HARRY K. CHARLES, JR., G. DONALD WAGNER, and JOSEPH L. ABITA

MICROELECTRONICS AT APL: 30 YEARS OF SERVICE

With the integrated circuit revolution in electronics continuing at a rapid pace, the need to harness today's high-density, high-performance chips and combine them with other devices to form functional electronic systems is paramount. The Microelectronics Group at APL is developing many of the design, fabrication, and testing tools and services necessary to provide modern electronic systems for space science, communications, avionics, biomedicine, and ocean science.

The Microelectronics Group at The Johns Hopkins University Applied Physics Laboratory will be 30 years old in 1990. The group was organized in 1960 to allow APL to participate actively in the rapidly advancing field of electronic microminiaturization and packaging. The founding charter[1] included the establishment of a microelectronics laboratory able to fabricate functional circuit blocks and systems; research and development in materials, circuits, packaging, interconnections, and solid state applications; system design for miniaturized electronics, considering such related topics as thermal problems, radiation damage, power distribution, and sensors (transducers); and liaison and subcontracting.

The charter is as viable today as it was 30 years ago. Although the focus of electronics in 1960 was on the individual transistor, today's miniaturized electronic systems may contain several million transistors, operate at very high speeds (e.g., 100-MHz digital clocks or analog signals at tens of gigahertz), and dissipate large amounts of heat (watts/square centimeter).[2]

The decade of the eighties was an era of change for microelectronics at APL. A major modernization plan added significant new equipment, new processes, and the groundwork for a new facility to be occupied during 1990, aspects of which have been described in a previous *Digest* article.[3] Microelectronics activities at APL are now strong service resources, offering advanced design, fabrication, assembly, testing, and packaging for digital, analog, and microwave circuitry.

In response to the changing technological requirements of the electronics industry, the Microelectronics Group has developed new technologies for the design and fabrication of microelectronic components, circuits, and systems. Recent efforts have led to greater use of thick- and thin-film multilayer substrates; the computer-aided design of circuits; hybrids; advanced ceramic and silicon substrates; monolithic microwave components; microwave hybrids and assemblies; and improvements in reliability and quality assurance procedures.

Examples of standard, miniaturized, electronic packaging concepts (hybrids and chip-carrier surface-mount assemblies) developed and implemented at APL also were described in Ref. 3. Because of the ever-increasing pressures of device integration, the packaging of individual devices and circuits is being replaced by the integrated, miniaturized packaging of complete systems. Thus, our expertise in package design, analysis, and fabrication continues to grow in several important areas.

Large multilayer board structures up to 230 cm^2 can be easily designed (using new computer-aided engineering tools), modeled (mechanically, thermally, and electrically), fabricated (either by subcontract or internally), assembled, and tested. An example of a modern, large, high-density surface-mount board is shown in Figure 1. This board, with its heat sink (of copper-clad Invar) having a matched coefficient of thermal expansion, was developed for NASA's Topography Experiment for Ocean Circulation radar altimetry programs. The design of both the board and the heat sink was made possible by using the integrated packaging software described in an article by Charles and Clatterbaugh elsewhere in this issue.

Other program requirements not only necessitate extensive circuit design and packaging activities, but also involve the development of special processes, the application of new materials, and the development of one-of-a-kind assembly procedures. For example, we have developed the following processes and procedures:

1. High-temperature brazing and Teflon coating in support of the hydrogen maser program.
2. Chemical conversion plating of fiberglass for a dual Doppler beacon.
3. Standard and photoimagable polyimide dielectric layers for a neuron probe[4] (Fig. 2) sponsored by the National Institutes of Health.
4. Tantalum and titanium anodization methods for undersea thermistor work and medical system sealing.
5. Indium and tin films for immunoassay applications.[5]
6. Platinization techniques to increase undersea electrode conductivity.

Two material systems (and their related circuitry) are currently under development: aluminum nitride (AlN)

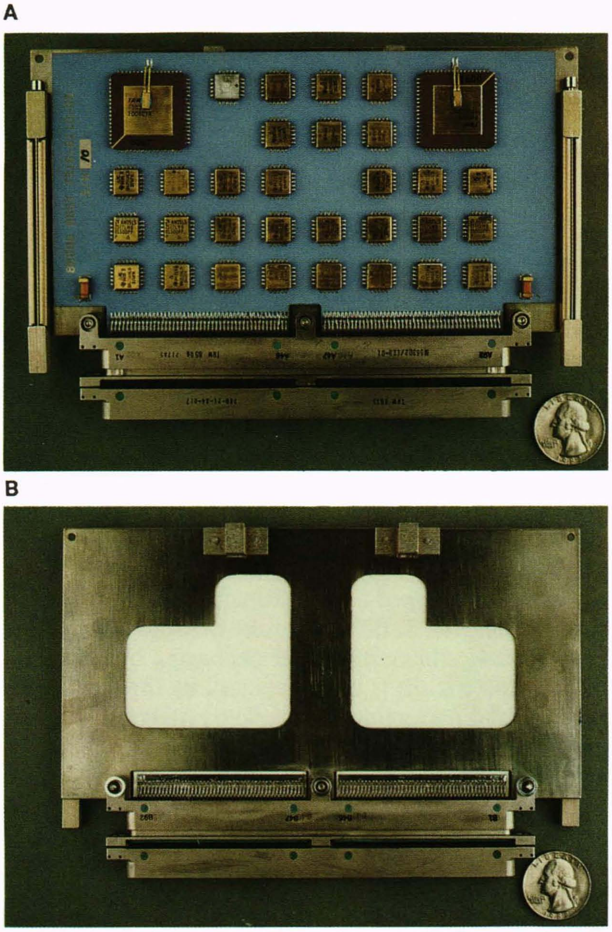

Figure 1. High-density surface-mount board assembly. **A.** Leadless chip carriers on multilayer ceramic board. **B.** Copper-clad Invar heat sink.

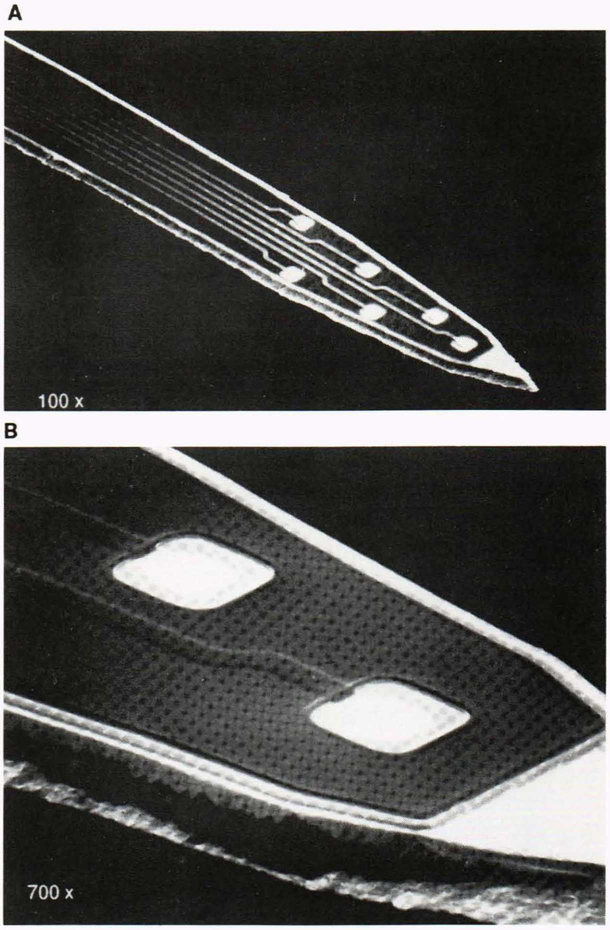

Figure 2. Six-sensor-site neuron probe. **A.** Probe tip and location of the six sensors. The three layers of the probe are polyimide dielectric, gold electrodes, and molybdenum substrate. **B.** Enlargement of a 30-μm-square sensor site.

substrates and thick polyimide dielectric layers. Aluminum nitride is being used to create high-power–dissipating thick- and thin-film hybrids. A representative power hybrid on AlN is shown in Figure 3. This and similar hybrids have successfully passed military standard (MIL-STD-883C-type) qualifications and have survived extensive high-temperature burn-in (2000 hours) without any changes in performance, thus attesting to the stability of the AlN material and the suitability of the metallization methods.[6] Thick polyimide layers for use as dielectrics in multilevel thin-film circuits (e.g., hybrids and multichip modules) are also being developed. Details of this work along with further aspects on the use of AlN are presented in an article by Charles, Clatterbaugh, and Dettmer elsewhere in this issue.

A major new activity that promises extensive use in the future is microwave technology (see the article by Abita in this issue). Resources have been assembled to design, package, and test microwave components, assemblies, and systems. Currently, equipment and processes have been established for the design and fabrication of microwave hybrids, monolithic-scale miniature components and networks, and supporting printing/wiring board structures.

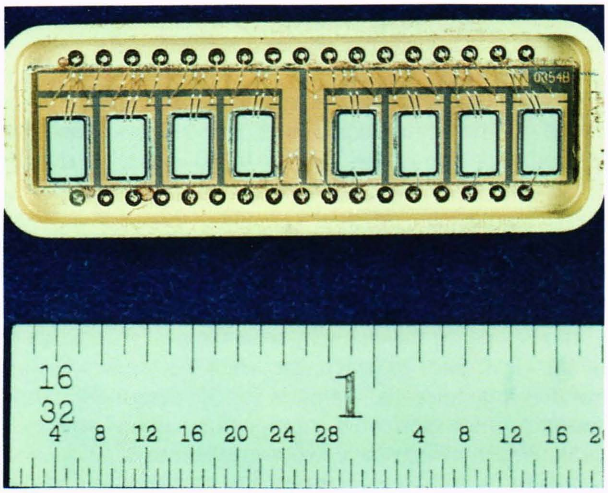

Figure 3. Thin-film power hybrid on aluminum nitride (AlN) substrate. With the AlN substrate, the hybrid can dissipate up to 5 W without self-heating problems.

Key to any microwave endeavor is the accurate characterization of both active and passive devices. Micro-

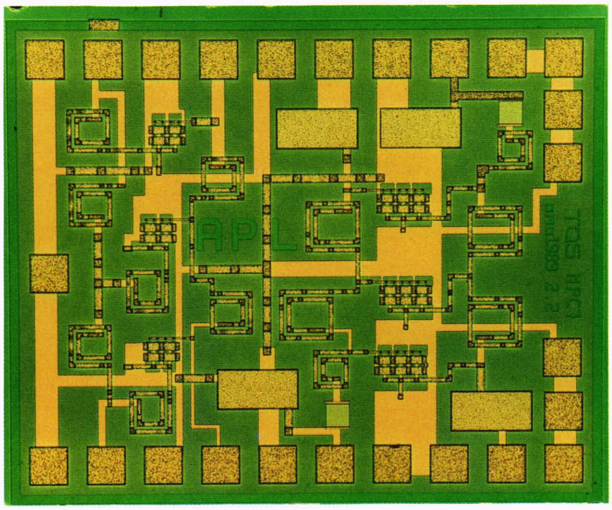

Figure 4. Broad-band distributed MIMIC (microwave/millimeter-wave monolithic integrated circuit) amplifier developed by the APL Space Department with support from the Engineering and Fabrication Branch. This 2.2 × 1.7 mm chip has an average gain of about 4 dB over the 1- to 10-GHz frequency range. Fabrication was performed by a commercial foundry.

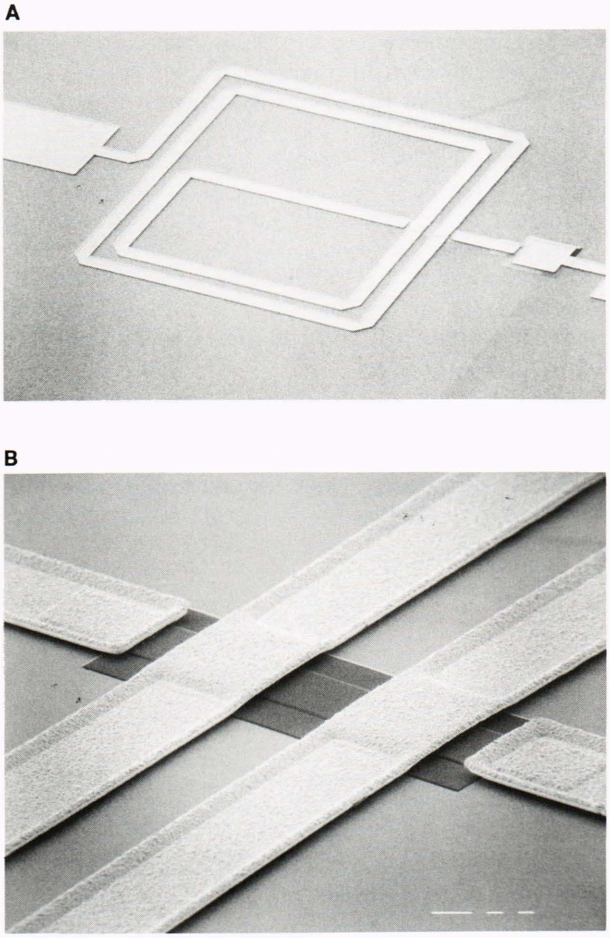

Figure 5. A miniature notch filter designed and fabricated by the Microelectronics Group is the basis for monolithic-scale passive monolithic networks. This basic circuit consists of a metal–insulator–metal capacitor, microstrip inductor and transmission line, and two 2-μm-high air-bridge interconnects. **A.** Entire notch filter. **B.** Enlargement of air-bridge region.

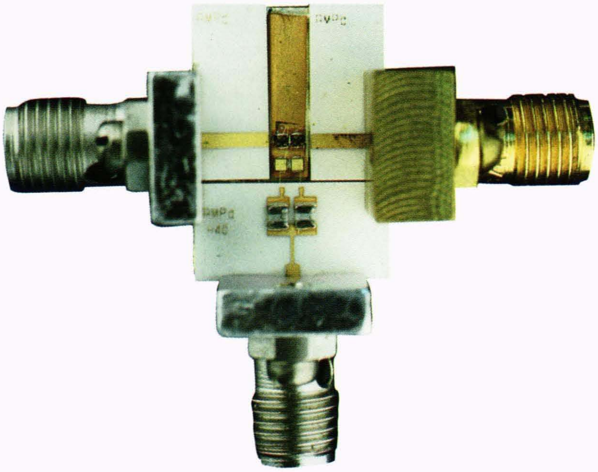

Figure 6. Two commercial MMIC (monolithic microwave integrated circuit) chips packaged by the Microelectronics Group for an X-band (8- to 12-GHz) amplifier breadboard module.

wave test and measurement facilities are being established in the Microelectronics Group to perform a variety of critical measurements (e.g., spectrum analysis, *S*-parameters, noise figure, gain, phase noise) up to a frequency of 40 GHz.

Extensive computer design resources are available using fourth-generation software for linear and nonlinear circuit analysis, layout, process mask generation, physical packaging, and thermal performance evaluation. These design systems use verified library elements for common microwave components and structures in conjunction with microwave application-specific integrated-circuit software compatible with the design rules and processes for commercial microwave foundries. Figure 4 is a custom monolithic distributed amplifier recently developed using the APL microwave design resource.

Increased sophistication of microelectronic processes and assembly techniques has resulted from requirements associated with high-frequency, high-speed module packaging and integration. A previous article[3] outlined some of the new equipment (e.g., plasma etchers, sputter deposition systems, laser machine tool) that has been brought on-line to satisfy the changing packaging needs. This equipment, coupled with new processes, is now being used to fabricate microwave circuits. Figure 5 is a monolithic-scale 5-GHz notch filter comprising a metal–insulator–metal capacitor, spiral inductor with air-bridge crossovers, second-level interconnects, and microstrip transmission lines. The hybrid has taken on new significance for microwave technology. Figure 6 is an APL-built microwave hybrid using commercial gallium arsenide chips. It is an X-band (8- to 12-GHz) amplifier.

We anticipate that the microelectronics activities at APL will continue to provide a wide variety of exciting developments. As dimensions of electronic devices continue to shrink, increased emphasis on materials, quality and process control, and cleanliness will become paramount. Consequently, we are devoting our efforts to improving clean areas (our new facilities will contain over 20,000 square feet of cleanroom space) and to many aspects of reliability and quality control. The first floor of the new building will include modern cleanroom facilities and special laboratories for microelectronics development. When fully occupied by late 1990, the new microelectronics facility will be one of the best in the country for hybrid and electronic packaging. It will feature the latest in environmental control and will be equipped with modern tools and methods for reliability and quality assurance.

Microelectronics is still one of the most rapidly growing technologies. The Laboratory's Microelectronics Group is leading the way into the 1990s with many new products and services, while still performing the activities on which it built its 30-year history of successful accomplishments.

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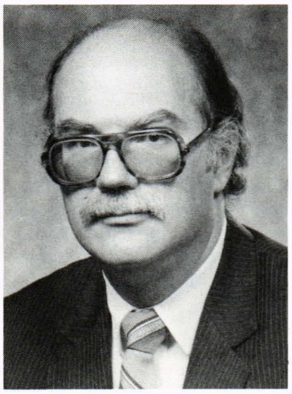
THE AUTHORS



HARRY K. CHARLES, Jr., received a B.S.E.E. degree from Drexel University in 1967 and a Ph.D. degree in electrical engineering from The Johns Hopkins University in 1972. Following a postdoctoral appointment in the APL Research Center, he joined the Microelectronics Group in 1973, where he has held various engineering and managerial positions including group supervisor. Since January 1989, he has been leading the Engineering and Fabrication Branch, which is responsible for all electronic and mechanical design and fabrication at APL. Dr. Charles has been engaged in electronic research and advanced microcircuit packaging for 17 years. He has published 100 technical papers and has been a member of the Principal Professional Staff since 1982. Dr. Charles is a senior member of the IEEE and a member of the American Physical Society and the International Society for Hybrid Microelectronics (ISHM). In 1987, Dr. Charles was selected for an ISHM Technical Achievement Award. In 1989, he received Maryland's Distinguished Young Engineer Award.

G. DONALD WAGNER is Assistant Branch Supervisor of the Engineering and Fabrication Branch of the Technical Services Department. He holds B.S. and M.S. degrees in electrical engineering from The University of Maryland and attended graduate classes at the University of Colorado and The Johns Hopkins University. Between 1960 and 1962, he worked with the Bendix Avionics Division developing an air traffic control radar transponder. In 1962, Mr. Wagner joined APL's Space Department, where he specialized in the development of low-power digital systems for space and airborne applications. In 1973, he was appointed supervisor of the Microelectronics Group, where he led the design and fabrication of miniature implantable biomedical devices and circuits for satellites, missiles, and underwater instrumentation. Currently Mr. Wagner is coordinating the construction of new design and fabrication facilities. He is a member of the Components, Hybrids, and Manufacturing Technology Subgroup, the International Society for Hybrid Microelectronics, and a senior member of the IEEE.

JOSEPH L. ABITA's biography can be found on p. 153.