MIMIC from the Department of Defense Perspective

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Abstract — The Microwave and Millimeter Wave Monolithic Integrated Circuits (MIMIC) Program is a Defense Advanced Research Projects Agency initiative to provide affordable, reliable, and reproducible microwave and millimeter-wave circuits in monolithic format for use in Department of Defense systems. This paper describes the objectives of the program, progress being made toward meeting those objectives, and some planned future work.

I. INTRODUCTION

In 1987, the Department of Defense began funding the Microwave and Millimeter Wave Monolithic Integrated Circuits (MIMIC) Program. The program was initiated in response to the realization that monolithic format circuitry was the best possible candidate for meeting the DoD need for affordable, reliable, and reproducible microwave and millimeter-wave components. During the past three years, many substantial technical achievements have been made under MIMIC Program sponsorship, and numerous systems have been identified by both the military services and system manufacturers that will benefit from the use of MIMIC's. A system already in production is making use of MIMIC's; costs of the chips themselves and of packages and testing have dramatically decreased; a start has been made on the development of open architecture computer-aided design systems; and the first commercial "spin-offs" resulting from MIMIC program activities are about to appear. Most gratifying is the unprecedented degree of cooperation that has developed among all of the MIMIC team members and has spread to an increasing number of companies associated with MIMIC program participants. Much work remains to be done in many technical areas; costs must decrease still further to allow widespread use; and MIMIC advantages must be validated by use in many systems, military and commercial. An excellent start has been made and full funding and support through the completion of the final hardware development phase will ensure successful attainment of program goals.

II. BACKGROUND AND OBJECTIVES

The MIMIC Program is sponsored by the Defense Advanced Research Projects Agency (DARPA) and has full participation by the Army, the Navy, and the Air Force. The MIMIC Program Manager is E. D. Cohen and the Deputy MIMIC Program Manager is E. I. Sobolewski. Each military service also has a resident MIMIC Program Office and a program director. For the Army, the Navy, and the Air Force these are Dr. C. G. Thornton, D. W. McCoy, and W. J. Edwards, respectively.

The program is divided into four portions, designated phases 0, 1, 2, and 3. Phase 0 was a one-year program definition or study phase, which began in January 1987. Phase 1, the first of two three-year hardware development phases, began in May 1988. Twenty-six companies grouped into four teams are participating in this portion of the program. Phase 2, the second of the three-year hardware definition phases, is scheduled to begin in September 1991. Phase 3 consists of a number of critical technology programs, 12 at present, that are being conducted in parallel with phase 1 to allow special emphasis and additional work to be performed in areas requiring particular attention. Programs in progress include work on gallium arsenide epitaxial growth techniques; multiple chip ceramic packages; process, device, and circuit modeling; on-wafer testing techniques; and advanced fabrication techniques. During 1990, additional work will be initiated to encourage the development of a standard microwave hardware description language, to produce gallium arsenide substrate material with superior, predictable electrical properties, and to increase the viability and capabilities of merchant foundries.

III. SPECIFIC OBJECTIVES OF THE DEPARTMENT OF DEFENSE

The overall program objective can be succinctly stated as follows:

Provide the needed microwave and millimeter-wave products at a price that will allow their use in fielded Department of Defense systems, that meet all required electrical, mechanical, and environmental parameters, and that continue to operate reliably for the time necessary to fulfill their intended application.

During the program planning stages, in 1985 and 1986, it was recognized that a substantial baseline of MIMIC technology existed and that progress was being made toward solving at least some of the technical problems that were preventing the widespread use of MIMIC's in military systems. It was also apparent that there were numerous types of systems with military characteristics that could be greatly improved while increasing their readiness. How-
ever these systems would never be fielded without the achievement of a significant cost reduction for the required microwave and millimeter-wave components. It was clear that what was (and is) needed to meet the objective stated above was a comprehensive initiative that could address technological problems in all areas, would focus upon the development of needed and appropriate products for specific systems and classes of systems, and would be adequately funded and staffed with the most outstanding leaders in the microwave industry. These requirements are being addressed by the MIMIC Program.

Specifically, it was determined that the main impediments preventing the costs of MMICs from being significantly reduced included: (1) the high cost of starting material; (2) poorly controlled production of active material layer(s); (3) the lack of comprehensive computer-aided design systems, in particular, appropriate circuit models for many classes of MMIC's; (4) the lack of adequate production facilities and capabilities; (5) the absence of data bases that could be used to link design and processing parameters with test results; (6) inadequate and expensive packages; and (7) the extremely high cost of testing techniques. The last two of these represent the largest portion of the cost of producing MIMIC's. However, all areas need to be addressed to achieve program success.

Fortunately, during the past 18 months, substantial progress has been made in every area listed above. This has resulted in an estimate by one MIMIC manufacturing team that the cost per square millimeter of producing an MIMIC chip has dropped from $20/mm² at the start of phase 1 to approximately $3–8/mm² in October 1989. The $3/mm² cost is for a small-signal amplifier, the $8/mm² for a higher output power circuit. This team's goal is a cost of $0.80/mm² at the end of MIMIC phase 2. Achievement of this cost target will allow affordable production of phased array systems for electronic warfare and phased array applications. Other teams have similar cost objectives for the MIMIC's that they are producing. In addition to producing the MIMIC chips themselves at a cost between ten and twenty times below their cost at the start of the program, it is critical that packaging costs and testing costs also be substantially reduced.

All of the cost objectives for the various technological components must translate into affordable overall system costs. These costs vary from system type to system type. For example, for electronic phased array radar systems, a per element module cost of a few hundred dollars is required; for a fuse application a MIMIC cost of less than $10 is needed and an overall fuse cost of less than $80 must be achieved. In all cases, MIMIC contractors have developed and are refining comprehensive cost models which are included in their overall business plans. These plans are formally updated at least every 12 months and include a compendium of systems targeted for MIMIC insertion and the cost objectives that must be met to allow these insertions to occur.

IV. Progress Toward Meeting Program Objectives

Several developments during the past year have justified optimism that costs can indeed be lowered concurrently with meeting necessary performance requirements. The first of these developments is the successful demonstration that injection-molded metal matrix composite packages can replace conventional packages machined from metal. Not only are the thermal and electrical characteristics of the injection-molded packages excellent, but their base cost in reasonable quantities is projected to be less than $5.00. A complete package assembly including feedthroughs, metal plating, and covers for a transmitter module of a phased array system is expected to cost between $50 and $60.

On-wafer testing techniques have also greatly improved during the past year, with accurate measurements of small-signal MMIC's now routinely accomplished at frequencies up to 40 GHz. Substantial progress is also being made in on-wafer measurements of higher power MMIC's. One MIMIC phase 3 program is focused upon accurate RF pulse power measurements of circuits in the microwave frequency range; another will extend the ability to perform S-parameter measurements to frequencies up to 75 GHz; and two others are directed toward contactless measurements using lasers and fiber-optic techniques. When available, these contactless techniques will lower costs considerably further because they are extremely broad band and can be extremely rapid.

Impressive progress is also being made in improving the quality and yield of the substrate material being used in the program. Airtron, in conjunction with Ferrofluidics, has developed a new medium-pressure liquid encapsulated Czochralski (LEC) crystal puller equipped with advanced sensors and fiber-optic connections to accurately monitor crystal growth parameters. In a related DARPA-sponsored program, General Electric and Spectrum have developed growth models and algorithms, equipped a high-pressure LEC puller with a wide variety of sensors, and implemented a computer-controlled growth sequence that will provide conditions that result in large boules of single-crystal gallium arsenide appropriate for microwave and millimeter-wave device and circuit production. This program will make use of these techniques and sensors in a new high-pressure LEC puller that will be capable of producing 4-in.-diameter, 25 kg boules of gallium arsenide. This should result in further cost savings because of increased yield of "good" circuits.

Computer-aided design capabilities have increased markedly since the inception of the program. Several commercial microwave CAD producers are marketing MIMIC workstations, and serious attention is being paid to the mandate of open architecture CAD approaches. Models for both active and related passive circuits are being refined under both MIMIC phase 1 and MIMIC phase 3 program sponsorship. Of particular interest and importance is work in progress that will provide accurate
linking of device and circuit models with process parameters. This will make it possible to use test results to automatically adjust modeling parameters. These, in turn, will be used to adjust processing parameters. Progress is also being made in the ability to rapidly synthesize monolithic circuits from electrical specifications. The expansion of "macrocell" libraries connected to appropriate CAD systems will extend the range of circuitry that this technique can be applied to. This should result in further cost decreases and substantial reductions in development time.

Every MIMIC contract team has in place "clean room" pilot production facilities capable of producing at least 100 3-in-diameter wafer starts per shift per week. In addition, most of the teams have already passed MIMIC requirements for process validation by the Government. This is required before they proceed to produce the chips required for their MIMIC phase 1 brazeboard demonstrations. Work has begun toward ensuring that all MIMIC production facilities are "qualified manufacturing lines."

Among the most important and helpful improvements in manufacturing techniques that have been accomplished under MIMIC Program sponsorship are the development, maintenance, and ability to successfully use substantial data bases of processing information. Proper and accurate collection and use of this type of information are essential to allow the rapid and inexpensive production of MIMIC's. Perhaps most exciting is the acceptance of circuits being produced in MIMIC facilities for use in production systems. Early in 1989, the High Speed Anti-Radiation Missile Program (HARM) began using 1200 MIMIC's per month. This level of production is expected to continue for the next five to six years. Other military systems including phased array radars for advanced aircraft such as the Air Force's Advanced Tactical Fighter (ATF) are expected to use MIMIC's. Even if these specific platforms (or other candidates) are not fielded because of budget limitations in the coming years, MIMIC's will provide cost advantages for upgrading existing predecessor systems and increasing their reliability.

Commercial applications of MIMIC-type circuits are also beginning to become reality. These are presently occurring in the automotive industry, but it is likely that MIMIC's will also be widely used for communication and commercial security applications.

V. WORK PLANNED FOR THE NEAR FUTURE

Several new MIMIC projects are expected to begin in the 1990 fiscal year. They will be undertaken to increase the probability of meeting overall program objectives and will provide lasting benefits to the microwave industry. The first of these is MIMIC Program support for the development of a universal microwave hardware description language (MHDL). If this language is comprehensive enough and if it is accepted as a standard, it will allow a still higher degree of rapid design and interchangeability of MIMIC products from many manufacturers. It will also make it markedly easier to retrofit or provide spare parts for existing systems whose designs have been achieved in a standard language. The importance and advantages of a language of this type were demonstrated by the acceptance and increasingly widespread use of the VHDL Hardware Description Language (VHDL), which has become an IEEE standard.

The second planned program is directed toward increasing the availability and use of merchant supplier "foundries" to produce MIMIC's for all appropriate customers. Tangible encouragement of merchant suppliers to produce circuits meeting MIMIC design rules and quality requirements should result in rapid availability of low-cost products.

A third program will explore the viability of using a vertical float zone technique for producing gallium arsenide substrates. This technique has already been demonstrated on an R&D basis at the Naval Research Laboratory and offers the possibility of providing superior material because of reduced thermal stresses.

Additional work in the advanced packaging area is also under consideration.

VI. CONCLUSION

The MIMIC Program is progressing extremely well, with substantial progress being made in every technical area related to satisfying the overall program objectives. The program is at (approximately) the 25% point of the six-year planned technology development and hardware production efforts. Intense activity is still under way in all of the areas of work that must be completed before full success is achieved. Planning for phase 2 is taking into account the progress made during phase 1 both under MIMIC Program sponsorship and in related R&D developments. Of interest are the successes being achieved with newer device types such as high electron mobility transistors (HEMT's) and heterojunction bipolar transistors (HBT's).

All of the participants of the MIMIC Program, i.e., government, universities, and industry, are dedicated to producing the highest quality microwave and millimeter-wave products for the widest possible range of applications at the lowest possible cost. The dedication and perseverance of the personnel and organizations associated with the program are enhancing the probability of program success. This success will be instrumental in ensuring the viability and sustenance of the microwave industry for the foreseeable future. In turn, this will ensure that the Department of Defense will be able to obtain needed microwave and millimeter-wave products as required and at the right price.

He is Deputy Director of the Defense Manufacturing Office at the Defense Advanced Research Projects Agency (DARPA). He shares responsibility with the Director of the Defense Manufacturing Office for guiding and directing technical projects in support of Department of Defense requirements for advanced manufacturing capabilities. Currently, the overall program includes projects on semiconductor manufacturing, infrared focal plane array production, high definition display technology, X-ray lithography, microwave/millimeter-wave monolithic integrated circuits, and intelligent processing of semiconductor materials. The office also has responsibility for administering the Department of Defense grant to the Semiconductor Manufacturing Technology Consortium (SEMATECH).

Concurrently, Mr. Cohen is the Manager of the Microwave/Millimeter-Wave Monolithic Integrated Circuits (MIMIC) Program. The primary objective of the MIMIC program is to produce affordable, monolithic-format analog gallium arsenide circuits in the 1 to 100 GHz frequency range for systems use. Between April 1986 and December 1988 he served as Deputy Director for Microwave and Millimeter Wave Programs in the Department of Defense's Technology Analysis Office (DTAO). In this capacity, he had primary responsibility for most aspects of the MIMIC Program. Between November 1980 and April 1986 he served as Navy Director of the Very High Speed Integrated Circuits (VHSIC) Program at the Space and Naval Warfare Systems Command (Formerly: Naval Electronic Systems Command). Under this program, two generations of high-speed, high-density, silicon digital circuits were developed for advanced signal processing applications. From 1972 to 1980, Mr. Cohen was Head of the High Frequency Devices Section at the Naval Research Laboratory, where he performed and directed research on microwave and millimeter-wave solid-state devices and circuits. From 1963 to 1972, he was an electronic engineer at the Naval Research Laboratory. There he performed research on microwave and millimeter-wave solid-state devices and circuits.