MICROWAVE AMPLIFIER MANUFACTURING WITH ADVANCED THIN-FILM MIC AND ELEMENTARY MMIC TECHNOLOGY

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ABSTRACT

New thin-film MIC processes, a coined carrier, and elementary MMIC devices are applied to construct amplifier modules with only five parts. Costs are significantly reduced while maintaining performance and insertion equivalence with conventional circuits. The approach offers an attractive alternative to classic MIC and pure MMIC realizations.

INTRODUCTION

The objective of this work was to minimize the number of parts used to construct hybrid amplifier modules while maximizing compatibility with established manufacturing processes. This approach resulted in balanced amplifier modules consisting of five parts: one carrier, two MIC substrates, and two elementary GaAs MMICs. Capacitors and resistors were fabricated with thin-film processes, both on alumina substrates and as a part of simple GaAs MMICs, thus avoiding use of chip-type passive elements. Module parts count and assembly labor were reduced by 2/3, while maintaining application and insertion equivalence with conventional circuits. Custom low-volume applications require minimal nonrecurring engineering due to the generic nature of the elementary MMICs. This approach offers an attractive alternative to classic hybrid and pure MMIC realizations.

CONVENTIONAL MIC CIRCUITS AS A REFERENCE FOR COMPARISON

A MIC amplifier circuit module which is representative of current manufacturing technology is shown in Figure 1. It consists of 20 parts: a carrier, two substrates, two FETs, a rib, and 14 discrete capacitors. This 1988 hybrid MIC module is hardly advanced relative to circuits reported 20 years ago (1), in which resistors and capacitors were incorporated in deposited thin-films on the circuit substrates. Deposited capacitors are infrequently applied today (2, 3, 4) in MIC manufacturing due to low yield, although novel new MIC media with high capacitor yield have recently been reported (5).

APPROACH

A new thin-film capacitor process was developed which supports high capacitor yield on alumina substrates. These MIC capacitors are conveniently incorporated in RF matching and DC bypassing circuitry. However, they are not well suited for FET source bypass applications because of parasitic inductances inherent in typical layouts. This led to an approach in which the source bypass capacitors are realized as part of an elementary GaAs MMIC, with the capacitors immediately adjacent to the FET on the GaAs material. The problems of substrate, rib, and carrier alignment, and access to RF ground were addressed by developing a carrier with integral rib and sides. The approach is shown schematically in Figure 2. The resultant module consists of five parts - significantly fewer than the number required by equivalent conventional assemblies.

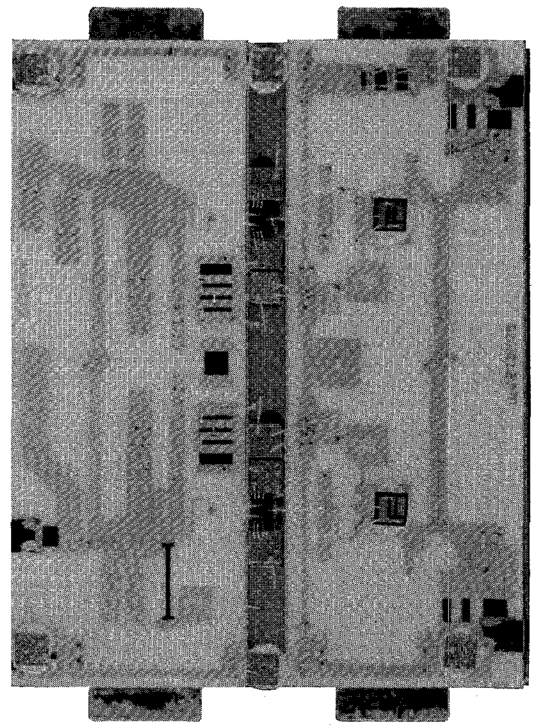


Figure 1. Conventional Hybrid Amplifier Module (20 Parts: A Carrier, Rib, 2 MIC Substrates, 2 Discrete FETs, and 14 Chip Capacitors)

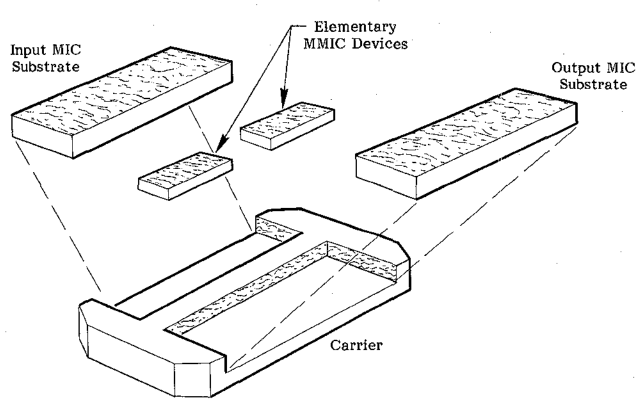


Figure 2. Five Part Amplifer Module (All Capacitors and Resistors are Deposited on Alumina MIC Substrate and Elementary GaAs MMICs)

COINED CARRIER DESIGN AND FABRICATION

A carrier with integral rib for device mounting and side surfaces for access to RF ground is shown in Figure 3. The substrates are located in the recesssed areas. This carrier serves as a braze fixture, guiding substrate placement. It is formed from copper by a coining operation which results in nearly vertical walls and outstanding dimensional repeatability. The top surface is lapped to exceptional flatness, simplifying die attach and lowering the thermal impedance of the device-to-carrier interface. A substrate-to-carrier AuGe braze process and associated fixturing was developed that allows batch processing of 42 circuits per operation.

The large difference in thermal coefficients of expansion between the alumina substrates and copper carrier requires that the substrates be relatively small (0.10 x 0.20 inches in this case), so that excessive stress will not cause substrate cracking. The expansion coefficient difference results in post-braze substrate bowing of typically 8 microns. Extensive temperature cycling (-60 to $+150^{o}$C) has produced no failures. Newer composite materials have been developed that reduce bowing to less than one micron, and are intended for substrates with dimensions exceeding 0.25 inch.

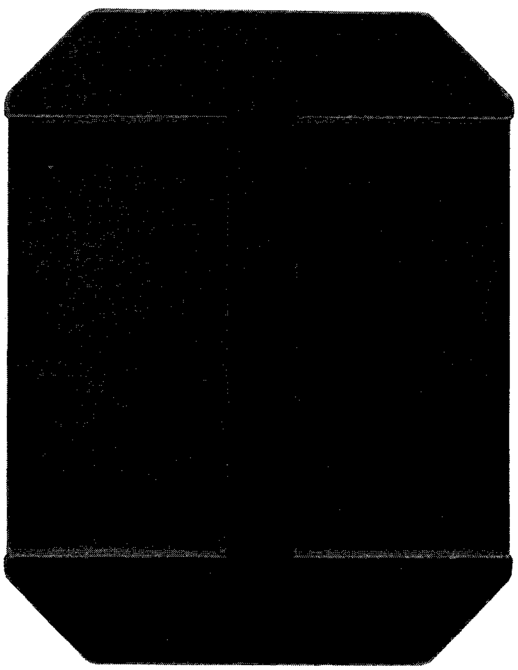


Figure 3. Carrier Formed by Coining Process (Center Rib is for Device Mounting, and Side Surfaces Provide Convenient Access to RF Ground)

MIC THIN-FILM CAPACITOR AND RESISTOR PROCESSES

The thin-film MIC process includes deposited tantalum nitride resistors and silicon nitride capacitors, with a titanium-tungsten/gold conductor system. A process using the WJ-999 CVD System was developed which is key to obtaining high capacitor yield on polished alumina substrates. It involves coating the alumina substrates with a borophosphosilicate glass (BPSG) film (typically 2 microns thick) which is reflowed to form a microscopically smooth surface, effectively covering substrate inclusions and roughness. This process is depicted schematically in Figure 4.

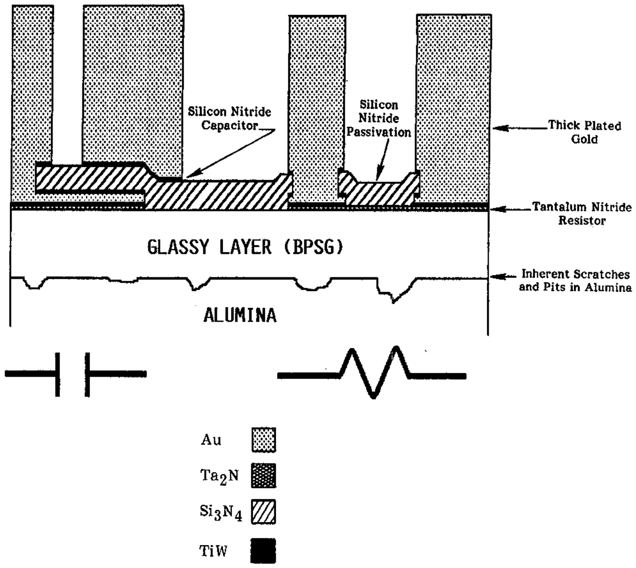


Figure 4. Schematic Cross-Section of the MIC Thin-Film Capacitor and Resistor Process

MESFETS WITH INTEGRAL SOURCE BYPASSING - "ELEMENTARY MMICs"

The coined carriers and MIC substrates with deposited resistors and capacitors have been applied with the three GaAs FET configurations shown in Figures 5 and 6: A) conventional discrete FETs with adjacent chip source bypass capacitors, B) elementary MMICs with FETs and source bypass capacitors integrated in a single GaAs structure, but with external wirebond ground connections, and C) elementary MMICs with FETs, source bypass capacitors, and via ground connections all integrated in the GaAs structure.

The discrete devices (A) allow the greatest design freedom, but require greater skill in assembly and exhibit sensitivity to variations in source inductance. The FET-capacitor devices (B) eliminate the capacitor placement difficulty, but exhibit significant source inductance due to the wirebond connections to ground. Good broadband RF performance has been achieved through 12 GHz with this device.

The FET-capacitor-via ground devices (C) achieve greatest assembly simplification, minimum source inductance, and highest frequency of operation, but also involve more complex GaAs processing. The choice of device is a matter of cost tradeoffs, and may ultimately be determined by the production rates anticipated.

HYBRID CIRCUIT ASSEMBLY WITH AUTOMATIC WIREBONDING

One aspect of the amplifier module realization presented is extensive application of automated wirebonding. We have specifically excluded airbridge crossovers from our MIC processing because of satisfaction with the repeatability and reliability of current automatic wirebonding technology for microwave applications.

These circuit assemblies are wirebonded with a Hughes 2470 automatic, ultrasonic, wedge bonder, utilizing 0.0008 inch diameter gold wire. A 30 position step and repeat fixture accommodates our typical lot size. Pattern recognition is used to

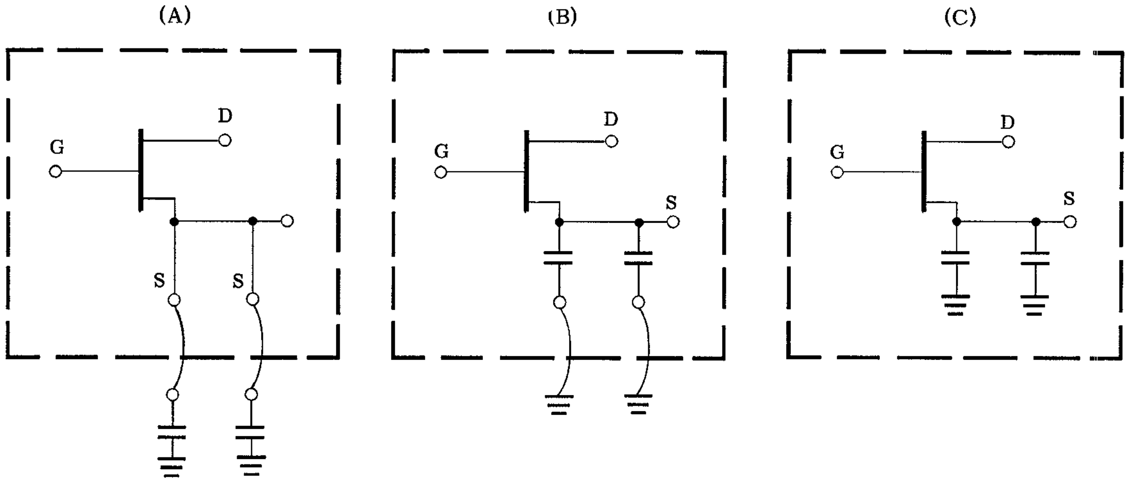
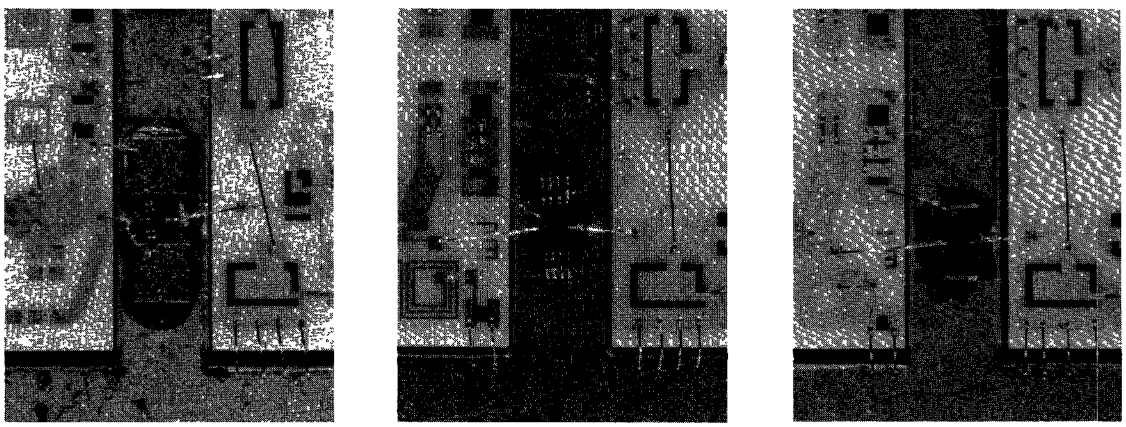


Figure 5. Schematic Representation of Three GaAs Device Configurations - (A) Discrete FET with Chip Source Bypass Capacitors - (B) FET with Integral Source Bypass Capacitors, Requiring Wirebond Grounding, and (C) FET with Integral Source Bypass Capacitors and Via Grounds



(A) (B) (C)

Figure 6. Photographs of the Three GaAs Device Configurations Schematically Depicted in Figure 5

locate all substrate and device reference points. The tool path has been tailored to produce low looping wirebonds while maintaining stress relief. The consistency in bond and loop geometry is excellent. This wirebonding operation has thus far been applied to all areas of the MIC circuits, but is not yet routinely used to bond to the elemental MMICs. Work is in process to achieve 100% automatic wirebonding (no manual bonds).

TYPICAL CIRCUIT EXAMPLES AND ELECTRICAL PERFORMANCE

This approach has been applied to approximately 3000 modules to date. Typical examples are the 5-12 GHz circuit of Figure 7, and the 6-18 GHz circuit of Figure 8. Electrical performance is competitive with conventional discrete device MIC circuits. Circuit-to-circuit repeatability has been excellent for the 5-12 GHz circuits (which produce typically 9.5 $\pm$ 0.2 dB gain, 3.5 dB noise figure, and <1.5:1 VSWR). The 6-18 GHz module includes adjustable MIC capacitors in the input RF matching circuit which simplify circuit alignment (typical performance is 6.7 $\pm$ 0.3 dB gain, 5.0 dB noise figure, and 1.7:1 VSWR). These results are with our lowest cost ion-implanted devices; one to two dB improvements in gain and noise figure have been observed in limited quantities with newer GaAs MESFET technology. An advantage of the MIC and carrier approaches presented is that they facilitate experimentation with new MESFET and HEMT discrete devices, including direct substitution of competing devices in idential circuits.

CONCLUSIONS

The approach presented allows the designer the option of partitioning passive circuitry between alumina substrate and GaAs media, with the thin-film processes of each exhibiting several similarities. The elemental MMICs described have an advantage of being generic with wide application. A reduction in parts count to 1/3 of that for conventional MIC modules with similar functions was achieved. Custom applications are made less costly by use of the MIC circuits, particularly for small or moderate quantities. This results in an attractive alternative to classic MIC and pure MMIC approaches.

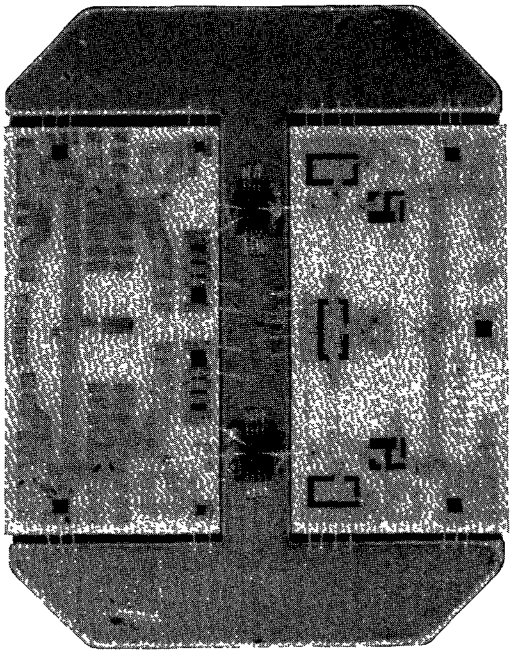


Figure 7. 5-12 GHz Balanced Amplifier Module Utilizing the Advanced MIC Substrate Process and Type B Elementary MMIC Devices

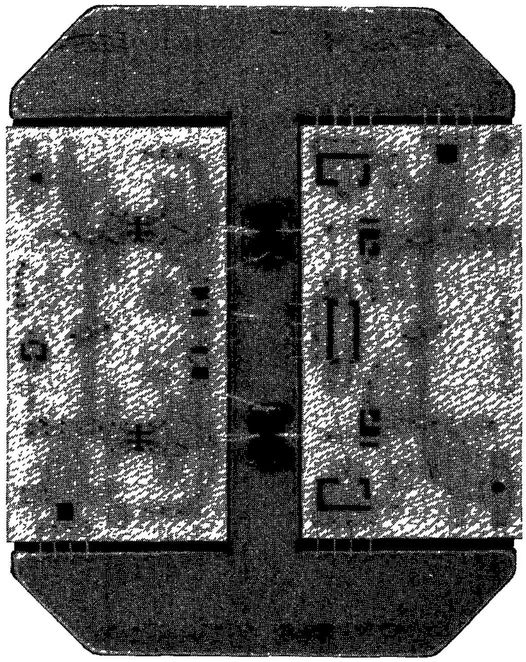


Figure 8. 6-18 GHz Balanced Amplifier Amplifier Module Utilizing the Advanced MIC Substrate Process and Type C Elementary MMIC Devices

ACKNOWLEDGEMENTS

The success of this work has required the support of a team of individuals in several technological and manufacturing diciplines. The authors gratefully acknowledge the particular contributions of Arlene Rodriguez, Maria Lozada, John Guarino, David Fisher, Stephanie Oberg, Ted Washburn, Shelley Fowler, Bob Buss, and Grant Kuykendall.

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