MIMIC TECHNOLOGY TRANSPORTABILITY

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ABSTRACT

Technology transportability is a primary goal of the MIMIC program. Successful transfer of GE's design and process for a C-band 3-watt, 2-stage amplifier from GE's pilot line to four Hughes/GE MIMIC team foundries is an important milestone in that effort. This paper details the cooperative exchange of technology which has enabled transport of this C-band MIMIC, and describes fabrication status, examines process variations, and compares data achieved by the foundries.

INTRODUCTION

A primary goal of DARPA's Microwave and Millimeter Wave Monolithic Integrated Circuit (MIMIC) Program is the demonstration of process-tolerant designs that can be fabricated in multiple facilities at affordable cost. This paper will describe the Hughes/GE team's experience with transporting the design and process for a C-band 3-watt, 2-stage amplifier. This amplifier, based on a mature GE design, is now being produced by the five team foundries (Hughes, GE, AT&T, Harris Microwave Semiconductor, and M/A-COM). Problem areas and their solutions will be highlighted. This work verifies that specific MIMIC designs and processes can be transferred to commercial foundries, and that multiple production sources can be established for identical parts. This successful transfer constitutes an important first step toward proving that MIMIC technology is transportable to the industry.

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MEETING THE MIMIC OBJECTIVES: THE HUGHES/GE PLAN

Systems companies have traditionally approached MMIC source development in one of two ways. Either an in-house capability was established or they have made use of commercial foundries. Foundry interaction also occurred in two manners. The system house could provide a circuit specification to those foundries with design capability, who in turn would design and fabricate the part. Alternately, a system house with design expertise could design their MMIC in accordance with foundry FET models and layout rules. Usually, PCM-based wafer acceptance and possibly DC functionality of the MMICs were the only guarantees offered. Most system house to foundry relationships did not involve technology transfer or exchange, and design and process details were protected as company proprietary.

The Hughes/GE MIMIC team, sponsored by the Air Force, has established a working mechanism for technology exchange between the pilot lines and between the commercial foundries using a team private agreement. This agreement allows any team member to share information with any other team member, as provided under the agreement. This method has been used for design and process details, as discussed below.

The Hughes/GE team foundries will be suppliers of the MIMICs required by the Hughes and GE businesses for surface and airborne phased array radars. Our process line validation will allow these foundries to supply other DoD MIMIC requirements, using the team fabrication technology.

Critical process yield limiters were identified during MIMIC Phase 0. For each task area, a project team was assigned to address the technology and transfer it among the 5 process lines as required. Project teams covering design methodology, device design, gate formation, passivation, flipside processing, wafer-level test, process control, and materials are among those that assisted in our design transport exercises. These project teams consist of

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key engineers from each of the 5 team members, who actively work in the assigned area at their respective company. This has allowed the Hughes/GE team to effectively expand its engineering base, by dividing specific manufacturing tasks among the 5 team members. The team private agreement and project team concept has allowed for full sharing of the manufacturing techniques developed by the whole engineering force, with minimal duplication of effort at the five processing facilities.

PROCESS LINE VALIDATION

In cooperation with the Air Force MIMIC program office, process line validation procedures have been established.

Validation standards include the criteria shown in Figure 1. Each of the team foundries will validate their process lines using the C-Band 3-watt amplifier (Figure 2) as one of the MIMIC test vehicles discussed in this paper. The other two required test vehicles include an X-Band high power amplifier and an X-Band low noise amplifier. For the 3-watt amplifier, GE will complete validation in early 1990, with the four team members following by the third quarter of 1990. Once validated, each company will be a qualified source for production orders and will participate in fabricating the 3-watt chip as part of a 1000-wafer Phase I prototype build.

DESIGN TRANSPORT

This paper focuses on one of our three test vehicles, the C-Band 3-watt design, which was selected because of its maturity and suitability for high-volume production, and because it meets most of the specifications required for GE's system applications, as shown in Figure 3. The implementation of each chip, at GE's pilot line, and at the 4 foundries is shown in Figure 2. This two-stage amplifier consists of a driver stage with two 1 μm gate length by 1268 μm wide cells followed by an output stage with 1 x four 1968 μm cells. The MMIC has been processed at GE's epitaxial pilot line in prototype quantities, on both VPE and MBE material, with equivalent results. Design transfer from GE to the 4 foundries included Touchstone and Supercompact design files, device models, GDSII layout tapes, and process traveller and material specifications. Joint design and process reviews were held. Only minor layout changes were required to accommodate process differences,and the overall amplifier topology remained fixed. We intentionally chose implementation strategies that ranged from conservative to aggressive, in order to test our design transport understanding and capability. AT&T followed exactly the GE process, using the same type epitaxial materials, and the same layout. M/A-COM followed the same route through prevalidation, and is presently investigating a design modification that allows them to make use of their ion implantation expertise. Harris redesigned the circuit to their 0.5 μm ion implanted FET cells, using the GE topology, so that they could use their well-established manufacturing data base. Hughes elected to implement the design using their X-Band HPA-based ion implant power FET process, with only minor layout changes, as a test of design and process resilience. A comparison of the process flow shown in Figure 4 indicates that we have minimized process flow differences.

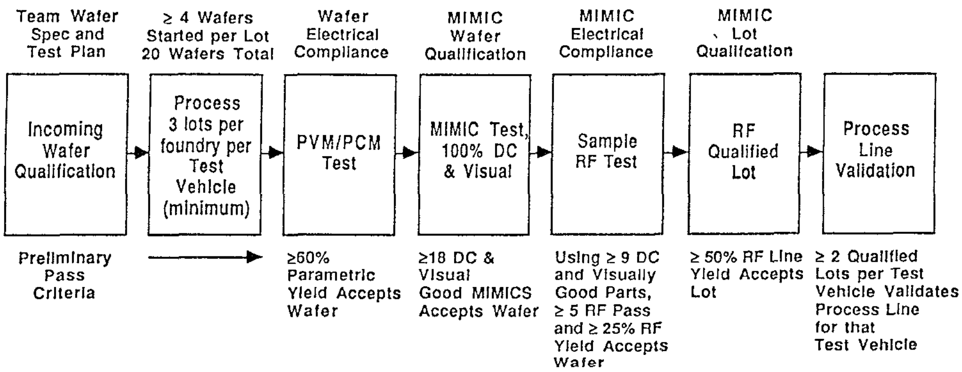
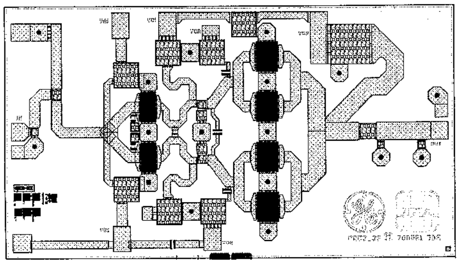
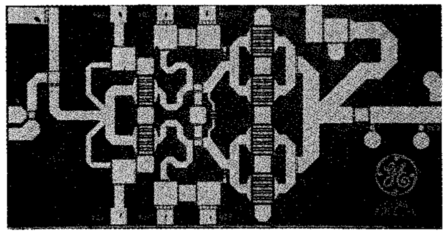


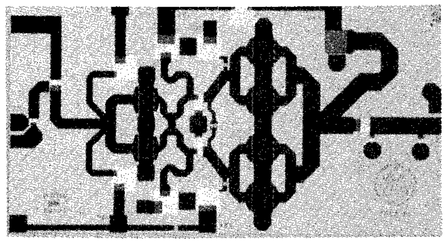
Figure 1. Process Validation Plan



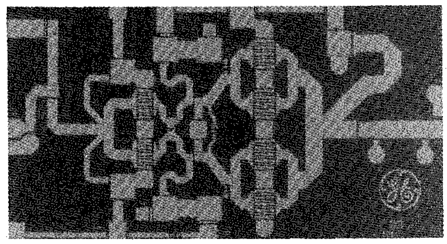
- Epitaxial process
- 1.0μm gate
- >3W, 20-25% PAE
- Design files delivered to foundries: models, simulation files, process details
- Supported design, process, and layout reviews



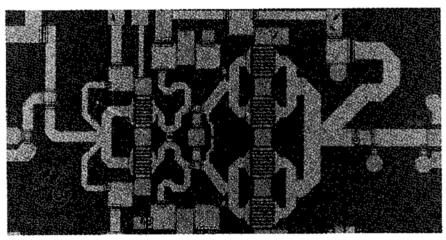
- I^2, 0.7μm Gate >3W, 15-20% PAE



- EPI, 1.0μm Gate >3W, 18-22% PAE



- EPI, 1.0μm Gate >2W, 12-17% PAE



- I^2, 0.5μm Gate In Manufacturing

Figure 2. C-Band 3-Watt HPA Used as MIMIC Test Vehicle.
Design transportability is underway with good initial results.

	BASELINE	VALIDATION TARGET	PHASE I TARGET	SYSTEM INSERTION
PERFORMANCE				
RF Frequency (GHz)	5.2 - 5.85	5.2 - 5.85	5.2 - 5.85	5.2 - 5.85
Power (dBm)	34.2	34.0	34.2	34.2
Efficiency (%)	20	18	25	25
Gain (dB)	14.5	14.5	14.5	14.5
Input VSWR		1.6:1	1.6:1	1.6:1
DC V_P (v)	-3.7 - -6.3	-3.7 - -6.3	-3.7 - -6.0	-3.7 - -5.5
BV (v)	15	15	15	15
I_{DS} (A)	1.0 - 1.6	1.0 - 1.7	1.0 - 1.7	1.5
Cost (Total) $ Per Chip MATERIAL PROCESSING TESTING SUSTAINING LABOR ASSEMBLY	300	381 (DC) 681 (RF)	130	30
RATE Chips/Month	100	400	1000	6000

Figure 3. C-HPA Validation Specification.
The C-HPA validation specification meets most performance requirements; cost projections and model will be verified for Phase I.

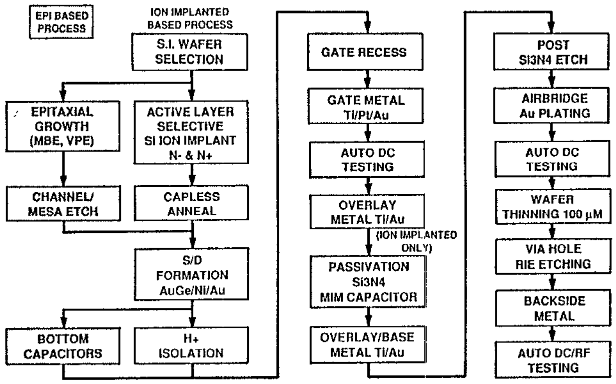


Figure 4. MMIC Manufacturing Baseline Process Flow.

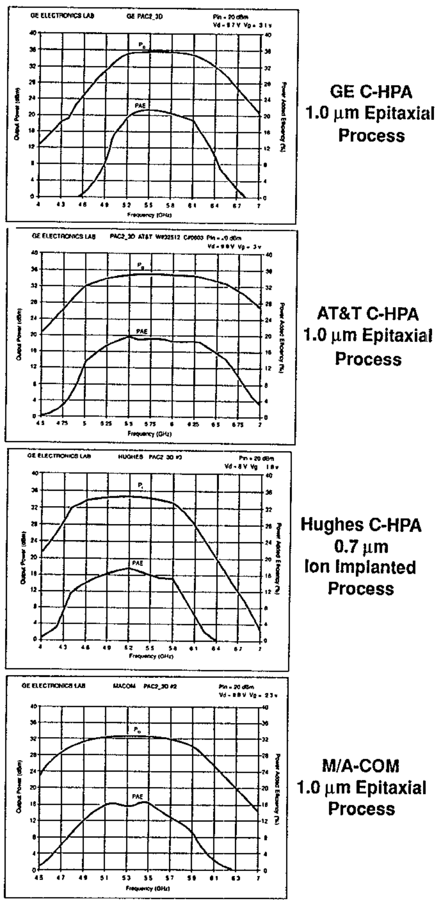


Figure 5. C-Band MIMIC Test Vehicle Performance.

Source	Process
AT&T	Gate recess spray etch end point prediction algorithm
GE	0.5 µm fine line hybrid lithography
Hughes	I^2 x-HPA process flow
GE	Epi C-HPA, x-HPA process flow
Harris	I^2x-LNA process flow
M/A-Com	Auto test algorithms

Figure 6. Process Transfer Summary.

First pass results are shown in Figure 5, indicating that AT&T, M/A-COM, and Hughes have had a fair degree of initial success. Harris data is expected in the near future as their first circuits are entering RF test; their required redesign has delayed them as expected, compared to the foundries that used the GE layout.

BENEFITS AND LESSONS LEARNED

An immediate benefit to the Hughes and GE systems businesses has been verification that the technology can be transferred. Multiple team foundries are through early demonstrations. Formal validation and MIMIC Phase I prototype fabrication will complete the qualification of team foundries. In addition, design and process improvements suggested by the respective companies have improved performance and yield across the team. Several lessons have been learned to date.

1.Full cooperation with joint design reviews and step-by-step process descriptions are required for transportability. For example, even though the GE process is based on MBE material and the Hughes process on ion implantation, sharing the epitaxial doping profile allowed Hughes to select an appropriate implant profile with a double implant sequence.

2.Common specifications from substrates through test procedures provide basis for round robin resolution of differences. For example, initial RF test techniques resulted in different measurements from AT&T, GE, and Hughes. These differences were resolved by testing common parts at both AT&T and Hughes.

3.Specific process problem areas can best be solved through team participation. Figure 6 shows the major process technology transfer areas to date.

4.Team focus on yield and cost sensitive areas provide a win-win situation. As the cost comes down, affordable systems can be supplied by the system houses and volume chip orders can be given to the selected foundries. Each foundry has agreed to provide step by step yields and man hours. Coupled with DC, visual and RF yields, cost tracking is occurring across the team.

CONCLUSION

The Hughes/GE MIMIC chips selected for demonstration of technology transport are being successfully fabricated by the team foundries. The C-Band HPA is the first example. Due to the success to date, team foundries are quoting the larger quantities needed for a GE ground based radar. Thus, the MIMIC objective of technology development and transfer is being accomplished, and insertion of chips into phased array contracts will provide the incentive for continued sharing of technology. It is expected that this technology can now be applied to other systems through the close interaction of other systems houses with the team foundries.

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