THE THERMAL BENEFITS OF DIAMOND ENHANCED PLASTIC PACKAGES FOR MICROWAVE APPLICATIONS

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ABSTRACT

The superior material properties of diamond combined with the economics of plastic packaging provide the ultimate thermal management solution. A GaAs Power Amplifier dissipating 20 Watts (W) has been demonstrated in a diamond enhanced plastic package. In addition, a dramatic improvement in the electrical performance of a coplanar flip chip MMIC in plastic has been achieved.

I. INTRODUCTION

The continued demand to reduce the cost of microwave components for commercial applications has led to an increased use of injection molded plastic packages for Gallium Arsenide (GaAs) Monolithic Microwave Integrated Circuits (MMICs). Unfortunately, typical plastic packages are limited to devices that dissipate a maximum of 1W. Norton Diamond Film's NorCool™ package combines the superior thermal properties of Chemical Vapor Deposited (CVD) diamond with the low cost of plastic packages. The thermal efficiency of these diamond enhanced plastic packages is, thereby, significantly increased at half the cost of ceramic packages which are often used when higher power densities are required.

The NorCool™ package replaces the die paddle of a typical copper leadframe with a diamond substrate. The diamond substrate is physically attached to the copper leadframe creating a direct thermal path to the outside of the package. Figure 1 illustrates a plastic package with the integrated diamond substrate.

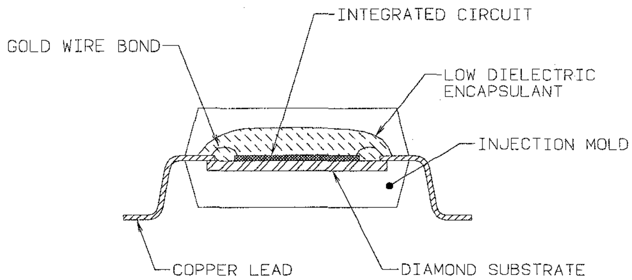

Figure 1. Diamond Enhanced Plastic Package

A 3-6 GHz GaAs MMIC dissipating 20W has been assembled in a NorCool™ package. Both thermal analyses and IR scans show that the maximum junction temperature is maintained below 150°C validating the benefits of diamond enhanced plastic packages for microwave applications. Furthermore, a coplanar Power Amplifier MMIC has been flip chip attached in a NorCool™ package. Unlike microstrip MMICs conventionally assembled in plastic packages, no electrical performance degradation was observed after plastic injection molding the coplanar flip chip MMIC. The process and methods to achieve these results are presented in this paper.

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II. TECHNICAL APPROACH

A. 30W GaAs MMIC in Plastic

A 3-6 GHz Power Amplifier GaAs PHEMT MMIC (0.242" x 0.183" x 0.004") was assembled in a diamond enhanced 128 lead plastic quad flat pack (PQFP). This MMIC, capable of dissipating 30W, was soldered onto a coplanar patterned Cr-Cu-Ni-Au metallized diamond substrate using Pb-Sn-Ag solder. The coplanar Cr-Cu-Ni-Au metallization on the diamond substrate was specifically designed to achieve the best electrical performance given the packaging constraints. These constraints included the leadframe geometry, MMIC die size and functionality, diamond dielectric constant, and copper lead to MMIC bond pad transition. A coplanar design was chosen for its enhanced electrical performance within the plastic package while also eliminating the need for any backside processing or vias in the diamond. Special attention was given to the RF transition from the MMIC to the leadframe to minimize electrical loss. Cr-Cu-Ni-Au metallization combined with Pb-Sn-Ag solder has been shown to overcome the Coefficient of Thermal Expansion (CTE) mismatch between diamond and GaAs; the CTE's of GaAs and diamond are 5.7×10^{-6} ppm/°C and 1.4×10^{-6} ppm/°C respectively [1].

Figure 2 shows the high power PHEMT on diamond assembly. As shown in this figure, a complex off-chip matching network is epoxied next to the MMIC.

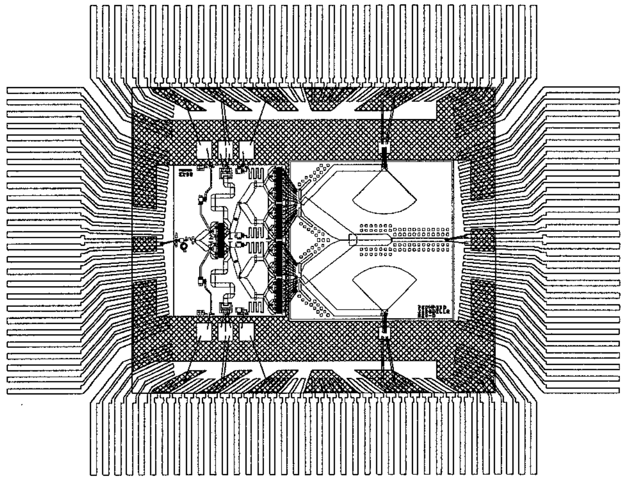

Figure 2. High Power PHEMT MMIC on Diamond

B. Coplanar GaAs MMIC

A coplanar GaAs MMIC was designed specifically for assembly into a NorCool™ package by taking the effects of the leadframe and the flip chip bumps into account. The coplanar GaAs MMIC Power Amplifier has a center operating frequency of 1.9 GHz and an overall size of 0.150" x 0.080" x 0.005". Figure 3 shows the coplanar MMIC containing 37 bumps. This MMIC was flip chip attached onto a diamond enhanced 20 lead SOIC leadframe. Similar to the high power PHEMT MMIC effort, the diamond was metallized with a Cr-Cu-Ni-Au coplanar pattern to achieve the best electrical performance given the packaging constraints.

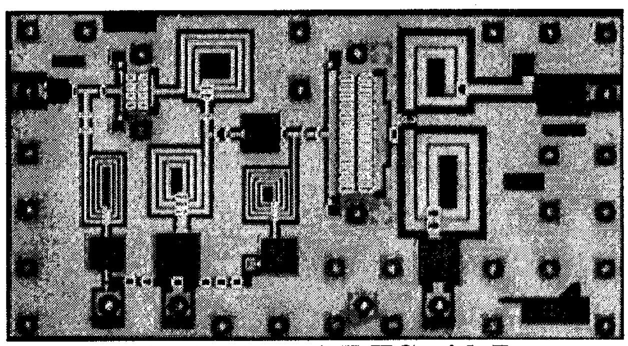

Figure 3. Coplanar MMIC with Bumps

III. RESULTS

A. 30W GaAs MMIC in Plastic

Figures 4 and 5 compare the on-wafer to the packaged measurements. As depicted in the figures, good correlation was achieved. Although a slight drop in Gain and Power Out was observed, these results are quite extraordinary given the MMIC frequency and power dissipation. As previously mentioned, this MMIC is capable of dissipating 30W but due to the extreme junction temperatures at 30W all measurements were taken while dissipating 20W. As shown in the figures, the MMIC was still operating as designed after 96 hours of continuous operation! The results of this effort provide an excellent indication of how diamond enhances the performance of plastic packages. Without the superior thermal dissipation capability of diamond, this MMIC could previously only be operated in pulsed mode and could certainly not have been packaged in plastic.

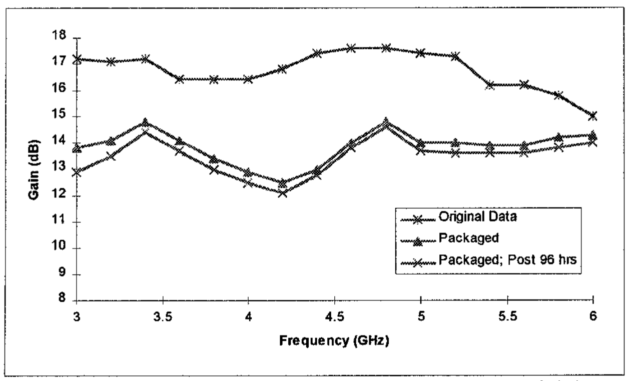

Figure 4. Assembled vs. On-Wafer S21 Measurements

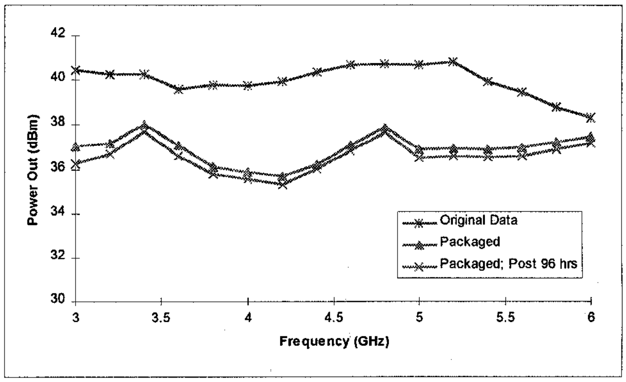

Figure 5. Assembled vs. On-Wafer Power Out Measurements

B. Coplanar GaAs MMIC

Figures 6a through 6c compare the on-wafer to the flip chip assembled and packaged measurements. As depicted in the figures, excellent correlation was achieved. Unlike the injection molded microstrip MMICs, no electrical degradation was observed after injection molding of the coplanar flip chip MMICs. Typically, a slight MMIC design modification would have to be made in order to compensate for the plastic effects. However, these results have shown that when using coplanar flip chip MMICs the results that were obtained on-wafer can be expected after injection molding.

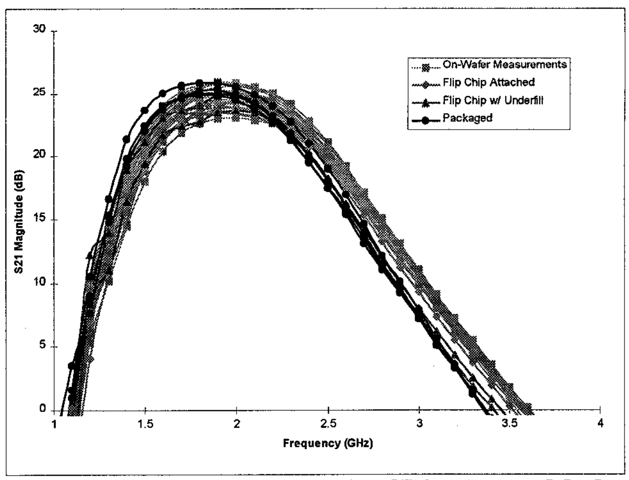

Figure 6a. Coplanar Flip Chip Assembled vs. On-Wafer S21 Measurements

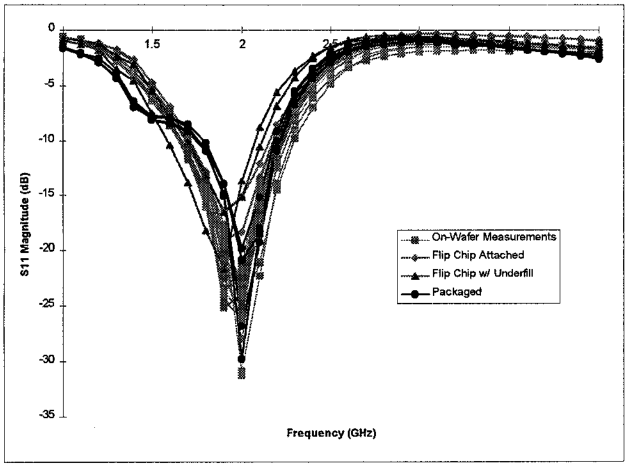

Figure 6b. Coplanar Flip Chip Assembled vs. On-Wafer S11 Measurements

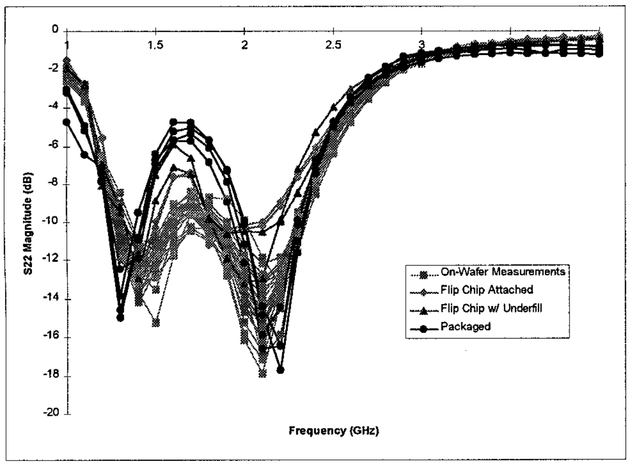

Figure 6c. Coplanar Flip Chip Assembled vs. On-Wafer S22 Measurements

IV. CONCLUSIONS

The NorCool™ package takes full advantage of the superior thermal properties of CVD diamond and the low cost of plastic packages. It has been shown that to take full advantage of the diamond enhanced plastic packages and maintain a low cost unit, the use of coplanar flip chip MMICs is essential.

Diamond enhanced plastic packages will allow high power GaAs MMICs to be packaged in plastic rather than in traditional ceramic packages. IR scans and thermal analyses proved that the heat dissipated by the GaAs MMICs have a direct thermal path to the outside of the plastic package. It has been shown that these diamond enhanced plastic packages could reliably house a GaAs MMIC dissipating as much at 20W! This is a 10 fold improvement over a traditional plastic package. Finally, the use of diamond enhanced plastic packages will reduce the cost and weight through improved thermal efficiency, higher package density, and increased reliability.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

1. M. Gomes-Casseres and P.A. Fabis, "Thermally Enhanced Plastic Packages using Diamond for Microwave Applications," IEEE MTT-S International Microwave Symposium Digest, 1996, pp. 227-230, San Francisco, CA.

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