MULTICHIP-ON-FLEX PLASTIC ENCAPSULATED MHDI - LOW COST SUBSTRATELESS MANUFACTURING FOR MICROWAVE AND MILLIMETERWAVE MODULES

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ABSTRACT

This paper describes Chip-on-Flex (COF) technology developed by Lockheed Martin/GE as a low cost derivative of the LM/GE Microwave High Density Interconnect (MHDI) technology. Cost take-out is being achieved by directly mounting MMIC chips onto a pre-fabricated polyimide flex circuit eliminating the need to procure expensive ceramic or metal substrates. Structural rigidity is provided by molded plastic to encapsulate the back of the chips. A C-Band T/R module is reported as the proof-of-concept demonstration vehicle, with up to 3.5 watts RF output having been measured over 5 to 6 GHz.

INTRODUCTION

Since 1989, there have been fundamental advances in high packing density multichip modules for microwave and millimeterwave applications primarily driven by the need for lower-cost T/R modules for military phased arrays. Both MHDI (Microwave High Density Interconnect) (Ref. 1, 2) and Flip-Chip (Ref. 3) technologies have demonstrated mature, high density, wirebondless production-ready processes. However, the unit cost of multichip modules manufactured with these processes generally remains out of reach for high volume commercial applications.

For commercial applications, the Lockheed Martin/GE team are developing a new process with two primary goals: 1) reduce cost by eliminating a large proportion of the processing steps of the basic MHDI technology, while retaining the nature of a 'wafer' of MCMs to enable high speed RF wafer probe testing, and 2) maintain all of the excellent electromagnetic integrity and low RF parasitics of MHDI for use up through 60 GHz. The result uses pre-fabricated interconnect flex, plastic encapsulation and direct metallurgical connection of the chip to the interconnect structure.

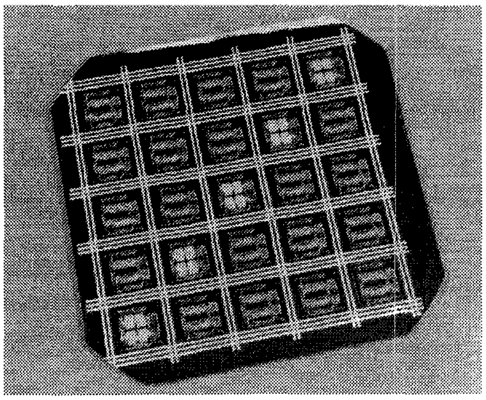

Figure 1. Plastic Encapsulated COF Wafer with 25 Module Sites.

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COF PROCESS

The growing commercial sector in wireless communications, coupled with a willingness to accept less than 'full hermeticity', has provided renewed vigor in the quest for a further 5:1 reduction in packaging and interconnect cost. Full hermeticity is defined as 1 x 10^{-8} atmos. cc/sec He, as the level requested by most military customers. The Chip-on-Flex (COF) technology in the basic form described in this paper will not meet this level, but is designed to provide Reliability - without - Hermeticity (RWoH). As commercial applications of the COF technology become commonplace we believe that the military sector will follow the same route, providing 'spin-on' applications that circumvent many of the cost barriers for military phased arrays

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The basic MHDI process (Ref. 1) utilizes a solid ceramic or metal substrate with wells of depth equal to each of the chips. Typically three layers of polyimide film are laminated over the chips, with each layer having laser ablated via holes and laser patterned interconnect traces. The basic process utilizes the metal on the top surface of the substrate (MT0) as the RF ground and the three thin film layers on the polyimide films (MT1, MT2, and MT3) as DC, E-M shield, and RF interconnect (Figure 2). The cost of an MHDI MCM is dominated by the cost of the externally procured substrate and the large number of laser via ablation, thin film metallization and laser patterning steps.

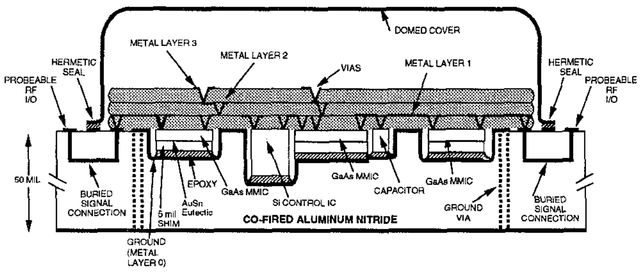

Figure 2. Basic 3-Layer MHDI with Solid Substrate

Figure 3 shows a conceptual cross-section of a microwave COF module based on a process which is being used for digital modules. The process begins with the pre-fabrication of a thin polyimide based flexible circuit. Vias are formed and metal levels zero and one (MT0 and MT1) are patterned to the required interconnect network (solid black lines in Figure 3). A film passivation layer is coated on the top surface of the doubled sided flex, to support subsequent processing of metal level two (MT2). This pre-fabricated flex circuit can be procured from a number of merchant vendors or fabricated internally. The flex is then panelized by bonding it to a large area frame. The frame size determines the number of MCM sites per 'wafer'. Currently a 5 x 5 inch active area is used, with 10 x 10 inch planned for production (giving a 4:1 increase in MCM sites).

The MMIC die is pre-assembled using Au/Sn eutectic to a deep-reach shim as the primary heat removal and DC return path. The bottom of the flex is coated with a thin layer of polyimide adhesive and B-staged. A high speed robotic pick-and-place machine is used to place the MMIC/shim face-down onto the B-staged adhesive on the bottom of the pre-fabricated flex. The B-staged adhesive is then cured bonding the chips directly to the flex.

An industry-standard filled epoxy is used to encapsulate the bottom of the flex. The encapsulant is cured under pressure to minimize voiding. At the present time the entire frame is encapsulated forming a solid 'wafer' using compression molding (Figure 1).

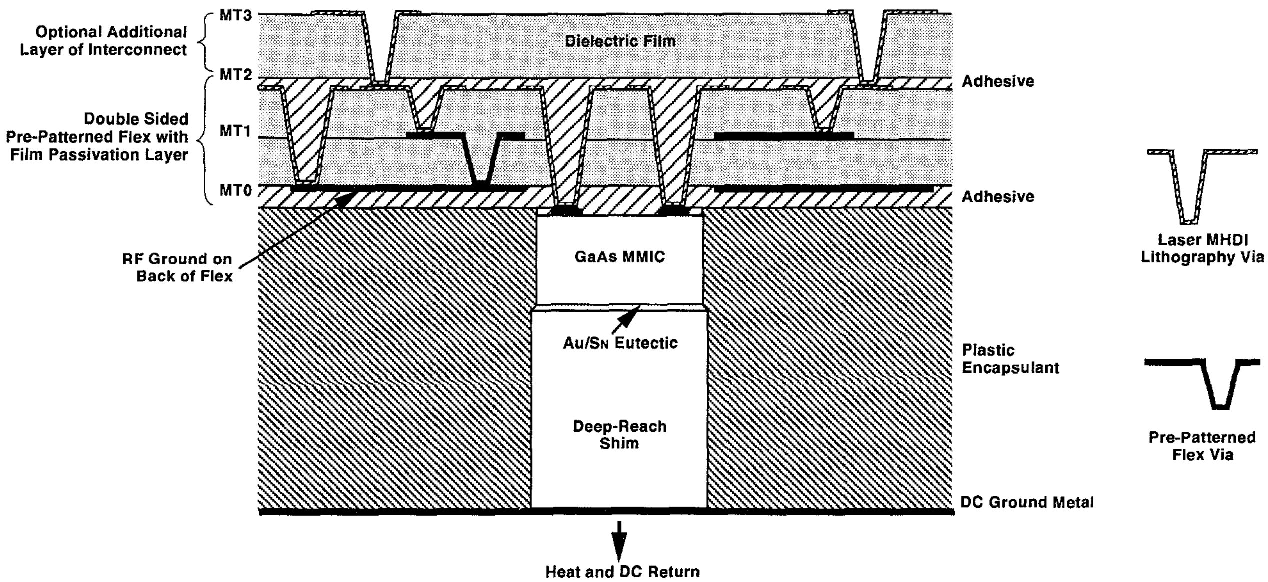

Figure 3 Plastic Encapsulated Chip-on-Flex (COF) Microwave Multichip Module

Via holes are drilled from the top side of the flex, through the passivation layer, the flex, and the adhesive down to the bond pads on the MMICs using laser ablation. Currently a maskless point and shoot laser system is used, although a higher speed mask based laser system is planned. Vias can be drilled to the chip bond pads or to the MT0 metallization on the bottom of the flex.

The top surface is then metallized using standard sputter and electroplate processes. A photoresist is applied over the metallization, exposed and developed to the required interconnect pattern and wet etched to subtractively form the traces. All traces and via structures (shaded lines in Figure 3) are formed during this sequence. The vias provide highly reliable direct metallurgical connections to the chip bond pads. A final conventional laminated MHDI dielectric layer is added if a metal level three (MT3) is required. The plastic is lapped flat at the back to expose the shim. This surface is then metallized to provide a DC ground and heat path.

MMICs, Si ICs, and other chip components including multiple forms of I/O pins can be interconnected in a single Microwave Multichip Module.

One of the unique electrical features is the use of the MT0 metal on the back of the pre-fabricated flex to provide the RF ground plane that was formally on the <u>top</u> surface of the substrate in the basic MHDI process.

HIGH PERFORMANCE MMICs

The MMIC die can optionally be pre-processed with polyimide standoffs on the die to provide an air gap over the device and matching element regions of the MMIC. This allows the MMIC to see an air dielectric Er=1 as was intended, so maintaining full RF performance from the chip (Ref. 2).

PROOF-OF-CONCEPT MODULE DESIGN

To establish 'proof-of-concept' for COF technology, a standard C-Band T/R module design was used (Figure 4). The module is the third generation of an existing C-Band design of which 6000 modules have been built using chip-and-wire technology. In 1991 the design was converted to basic 3-layer MHDI using the same chip-set, and 60 modules built (Ref. 1). The third generation design, reported here, was built using a variant of Chip-on-Flex technology to establish proof-of concept in late 1994. Each module contains 7 GaAs MMICs, integrated with silicon CMOS inverter and shift register chips, eighteen chip resistors and capacitors, and two quadrature couplers.

Eliminating the solid substrate from the MHDI design also removes the RF ground path to the back of the GaAs MMIC. To alleviate this problem the COF technology adopts a unique Ground-Transfer-Probe (GTP) design utilizing the co-planar G-S-G or G-S pads on the MMIC I/O that are normally used for RF wafer probing. Reference RF ground in the COF interconnect is MT0 on the back of the flex. Raising the ground plane to MT1 permits the vias through the

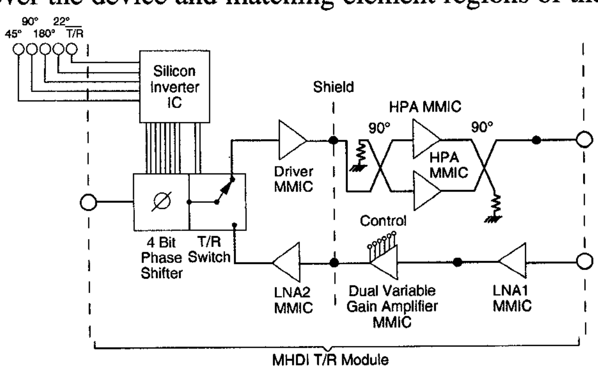

Figure 4 . C-Band Module Architecture

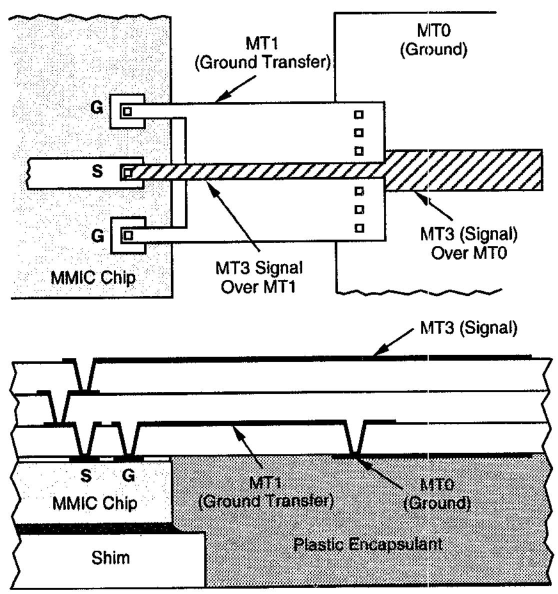

Figure 5 . COF Ground-Transfer-Probe (GTP)

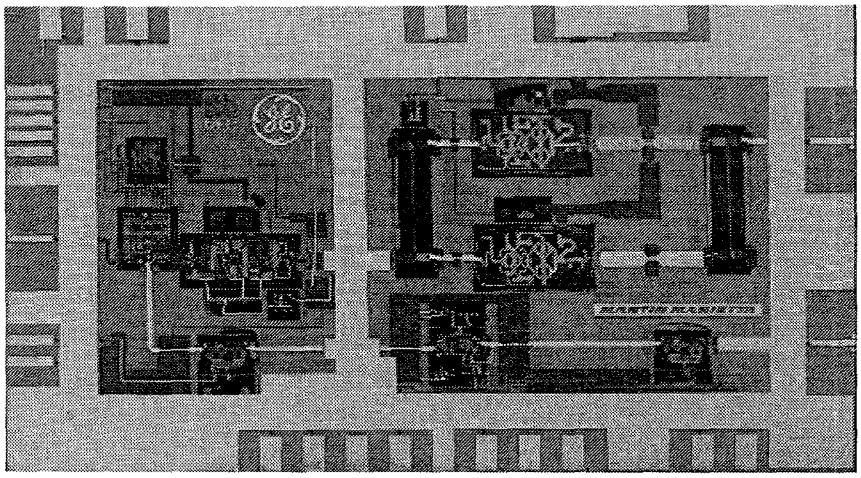

Figure 6. Plastic Encapsulated Chip-on-Flex (COF) 3.5 Watt C-Band T/R Module

lower flex layer to pick up the ground pads on the MMIC. The MMIC signal pad is connected through stacked vias all the way up to the top metal (MT3) forming a microstripline over the MT1. At the edge of the GTP the ground is again connected back to the MT0 layer allowing the MT3 microstripline to widen for lowest loss 50 ohm interconnect. The GTP provides a controlled impedance all the way up to the MMIC and eliminates the ground discontinuity in the 15 mil moat region as required around each chip in basic MHDI modules

MODULE RF RESULTS

Figure 6 shows the completed Proof-of-Concept COF T/R Module. The measured results are 3.5 watts RF output power (Figure 7), and 45 dB receive gain at mid band (Figure 8). Noise figure was 3.5 dB at 5.5 GHz.

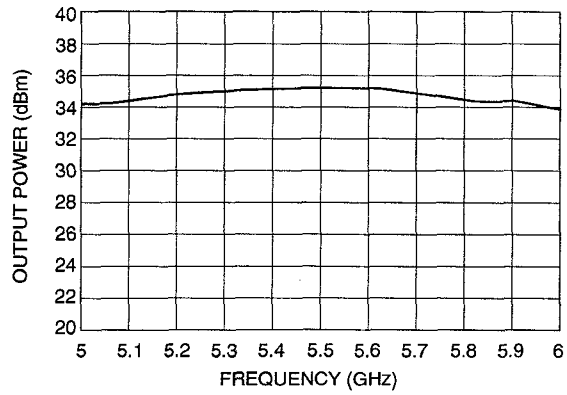

Figure 7. Measured RF Output of COF MCM

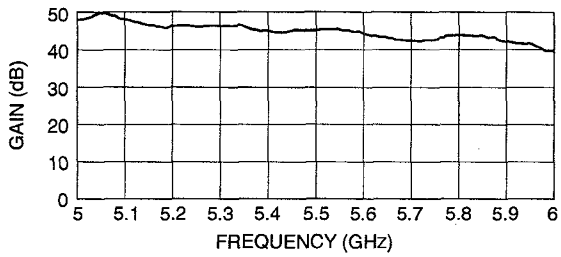

Figure 8. Measured Receive Gain of COF MCM

CONCLUSION

COF technology proof-of-concept has been established for RF MCMs. The opportunities for I/O pin variants and different form factors are virtually unlimited.

ACKNOWLEDGMENTS

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