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Materials science: technology and society *

1. INTRODUCTION

It seems appropriate to preface this International Conference on "Materials in Electronics" with a few remarks describing the background and the objective of materials research in general. The progress of civilization through the ages has been characterized by a slowly growing mastery of a number of materials for the purpose of fashioning tools and useful artifacts: thus we speak of the "stone age", the "bronze age", and the "iron age" as milestones in this development. Many of these advances were based on accidental discoveries that were refined by artisans and passed on to succeeding generations. During these millennia, materials were not "understood" in the sense that we now ascribe to this word, but practitioners of the art knew from experience where materials could be found that lent themselves to a favored treatment to produce desired properties. At times, this entailed journeys to distant lands, as the importation of tin ores from countries on the shores of the Atlantic or the vicinity of the Caspian Sea to the Mediterranean Basin indicate. Tin bronze became known in Egypt at about 2000 B.C.

These forward steps in the history of civilization were arduous and proceeded with many gaps and retrogressions. Thus steel was made in Iran as early as 1200 B.C., but the superb steel swords of Japanese manufacture did not appear until the 12th century A.D. Likewise, cast iron was first produced in China around 500 B.C. but not in Europe until 2000 years later. In device technology, one might refer to the "automatic toy" built by Hero of Alexandria in the first century A.D. that demonstrated the production of rotary motion by means of steam jets attached to a spherical vessel into which water was fed and heated. The steam engines with their many refinements introduced by Savery, Papin, Newcomen, and Watt, beginning around 1700 A.D. were a long time in coming.

When scientific methods were introduced during the 17th century and experiments began to lead the way to the establishment of the laws of nature, the rate of progress was enormously accelerated, and new vistas were opened in all fields of endeavor. Science and Technology have dominated our life style ever since.

* Presented at the International Summer School on subject electronics materials (Herceg-Novi 1971)

A better understanding of materials was a by-product of this historic development. Chemistry, Metallurgy, and Crystallography now permitted a look "into" materials where formerly a look "at them" had to suffice. The concepts of bond formation based in the electronic structure of the elements, the Phase Rule, alloy formation, and the importance of dislocations to the strength of materials, all these had their impact and culminated in a body of knowledge that is generally associated with "Solid State Physics". Research in this area was principally being conducted at universities and therefore not directed toward applications in the materials field. A few words about this distinction are therefore in order.

2. BASIC AND APPLIED RESEARCH AND THEIR RESPECTIVE SUPPORT

While the search for new materials electronic devices is frequently prompted by a foreseen need, it also happens quite often that unforeseen possibilities present themselves when the basic nature of materials is being investigated without the stated objective of finding a device application. The distinction between Basic and Applied Research has been the subject of lengthy discussions for many years; both are obviously important, and no sharp dividing line can be drawn between the two approaches, but it is poor policy to over-emphasize one over the other, except in a national emergency.

During World War II, the scientific resources, both in terms of manpower and available facilities, were effectively mobilized and directed toward a common objective within the framework of the Office of Scientific Research and Development (O.S.R.D.). The work done during that period was obviously mission-oriented and entailed mostly applied research. After the scientists had returned to their universities at the end of the war, the Office of Naval Research (O.N.R.) provided large sums to support basic research at many institutions until the National Science Foundation (N.S.F.) was organized in 1950 and took over that task. Originally funded at \$500,000, the N.S.F. budget this year amounts to 700 million dollars. However, efforts have been made in recent years, to extend the primary concern with basic research to "Interdisciplinary Research Relevant to the Problems of Society" (IRRPOS) which resulted in a program called "Research Applied to National Needs" (RANN) that was formally established in 1971 within NSF [Ref.2]. Meanwhile, "The National Policy and Priorities for Science and Technology Act of 1974" (Senate Bill 32) was passed in the U.S. Senate last October, but so far failed to gain support in the House. Senator Edward Kennedy has now re-introduced the Bill in the current session and hopes to get it passed with the altered date line of 1975. A similar reorientation of research systems has taken place in European countries, according to reports prepared by the Organization for Economic Cooperation and Development (OECD).

The earlier fragmentation of our research efforts is thus gradually being overcome by the creation of new institutions, a unified science policy, and a recasting of our societal goals [Ref.3]. Since these are in a large measure political objectives, their realization will depend on public consensus and therefore take a long time.

Research on Materials [Ref.4] has been similarly fragmented in the past and focused on the exploration of the properties of specific materials, e.g., metals, glass, ceramics, polymers, in university departments and at a few industrial research laboratories where enhancement of process technology was often the primary objective. The term "Materials Science" with its connotation of interdisciplinary research did not exist until 20 years ago. There were exceptions, to be sure. Cooperative research in materials was being conducted at the end of World War II at some of the large industrial research laboratories, such as the Philips Laboratories in Eindhoven, the General Electric Research Laboratory in Schenectady, and the Bell Telephone Laboratories at Murray Hill. There also existed three or four interdisciplinary materials laboratories at universities, one of the first of which was the Institut for the Study of Metals at the University of Chicago, founded by Cyril Stanley Smith in 1946.

It was soon realized that this effort was not sufficient to fulfil national needs both in terms of the advancement of the art and in terms of training an adequate number of graduate students. John von Neuman, then Commissioner of the Atomic Energy Commission (AEC), therefore proposed in 1955 that interdisciplinary laboratories for materials research be founded in larger numbers. The idea was carried forward by his successors, Herbert York, then Director of Defense Research and Engineering at the Department of Defense (DOD), and Willard Libby, a Commissioner at AEC. In 1958, the Advanced Research Projects Agency (ARPA) was organized as a separate arm of DOD and funded to carry forward the establishment of interdisciplinary laboratories at several universities. By 1966, twelve of these were in operation; the successful launching of Sputnik I in 1957 no doubt was an additional incentive for the vigorous pursuit of this program. New buildings were erected in many cases, expensive equipment, such as electron microscopes, electron probes, and spectrographs, was acquired, and a competent staff was engaged to attack challenging new projects. Professor R.A. Huggins, then Director of the Interdisciplinary Laboratory Program (IDL) of ARPA, reported in 1971 that the number of ph.D. degrees granted each year in materials science at the 12 universities had gone from about 100 in 1960 to between 350 and 360. Even outside the ARPA Program, the number of academic institutions in the United States giving degrees carrying the name "Materials Science" had increased to more than 40 where there had been only two or three at the time of the inception of the IDL Program.

Responsibility for the IDL Program was assumed by the Materials Research Division of NSF on July 1, 1972; the laboratories were then renamed "Materials Research Laboratories". The National Aeronautics and Space Administration (NASA) set up three block-funded programs at universities in the 1960's and the Atomic Energy Commission (AEC) established two of these in the same period. In addition, eleven universities have formed analogous materials research centers since that time, so that altogether 28 centers now exist. There is also being planned a Materials Research Laboratory focusing on Joining and one for Polymers [Ref.5].

Materials Science and Materials Engineering have in the past been looked upon as separate pursuits, so that the age-old distinction between basic and applied research was continued in a modern garb. Materials Science had developed from the much older discipline of Solid-State Physics, concerned with the study of electrical, optical and magnetic properties of crystalline solids, by broadening its scope to include all properties of all types of material, crystalline or noncrystalline, conductors, semiconductors, and insulators, such as glass, ceramics and polymers. Atomic structure, chemical composition, crystal habit, if any, presence or absence of defects, and surface texture were of prime concern when characterizing a material, but the methods used for producing the material and their possible effects on resulting properties were frequently not fully considered. This aspect was left to the Materials Engineer who concerned himself with applications. Such a separation of assignments contradicted the concept of a unified approach to materials research, since methods of fabrication can have a profound effect on materials properties. In recognition of this state of affairs, the Department of Metallurgy and Materials Science at M.I.T. has just been renamed "Department of Materials Science and Materials Engineering". Similar changes of names of departments in universities have taken place in the U.S. during the past several years.

The original creation of interdisciplinary materials laboratories at universities raised serious problems of organization and administration, since long-established boundaries between departments had to be crossed and new curricula be devised to fit the new requirements. As pointed out in the NAS Report [Ref.5], the academic community has traditionally resisted interdisciplinary and applied research; its reward structure is strongly tilted toward the disciplines, and funding agencies have favored the conventional approach. Strong efforts are therefore underway toward breaking these patterns of organization and leading the way to an integrated system of society and technology.

Professional societies have become aware of this trend and, in some cases, have revised their charter to allow for the inclusion of social questions, rather than exclusively technical ones, in their publications. An effort is also underway to reduce the large number of professional societies that are concerned with materials, so that the individual materials engineer has a better chance to follow their programs. After a prolonged study, initiated by Nathan E. Promisel, Director of the National Materials Advisory Board, a Federation of Materials Societies has been formed, and the majority of the approximately 35 societies concerned with materials have joined this Federation, so that duplication of effort can be avoided.

Technology and Society. We are accustomed to think of technology primarily in terms of machines, manufacturing techniques, and the processing of raw materials provided by nature. In this sense, technology produces artifacts that perform useful functions and that can be sold in the market place, if they satisfy an existing need. In a broader sense, the term technology also includes the introduction of new methods by which certain tasks can be more simply performed and the solution of complex problems made easier. The

invention of double-entry bookkeeping, for example, had a marked influence on the effective distribution of goods and services after the onset of the industrial revolution. In more recent times, advertising and marketing techniques have similarly affected these endeavors. In some fields, for example, in the printing industry, electronic processing is making heavy inroads on long-established procedures and is threatening to replace them. Computer-aided design and education are providing new insights into the intricate processes of creation and learning. Technology thus includes "hard" tools, such as the plow, the drill press, and the airplane, as well as "soft" tools, such as production scheduling procedures and computer programs—in other words, the gamut of practical media by which man purposefully interacts with his environment to satisfy his needs.

This interaction of technology and society is a dynamic process in which one or the other may push or pull. If technology pushes too hard, as has often been the case, society may not be ready to yield and accept the rapid advances. Dislocations are then created to allow an interplay of contravening stresses, but this can be a painful process. On the other hand, society has needs for which new technology could provide a solution. This possibility is often not recognized; indeed, there exists in our time a tendency to blame technology for all the ills of society and to prevent its further development.

Unfortunately, too many examples can be cited where the uncontrolled expansion of technology has led to dire consequences. The pollution of our rivers and lakes and that of the atmosphere is the result of unmindful dumping of waste products, the excessive use of pesticides and fertilizers, and the discharge of the by-products of combustion, both from smokestacks and exhaust pipes. These matters are now the concern of the Environmental Protection Agency and should be greatly alleviated in the future. But we will have to pay a price for the control measures. Having achieved industrialization and the affluence that flows from it, we can no doubt afford it. When we consider, however, that two thirds of humanity are still striving to improve their living conditions by adopting industrialization, we must realize that they will not pay much attention to the attending pollution of the environment that seems to be an unavoidable by-product. On a global scale, pollution is therefore likely to increase.

These questions were discussed at length among delegates from 114 countries at the United Nations Conference on the Human Environment held in Stockholm, Sweden, June 5 to 16, 1972. The agenda for the Conference had been carefully prepared in a series of preliminary discussions held over a period of several years and the gathering of reports from expert consultants in 58 countries which were condensed in an interesting book entitled *Only One Earth* under the editorship of Barbara Ward and René Dubos [Ref.6]. Maurice F Strong, a Canadian industrialist, was the Chairman of the Conference.

It would have been naive to expect a consensus of opinion on the vital questions that affect the global environment from such a diversified body of representatives; their parochial interests were too far apart to permit any

unified action. Indeed, the delegates spent much of their time on nationalistic trivialities. But, as Anthony Lewis pointed out, the very fact that the Conference was held shows that concern for the environment has entered the political consciousness of the world and that it is going to stay there. A number of positive actions were taken, such as the decision to establish an International convention on marine dumping, to declare a 10-year moratorium on whaling, and to set up a global atmospheric monitoring system comprising 100 stations to measure air pollution. It was also decided to create a Governing Council for Environmental Programmes (GCEP) charged with the responsibility to carry forward the plans endorsed by the Conference. This activity was later funded in the amount of \$100 million for the next five years by the major developed nations; the United States was to contribute up to \$40 million. The Headquarters of GCEP is being established in Nairobi, Kenya, far removed from other United Nations Centers in the West; this choice in itself was a considerable concession to underdeveloped nations. It is also noteworthy that the vital questions of population control and depletion of natural resources were not on the agenda in Stockholm.

Technology Assessment. The many studies described in the preceding pages clearly show that technology is a driving force that continually acts on society and brings about changes in our ways of doing things and in our expectations for the future. It has also been shown that harmful effects may result from an indiscriminate adoption of technology and that some of these may not show up until we have indulged in it for a long time. What is clearly needed is an "early warning system" by which harmful effects of technology can be foretold before it is too late to take corrective action.

Technology Forecasting and Technology Assessment [Ref, 7] thus became an increasing public concern in about 1965 when books on these subjects began to appear and conferences were organized to discuss the issues involved. Efforts to establish an Office of Technology Assessment (OTA) in the government were initiated by Senator Edmund Muskie and then by Representative Emilio Q. Daddario in 1967. Extensive hearings were held before the Subcommittee on Science, Research and Development of the House Committee on Science and Aeronautics in the ensuing years, and a Bill (H.R. 10243) was finally passed in February 1972. In its final form, the Preamble to the Bill contains the following highlights:

- Emerging national problems in the physical, biological, and social domains are of such a nature and are developing at such an unprecedented rate as to constitute a major threat to the security and general welfare of the United States.

- It is therefore imperative that Congress equip itself with new and effective means for securing competent, unbiased information concerning the effects, physical, economic, social, and political, of the applications of technology, and that such information be utilized whenever appropriate as one element in the legislative assessment of matters pending before the Congress.

As approved by the Senate-House Conference Report in September 1972, the Technology Assessment Act of 1972 was signed by the President on October 13, 1972 and became Public Law 92-484. OTA provides for a 12-member Technology Assessment Board (TAB) composed of six Senators and six Congressmen, with equal representation of Republicans and Democrats. The Director of OTA, Mr. E.Q. Daddario, is a nonvoting member of TAB and serves for a six-year term. Senator Edward Kennedy was Chairman of the Board during the first year of operation and Rep. Charles A. Mosher took his place in January 1975. In addition, a 12 member Public Advisory Council insures all segments of the public an opportunity to be heard.

OTA has a staff of about 50 people and calls on 200 consultants in its preparation of reports submitted to the Congress. Six major areas have been selected for study: Transportation, Materials, Oceans, Food, Energy, and International Technology Transfer. In the coming year (F.Y. 1976), the appropriated funds amount to 6 1/2 million dollars.

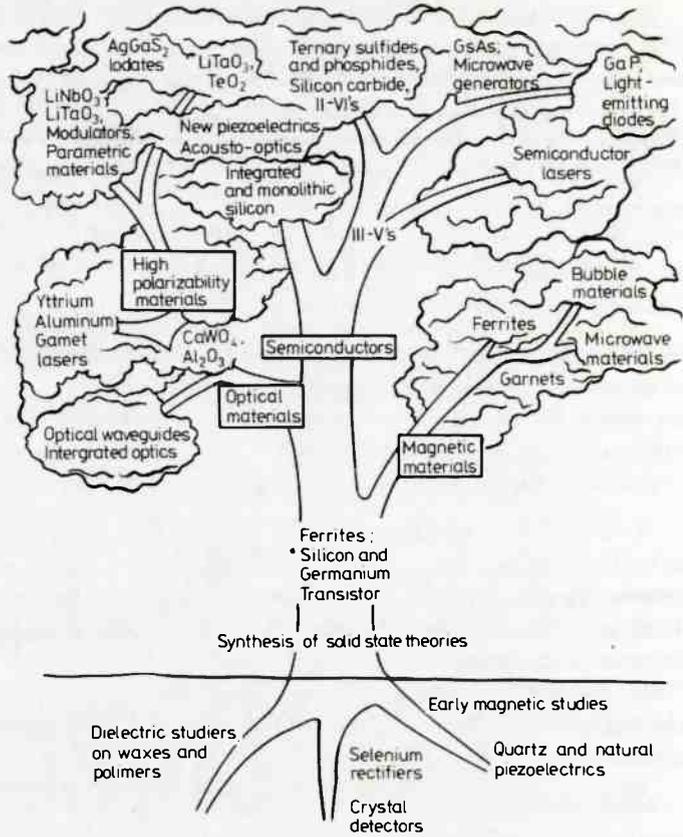
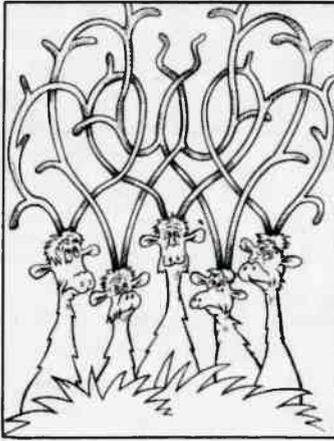
It is difficult to foresee what impact OTA will have on future legislation affecting technology. Essentially, it provides the Congress with an information-gathering agency that is not subject to the dictates of the White House. But TAB will have to rely on reports from outside evaluators* whose value judgment is bound to influence their recommendations. In spite of all good intentions, final decisions are likely to be governed by political considerations and not by the striving toward national, or world-wide, goals that have not as yet been defined.

Meanwhile, an International Society for Technology Assessment (ITSA) was formed in 1971 by a group of European and American scientists on the instigation of Alvin Toffler, the well-known author of "Future Shock". The first International Congress of this organization was held at The Hague, Netherlands, in May 1973 and was attended by 225 persons from 20 countries. A second such Conference was held in Tokyo in November 1974. ISTA [Ref.8] publishes The Technology Assessment Journal and a quarterly Newsletter "TA Update", an invaluable source of information on recent developments in this field. It is evident that there is a widespread interest in TA in many countries of the world, although no formal governmental institutions have been formed outside the USA. Within the U.S., there even exists a group that assesses the assessments of OTA.

The papers to be presented at this Conference on Materials in Electronics are not likely to be concerned with Futurology, but a recent article by Laudise and Nassau [Ref.9] offers some speculations on what the future may hold in store in this particular area. Since the authors are not present at the Conference, some of their forecasts will be summarized with their permission.

First of all, I should like to show you the Electronic Materials Tree, needless to say with the permission of the authors and that of Editor of "Tech-

* Research Contracts tend to range from \$ 200,000 to \$ 500,000, as recently reported in "The New York Times" (9 June 1975). There is a small but growing Technology Assessment Industry.



The Electronic Materials Tree, and another tree whose branchings are some what more confuser. Each might symbolize progress in the interdisciplinary field of electronic materials. The roots of the first tree lie in the basic sciences and in early studies of materials such as those used in Thomas Edison's inventions. The trunk signifies the development of the transistor-the solid-state device that superseded the vacuum tube. The branches represent three areas of current electronic materials progress: semiconducting materials more complex than those used in early transistors; magnetic materials now being used in computer memories; and optical materials, for use in light emitting, transmitting, and modulating devices. The second, and more uncertain, scheme was drawn by Dr. Seuss for *If I Ran the Zoo*, copyright 1950, by Dr. Seuss. Reprinted by permission of Random House, Inc.

nology Review" where it was published*. The insert at the left is taken from Dr. Seuss' book "If I ran the Zoo" (Random House, Inc., 1950) and gives a graphic illustration of what "Interdisciplinary Research" is all about, i.e., a locking of horns.

The main tree has its roots in the early developments around the turn of the century that produced Crystal Detectors, Selenium Rectifiers, Quartz Oscillators, Piezoelectrics, dielectric and early magnetic studies. There then followed a period during which theories of the solid state were synthesized. The names of Mott, Wilson, Fraenkel, Taylor, and Cottrell come to mind.

The trunk of the tree represents work on ferrites and the development of germanium and silicon transistors in the late 1940's. From then on, numerous branches emerge that are suitably labeled to indicate the proliferation of semiconductor materials to suit special applications, such as light emitting diodes, magnetic memories, low-loss optical wave guide fibers, and many others.

In looking to the future, Laudise and Nassau enumerate fields of application where substantial advances in electronic materials are called for, i.e., high-efficiency light sources, optical communications, super-large-scale integrated circuits, high-temperature superconductors, low-pollution energy sources, and others.

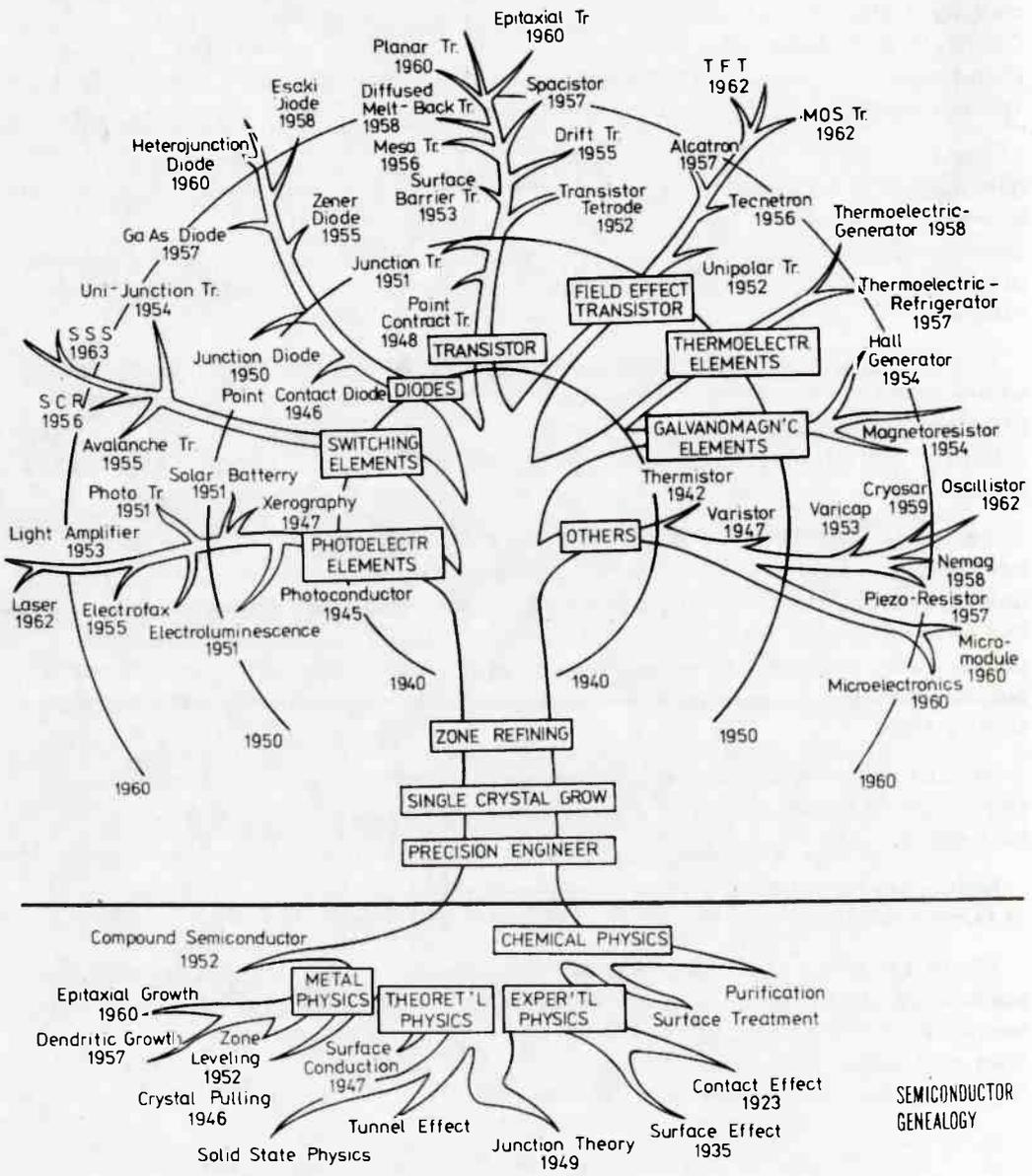
As Gatos [Ref.10] has pointed out in a sweeping review of electronic devices, and that of technology in general, depends on an interplay of the basic understanding of the underlying physical effect and the ability to produce the required materials with the needed purity and microstructure. In now appears that the basic effects are sufficiently well understood in most cases, but the mastery of materials technology will determine the rate of progress in this field.

In summarizing the content of the remarks made in this paper and fortifying some observations in the process, the following highlights may be listed:

Materials have been, and remain, an important ingredient of the organization of human society.

While the emphasis has been on the consumption of materials from an apparently unlimited supply in the past, it is now being realized that conservation and recycling of materials is becoming increasingly important. This shift of emphasis will affect our life style and requires government regulation and the recasting of government institutions.

*"The Evolution of Semiconductor Electronics" was depicted in the form of a similar tree by Kawakami and Takahashi of Tokyo University of Technology in 1965 ("Electronic Industries", February 1965, p.72). A still earlier sapling was drawn by white in the Sept. 1952 issue of "Electronics", p.98.



Since substitution of new materials whose basic ingredients are more plentiful is one approach to alleviating the excessive use of scarce materials, research on materials fulfills an important role that must not be neglected.

The interdisciplinary approach of Materials Science and Materials Engineering is well suited to elucidate the fundamental principles that underlie the properties of all types of material and thereby open the way to new applications.

New technologies should be carefully assessed by an impartial body of experts drawn from many fields to insure that the impact of such technologies on society is compatible with the stated objectives of resource and energy conservation and the preservation of a healthy environment.

International cooperation in all these endeavors is highly desirable, if not essential. While the exchange of scientific information on materials is well established, the maintenance of an adequate supply of raw materials to all nations and the control of pollution in the air, on land, and in the oceans call for much increased international collaboration.

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