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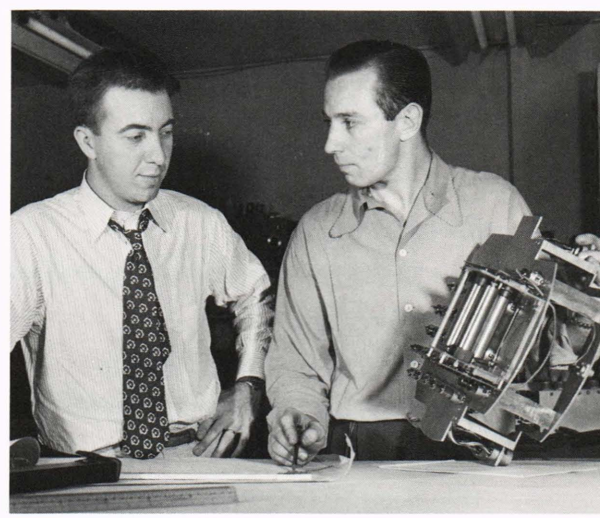
MILTON S. EISENHOWER RESEARCH CENTER: AN INTRODUCTION

Since 1947, the Milton S. Eisenhower Research Center's staff of physicists, chemists, engineers, and mathematicians has been engaged in research in selected key areas of the physical sciences and of mathematics. Their traditional assignment has been to carry out basic research on problems related to present and future task areas of the Applied Physics Laboratory. In addition, Research Center staff members collaborate or consult on problems that arise elsewhere at APL. They also perform joint research programs with staff members at the Johns Hopkins Medical Institutions, the Johns Hopkins Schools of Arts and Sciences and of Engineering, and with colleagues in other academic institutions in the United States and abroad. Currently, the research consists of 22 active projects in four program areas: theoretical problems, mathematics and information science, computational physics, and materials science.

BACKGROUND

The Research Center concept was originated by R. E. Gibson, A. Kossiakoff, and F. T. McClure in 1947 and was formally transformed into a unit of APL by L. R. Hafstad, then director, on April 1, 1947. The fundamental objectives as stated then, and still appropriate today, were (a) to carry on long-term basic research complementary to present and future tasks of the Laboratory, (b) to establish APL as a contributor to fundamental research, and (c) to provide an opportunity for the enhancement of professional competence and scientific growth of the staff through participation in fundamental research programs.

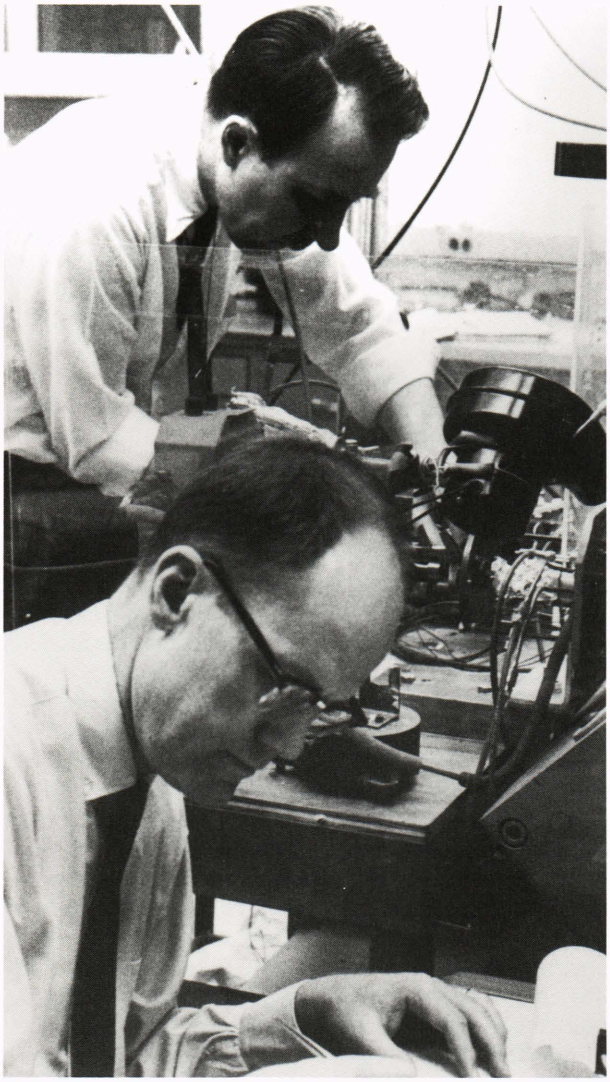
Originally, the Research Center was organized along informal academic lines, and the responsibility for the conduct of the technical activities resided in the senior staff who reported directly to the chairman of the Center. The early history of the center has been well documented in articles by R. E. Gibson,[1] D. E. Gray,[2] and, most recently, by S. N. Foner and R. W. Hart.[3] Inasmuch as the early work at APL focused on problems related to guided missiles and rockets, the work in the Research Center reflected those problems, including supersonic and hypersonic aerodynamics, combustion, transport properties, flame spectroscopy, low-temperature phenomena, properties of materials, and mass spectrometry of free radicals. An extensive program of upper atmospheric research was carried on under J. A. Van Allen for several years.



J. A. Van Allen, left, with physicist J. Jenkins, holding the Geiger counter used in V-2 and Aerobee rockets to measure cosmic radiation.

In subsequent years, the organization became more formal with the creation of groups whose leaders assumed the duties of technical supervisors. F. T. McClure was appointed the first full-time chairman of the Research Center in 1948. He led it until 1972, when he turned his full efforts to the office of deputy director of APL. During his tenure, the Center grew from a staff of 38 to 62. R. W. Hart succeeded McClure and served as chairman from 1972 until 1983, when he became APL's assistant director for Exploratory Devel-

Dr. Poehler, the director of the Milton S. Eisenhower Research Center, is the guest editor for this issue.

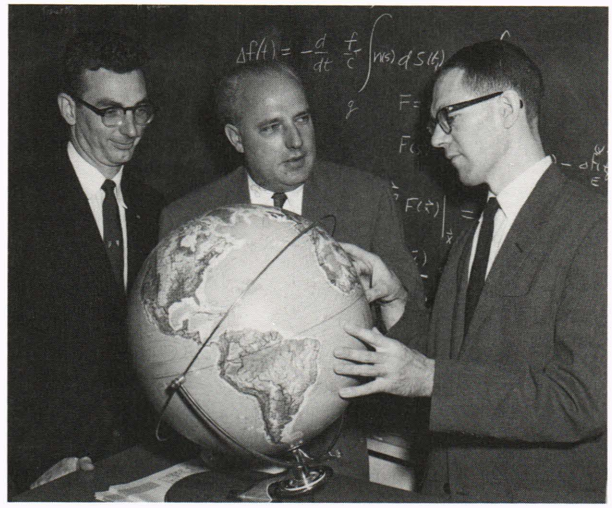


R. M. Fristrom (top) and A. A. Westenberg study elementary free radical reactions in the gas phase by electron spin resonance. For their fundamental research into the chemistry and physics of combustion reactions, they received the 1966 Hillebrand Award of the Chemical Society of Washington.

opment. Currently, the Research Center employs a permanent staff of about 55, complemented by a number of researchers with temporary or part-time appointments, graduate students, postdoctoral fellows, and staff members from other departments of APL.

BASIC RESEARCH AT APL

The Research Center has served many purposes, in keeping with the broad objectives stated by its founders. It has played a particularly important role in developing new knowledge and sustaining the vigor and professional competence of APL. Throughout its existence, it has established APL as a contributor to basic science through investigations in flame spectroscopy, upper atmospheric physics, combustion, mass spectrometry, free radical physics and chemistry, laser mechanisms, semiconductors, applied mathematics, ki-



From left to right, W. H. Guier, F. T. McClure, and G. C. Weiffenbach. McClure invented the Doppler method of navigation. Guier and Weiffenbach developed the first successful method of tracking satellites by use of the Doppler shift.

netic theory, wave scattering, and biomedical science. The scope of its work is shown by the lists of recent publications appended to sections of this article. Contributions from the Research Center also have generated new programs of major significance to APL, such as the birth of the Space Department and the Biomedical Research Program. The Laboratory's commitment to the goals of the Research Center were renewed with the dedication of the Research Center to Milton Stover Eisenhower in 1979.

While past accomplishments and achievements can be pointed to with pride, reason for the continuing support of basic research at APL lies in the need for intellectual renewal and growth to cope with rapidly changing science and technology. The Laboratory is devoted to solving practical technical problems in an era of extraordinarily rapidly changing technology. For example, activities in 1947 were almost entirely focused on guided missile research and development. The technical approach to the design of electronics systems in those missiles depended on vacuum tube components. Since then, we have seen a host of advances in that field including the transistor, the integrated circuit, the modern digital computer, microprocessors, the laser, and many related devices. Not only have science and technology related to electronics and systems virtually exploded, but APL's programs have undergone a significant evolution in scope, including moves into space and undersea systems.

In an era of rapid change, responding to the charter of making contributions to scientific knowledge and of providing fundamental research in fields important to APL requires constant reassessment of the specific research to be performed. While specific research areas are moving targets, there are certain fundamental disciplines that are central to any meaningful program, including physics, chemistry, electronics, mathematics and computer sciences, engineering sciences, materials,

A. J. Zmuda used magnetometers on APL satellites to discover the presence of large field-aligned currents in the auroral zone.

atmospheric sciences including oceanography, and the biological and medical sciences.

Other driving forces also reinforce the necessity for research. There is a continuing need to keep abreast of the rapidly changing, increasingly complex technologies of potential use to an institution such as APL. This requires that personnel engaged in the developmental programs have direct access to contemporary research results. An on-site research program provides a community of research scientists in relevant fields who are acquainted with the needs of technical programs and are able to consult on problems as they arise. Such a program can also bring into the institution highly qualified scientific personnel who might not otherwise be attracted. At the same time, this contact provides a means of acquainting research scientists with pressing technical problems of systems under development and it can suggest new research directions. Communication between members of the research staff and staff members involved in applied problems forges a strong bond between programs and provides significant mutual benefits.

THE CURRENT RESEARCH PROGRAM

By maintaining close contact with their fields of scientific expertise and their colleagues on the one hand, and the problems of APL and its sponsors on the other, the Research Center attempts to structure a program that responds to its charter. Such a task is difficult, particularly in view of the explosive growth and rapid evolution of both science and technology. However, within the constraints of available resources, the Research Center attempts to maintain a program that contributes meaningfully to contemporary scientific topics and also serves as a resource for the rest of the Laboratory. The Research Center also has endeavored to acquire a full spectrum of modern instruments for analysis and research that are widely available to other departments of the Laboratory and constitute a major resource.[4]

The current Research Center program is described in the following paragraphs and in the more detailed articles in this and the next issue of the *Technical Digest*.

Computational Physics

The Computational Physics program includes the application of numerical and analytical techniques to modeling and simulation of ocean properties and flow and a study of the physics, chemistry, and dynamics of the upper atmosphere, as well as the interaction of spacecraft and satellite materials with this environment.

Oceanography. Simply stated, the goal of the oceanography program is to describe accurately the motion and physical properties of water throughout the ocean. The program is directed toward determining the time history and future of patterns of currents and waves; the associated distributions of temperature and salinity; the basic physical principles derived from the general laws of dynamics and thermodynamics of fluids; the mechanisms of the transfer of energy, heat, and momentum into the sea; how they are dissipated; and how they are coupled to the atmosphere.

More specifically, the objective of the oceanography work is to elucidate the fundamental principles and basic physics underlying oceanographic phenomena, including the development of high-resolution models, mesoscale flow systems and the understanding of ocean surface effects, and the improvement of numerical techniques for handling mixed-scale fluid mechanics problems. The approach is to use numerical techniques to solve equations for fluid mechanics of ocean flow phenomena. Models and simulations of ocean properties and flows are verified with data derived from a unique combination of resources present at the Laboratory including satellite oceanography, in-situ ocean

COMPUTATIONAL PHYSICS

Oceanography
- Fluid mechanics of ocean flow phenomena (IR&D)
- Mesoscale modeling (IR&D)
- Atmosphere-ocean interactions (IR&D)
- Nonlinear processes in internal wave surface signatures (ONR)
- Wind stress surface temperature correlations (IR&D)
- Computational methods: vector and parallel processing algorithms (CDC, ICS/CSU)

Aeronomy
- Molecular beam-surface reactions and erosion (IR&D, ONR)
- Nonlinear dynamics (IR&D)
- Reactivity of particulates with atmospheric species: ozone soot reactions (IR&D, DNA)
- Rocket motor reliability
- Extended chemical systems (NSF)
- Molecular physics (NATO)

measurements, and a laboratory-scale hydrodynamic test facility.

Aeronomy. The physics, chemistry, and dynamics of the atmosphere, as well as the interaction of spacecraft and satellite materials and suspended particulates with the atmosphere, are far from fully understood even though they influence global climate and the effectiveness of space missions. To attack such problems, the thermospheric environment (temperature, pressure, concentration, and composition) is being simulated in laboratory and satellite experiments, oxygen atom reactions in gas-solid collisions are being investigated, and nonequilibrium flow regimes are being modeled.

In the stratosphere and below, there is concern over massive conflagrations that would be expected to follow any major nuclear attack. The effects of such fires will depend not only on their extent, but also on the details of local combustion, including the character, dispersion, and combustion of the fuel; the presence or absence of species such as halogens that promote smoke production; and local ventilation, which controls oxygen availability. Soot is a major contaminant from such fires. Successive explosions could drive these products to high altitudes. As the material, both gases and solids, rises through the various layers of the upper atmosphere, interactions will occur with existing reactive species, such as ozone, nitric oxide, and atomic oxygen, that will lead to eventual soot and dust destruction, ozone reduction, and contamination by various carbon species.

An important goal of the aeronomy program is to understand the basic physical, chemical, and dynamical processes that occur in the upper atmosphere and their interactions with spacecraft and satellite materials. Chemistry and physics in the upper atmosphere behave in significantly different ways than they do near sea level. Specifically, nonequilibrium distributions of ionized, dissociated, and excited state molecules are created by solar radiation and solar wind. As the atmospheric density varies, the hydrodynamic flow regime changes from conventional fluid mechanics supplemented with chemical kinetics to the Knudsen regime where nonlinear kinetic equations must be used to describe the fluid flow. Consequently, models of the upper atmosphere require a great deal more work. Also, little is known experimentally about the stability of surfaces that collide with the free radicals and excited molecules expected in this environment. Since atomic oxygen is the dominant reactive species, a problem of interest is the interaction of spacecraft material with this free radical.

Mathematics and Information Science

The Mathematics and Information Science program is a focal point for research projects in artificial intelligence throughout APL, as well as a Laboratory-wide source of expertise in advanced mathematical methods.

Artificial Intelligence/Expert Systems. The primary effort within the mathematics and information science area is research and development in artificial intelligence. Staff members are conducting basic research on knowledge representation and control strategies for knowledge-based expert systems, on problems in image and scene analysis for machine vision systems, and in automating the software development process for interactive information systems through the application of artificial intelligence techniques. A joint Fleet Systems Department and Research Center program is also being carried out concerning the acquisition and representation of knowledge for distributed command decision aiding.

The first of these activities concerns the techniques and research issues relating to expert systems and knowledge-based systems. Because of the increasing application of knowledge-based systems in both commercial and government activities, it is important to study the implications, applicability, and limitations of the systems. Emphasis is being placed on building tools and architectures for expert systems and their applicability to various practical problems.

In the area of computer vision, the chief concern is with issues that arise in building general-purpose vision systems. Although much work has been done on machine vision in the past 25 years, progress has been primarily in specialized systems operating within a limited domain of images. For example, in vision systems for robot welding, little progress has been made to implement general-purpose machine vision systems. Although a few architectures have been proposed, the system now under development at APL would be able to interpret many classes of images, a necessity for applications requiring general-purpose robotics. An example of great interest to the Defense Advanced Research Projects Agency is an autonomous land vehicle that could successfully navigate over unfamiliar terrain without a human operator.

Finally, effort is directed toward combining artificial intelligence and software engineering. It is well known that numerous problems occur in the software life cycle that lead to excessive development times and associated costs. It has become clear that artificial in-

MATHEMATICS AND INFORMATION SCIENCE

Artificial Intelligence/ Expert Systems

- Knowledge-based expert systems (IR&D)
- Machine vision (IR&D)
- Knowledge-based system for command decisions (Navy)
- Automated interpreter for sonar (Navy)
- Intelligent software development environments (IR&D)

Applied Mathematics

- Eigenvalue estmation (IR&D)
- Mathematics for modeling electromagnetic wave propagation phenomena (Navy/IR&D)

telligence techniques can be applied to software development processes to automate all or parts of them.

Applied Mathematics. Specific areas of emphasis within the field of advanced mathematical methods include partial differential equations, eigenvalue calculations, and large matrix systems. Traditionally, the emphasis in applied mathematics has been in the development of methods for the rigorous estimation of eigenvalue problems that arise in structural mechanics, in the development and application of a priori inequalities to the computation of the approximate solution of boundary value problems, and in the computation of viscous flow problems in complex geometries. The trend in the current program is to shift the focus from these traditional areas to modeling radar propagation, dealing in particular with problems relating to the processing of synthetic aperture radar data and to the mathematical problems associated with modeling phase change phenomena, i.e., moving boundaries.

Phase transitions, solidification of alloys, ablation, and oxidation processes all lead to moving boundary problems where the location of the reaction front changes with time. Such problems occur in many areas, as spacecraft reentry, insulation of rocket engines, and laser damage to satellites. Enthalpy formulation of these problems allows them to be treated in a uniform, highly effective way. Both theoretical analysis and development of fast, stable, and highly accurate numerical algorithms for various geometries, dimensions, and heat transfer mechanisms are required.

Computational requirements in synthetic aperture radar processing are large, time-consuming, and relatively expensive in computer and manpower time. Development of fast, efficient algorithms for such processing is a continuing and challenging problem area. Most signal-processing tasks require digital filtering. In synthetic aperture radar processing, for example, the filter containing several thousand points must be correlated with an essentially infinite string of data arriving at the rate of several thousand elements per second. For target detection, the processing must be carried out in real time. Therefore, the basic mathematical problem is how to do the correlation or, equivalently, a reversed convolution of two long sequences in the minimum number of operations. Using alternative techniques, there is the possiblity of making several orders of magnitude improvement in the implementation of the algorithms currently used to conduct this processing that are based on conventional fast Fourier transform methods. The difficulty with a practical realization is the conversion of theory into convenient algorithms that will map well into software. Some of this work is carried out in collaboration with APL's Fleet Systems Department.

Theoretical Problems

The Theoretical Problems program is responsible for work in electromagnetic wave propagation and scattering as well as in biomedical research. Current work in wave scattering includes rough-surface scattering with application to electromagnetic scattering by the ocean surface, and particulate scattering and absorption with applications to the cornea, to combustion, and to the design of broadband obscurants and radar-absorbing materials. Several of the Research Center's biomedical projects are combined in a program whose primary objective is to improve the understanding of biomedical phenomena through the development of basic science and the application of technology. There are active programs in the areas of ophthalmology, blood flow, and microwave biophysics.

Electromagnetic Propagation and Scattering. An understanding of the propagation, scattering, and absorption of electromagnetic and other waves provides potential tools for the probing of a variety of media such as the ocean's surface, particulate matter in the ocean, chaff and other obscurants, aerosols, bubbles, and a variety of military targets. Insights gained in such investigations could lead to the improved design and use of Naval systems such as radar, sonar, altimeters, scatterometers, and radiowave communications links. Such insights should also lead to a better understanding of the structural bases for the properties of certain composite materials. Because of their widespread importance, they have been widely investigated, but theoretical analyses remain incomplete and continuing research is important. The primary interest in the program has been scattering by statistically rough surfaces and by statistical assemblies of particles. The work includes the development of the variational principles as a calculational tool for systems where multiple scattering interference and polarization effects are important. An immediate goal is the development of methods that are accurate at all wavelengths, for applications to systems that contain a wide variety of scatterer sizes. These wave scattering studies were originally initiated in conjunction with the Submarine Security Program and have more recently been carried out in collaboration with APL's Fleet Systems and Space Departments.

THEORETICAL PROBLEMS

Electromagnetic Propagation and Scattering

- Variational stochastic scattering theory (IR&D, NASA)
- Theoretical and experimental study of scattering and absorption in obscurants and other materials (IR&D, ONR)

Biomedical

- Scattering in cornea (NIH)
- Hemodynamics research (IR&D)
- Microwave and IR corneal damage (Navy, Army)
- Mechanisms of tissue damage from electromagnetic radiation (IR&D, ONR)
- Excited-state oxygen in cancer photoradiation therapy (Civil)

Biomedical. Research in biomedicine provides insight into the processes by which disease, trauma, and environmental stresses affect living systems. The Research Center historically has had a strong biomedical research program directed toward these problems. Foremost, there has been serious concern over potentially hazardous biological effects due to nonthermal or low-level exposures to nonionizing electromagnetic radiation. Concern has increased over the years as the number of devices that produce this type of radiation has proliferated. Both civilian and military personnel have been exposed to increasing amounts of microwave radiation, and, more recently, there has been a dramatic increase in the use of infrared or visible lasers in range finders, military guidance systems, and in several nonmilitary commercial systems. Work in this area has been aimed at determining the mechanisms that cause changes to the eye due to exposures to nonionizing radiation. In addition, nonthermal microwave damage to the corneal endothelium and phototoxic-like damage to the retina are of special current interest, as well as the development of experimental techniques to reveal ocular structures in normal and damaged tissues.

Cardiovascular research in hemodynamics is concerned with how arterial geometry affects blood flow and with the mathematical modeling of pulsatile flow through arteries. The transport of chemical constituents to and from the arterial wall is also of concern. The program is directed toward identifying properties of the hemodynamic environment that are in some degree responsible for the formation of atherosclerotic lesions and toward investigating physical processes through which special features of flow could influence lesion formation. The techniques developed in internal flow problems of this type are applicable beyond the biomedical area, in other time-dependent viscous flows such as those that occur in lubrication or in heat and mass transport.

Materials Science

The Research Center is carrying out a Materials Science program aimed at understanding the physics and chemistry of materials and surfaces so that we can better utilize existing materials and can develop new materials with superior properties. The work includes the development of advanced materials for structural, electronic, and optical applications, as well as new methods for characterizing their properties nondestructively.

Advanced Materials. The need for advanced materials for communications, guidance information, and weapons systems is well known. There are specific needs for materials for very-high-speed electronics that are insensitive to high radiation or electromagnetic fields; for improved structural materials; for superior optical materials and for optical processing capabilities; and for materials for energy generation and sensing. An understanding of the relationship of the composition and structure of materials to their functional properties would lead to the creation of better materials for many applications as well as an improvement in the performance of existing materials. This goal makes sense in light of modern techniques that have been developed for systematically modifying the physical properties of materials through careful structural and compositional control. Furthermore, the ability to synthesize complex organic and inorganic materials has been greatly enhanced by the introduction of a wide range of quantitative analysis techniques that allow detailed measurements of the physical properties of new materials. A number of new materials have been created in this program, including polymers and organic compounds for optical, electronic, and information processing applications; metal alloys for magnetic and structural applications; and semiconductor and thin-film compounds for electronic applications. One material resulting from the program (copper-tetracyanoquinodimethane) is now

MATERIALS SCIENCE

Advanced Materials

- Rapidly solidified alloys (IR&D)
- Transition metal oxides (IR&D, ONR)
- Organic conductors and polymers (NSF, IR&D)
- Optical storage materials (Civil)
- Nondestructive evaluation of nylon (Navy)
- Materials for optical information processing (DARPA)
- Magnetic resonance imaging in solids (Civil)

Surface Science

- Physical and chemical processes at surfaces and interfaces (IR&D)
- Surface structure (IR&D)
- Surface problems in microelectronics (Navy)
- Microelectronic adhesives (Navy)

Nondestructive Evaluation of Structural and Electronic Materials

- Experimental and analytical nondestructive evaluation methods (IR&D)
- Photothermal imaging of cracks and defects (Air Force, Army)
- Laser-detected acoustic emission (Navy)
- Magnetic sensing of corrosion (Civil)

Microphysics

- Laser-aided processing for very-large-scale integrated circuit systems (IR&D)
- Microscopic atomic phenomena at solid/gas and solid/liquid interfaces (IR&D)
- Computer models of compound semiconductor and heterostructure device very-large-scale integrated systems (IR&D, Navy)

being developed in conjunction with a major chemical company as a potential information storage medium for optical data storage systems.

Nondestructive Evaluation of Structural and Electronic Materials. The use of both conventional and advanced materials has been impeded by a lack of understanding of their inherent defect structure, which may limit their performance and useful lifetime. The presence of well-characterized defects such as fatigue-related cracks in metal alloys is difficult to determine while in service and can often lead to catastrophic failure when undetected. In electronics applications, the performance of advanced semiconductors and integrated circuits depends on dopant concentrations and their spatial distributions. A knowledge of these factors and of their time variation in the presence of thermal diffusion and electromigration is important in the development of improved devices and in the understanding of device failure.

An objective of the current work is to study defect structures and spatial compositions that lead to failure in service for a wide variety of structural and electronic materials that are important to the Navy. The advances in materials technology have been paralleled by similar advances in analyses technology that permit vastly improved quantitative determination of the physical properties of defects and impurities, as well as the ability to image the structure of these materials and devices. The work includes investigation of the physics and chemistry both of structures within the bulk of solids and devices and of the important surface regions. In the latter area, a broad range of investigations has been carried out at both a fundamental level and a very practical level on the physical and chemical processes associated with the use of polymer adhesives in microelectronics. Research on surface problems in microelectronic materials is carried out in collaboration with APL's Microelectronics and Satellite Reliability Groups, while other work on missile materials is conducted in conjunction with the Fleet Systems and Aeronautics Departments.

Microphysics. Another important aspect of the work on materials is the attempt to build a knowledge base that will allow eventual fabrication of electronic components with higher speed, circuit density, and increased robustness. The new materials whose behavior can be chemically tailored are very attractive alternatives to the conventional silicon for electronic circuitry. However, materials with many favorable characteristics from the viewpoints of speed, density, and robustness currently present difficulties in the production of high-quality crystals and do not actually achieve high-density digital circuitry. Current work combines a search for alternatives to silicon materials and to the conventional processing technologies used in very-large-scale integrated circuit production. The effort centers on heterostructures and semiconductor compound devices combined with laser-aided processing and includes the establishment of a capability for laser fabrication of microstructures by using solid/gas or solid/liquid reactions. The investigation includes photodeposition, photoetching, and photochemical doping in addition to microalloying and annealing. Success in the program could lead to a new device fabrication process whereby electronic circuitry can be built nonlithographically, thus avoiding many of the major difficulties of planar processing technology, including the generation and propagation of defects, redistribution of dopants, and warping of wafers.

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