitiveness in the United States. The Panel on Research Resources in Materials Science and Engineering assessed the resources available now and in the future for materials science and engineering in terms of facilities, instrumentation, and funding at universities, national laboratories, and industrial laboratories. The Panel on Education in Materials Science and Engineering considered personnel issues and the means by which future generations of materials scientists and engineers are to be educated.

The leadership of each panel consisted of one chairman and two vice chairmen drawn from the committee (the two committee co-chairmen were the only committee members not serving on a panel). Panel leaders included one person from industry, one from a government laboratory, and one from academia. In turn, the National Research Council appointed a balanced panel, and the panels conducted meetings and surveys, commissioned papers, and gathered data. In this way, a broad cross section of the materials community was involved in the preparation of this report (there were 109 formally constituted committee and panel members and nearly 400 other individuals who contributed to the study). The co-chairmen of the committee and the committee members also appeared before a number of professional societies to present status reports on the committee's deliberations and to encourage participation and feedback.

Each panel produced a major report on its assigned issue, and these panel reports form the basis for this report. However, this report is not organized