# *Using MMIC Flip Chips and CVD Diamond For Improved Thermal Management Of Microwave Modules*

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**Abstract**

MMIC flip chips offer several benefits over conventional face-up versions. This includes lower cost, ease of interconnection, self alignment to motherboard, and simultaneous attachment and electrical connection. High power MMIC flip chips use bumps on the FET source to provide for an improved thermal path. When connected to a high thermal conductivity mounting substrate such as aluminum nitride, high power flip chips operate at lower temperatures than conventional flip chips. In fact, modeling has shown that they can have a 15 °C lower junction temperature compared to conventional MMICs. However, it is often desirable to use lower thermal conductivity mounting substrates such as LTCC. In these cases the junction temperate of a MMIC, flipped or face-up, can be too high for practical use. By using Chemical Vapor Deposition (CVD) diamond substrates, it is possible to reduce the junction temperature to acceptable levels. This work describes the uses of diamond with MMIC flip chips on low thermal conductivity substrates.

**Introduction**

MMIC flip chips offer many advantages over conventional chips. In high power applications such as high power amplifiers (HPAs), thermal bumps are placed over the FET sources to increase the thermal path from the heat generating region between the drain-gate to the motherboard[1]. In this case, a high thermal conductivity motherboard is required to transfer heat from the MMIC to a heat sink. Substrates such as AlN, with a thermal conductivity of 140-190 W/mK, are used in these cases. However, it is often desirable to use low thermal conductivity substrates such as LTCC or Cyanide-Ester for cost reduction. Attachment of a flipped MMIC HPA to low thermal conductivity substrate causes the junction temperature to increase well beyond the useable range.

An alternative is to use a high thermal conductivity heat speader, such as CVD diamond, between the MMIC and motherboard. In this technique, a heat speader can reduce the junction temperature to acceptable levels. This report presents such a technique. Microwave materials test are conducted on diamond to determine its electrical characteristics. Also, thermal modeling demonstrates the usefulness of this method in achieving lower junction temperatures. The packaging technique is described and microwave transitions are designed to achieve acceptable microwave performance. Finally, measurements are conducted to confirm the predicted results.

**Microwave Materials Tests**

Materials test were conducted to determine the loss tangent and dielectric constant. A ring resonator technique was used [2]. Both the dielectric constant and loss tangent were measured. Figure 1 illustrates the metallization pattern that was used.

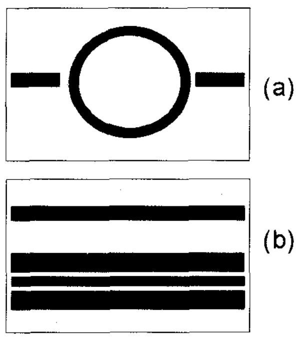


Figure 1. Ring resonator and transmission lines used in the materials test.

The results of the tests demonstrate that diamond is a very good dielectric at microwave



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frequencies. Table 1 lists several common dielectric materials with their associated material patterns. It can be seen that diamond ranks among the lowest loss materials.

| Material | $\varepsilon_r$ | tanδ |
|---|---|---|
| AlN | 8.5 | 0.003 |
| Alumina | 9.8 | 0.0003 |
| Diamond | 5.7 | 0.0005 |
| Teflon | 2.2 | 0.0003 |

Table 1. Comparison of the dielectric constant and loss tangent of several dielectric materials.

Diamond substrates from three sources were evaluated. Although all three sources use CVD techniques, each has its own method. As a result, there was some concern regarding the variability in electrical performance between several suppliers. Therefore, diamond from three sources will be shown to demonstrate the effect of differing fabrication techniques upon the electric characteristics of the material.

**Description of The Method**

One of the benefits of diamond is its extremely high thermal conductivity. This allows it to be used as a heat spreader as shown in Figure 2. The benefit of this technique is that low thermal conductivity substrates can be used with high power MMIC flip chips. In general, low thermal conductivity substrates (Cyanide Ester, LTCC, TMM) are low cost and have rapid fabrication cycles compared to high thermal conductivity ceramics.

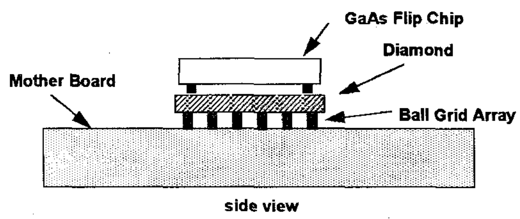


Figure 2. Illustration of the flip chip on diamond technique.

High power MMIC flip chips use bumps on their parameter as well as thermal bumps on the FET sources. In this application the thermal bumps attach to a high thermal conductivity diamond substrate. Diamond can spread heat across itself in the lateral direction. The heat speading allows the use of lower thermal conductivity substrates. This heat spreading results in a lower temperature rise in the motherboard.

**Thermal Modeling**

To demonstrate the benefit of using diamond with MMIC flip chips, a thermal model was generated. The analysis was conducted using CINDA and several motherboard materials were compared. Table 2 shows the results and the benefit of using diamond. It is interesting to note that without diamond there is an 862 °C rise in temperature. The FET would, of course, fail before this temperature would be reached.

| Motherboard Material | Temperature rise without diamond °C | Temperature rise with diamond °C |
|---|---|---|
| AlN | 14.3 | 9.3 |
| LTCC | 862 | 135 |
| Alumina | 70.8 | 20 |

Table 2. Results of thermal modeling shows the temperature rise from the back of the motherboard to the thermal bump on the MMIC.

**Electromagnetic Modeling**

As part of the design, electromagnetic modeling of the interconnect was performed. The transition can be divided into four portions (1) the motherboard to ball grid array, (2) ball grid array into vias(in the diamond), (3) vias to CBCPW on the surface of the diamond, (4) CBCPW to MMIC flip chip. Because of the close proximity of the various portions of this transition, a complete model was created. The model and results will be included in the final submission.

**Environmental Investigation**

A critical part of this development is the determination of the environmental survivability. The mechanical connection of the motherboard to diamond (ball grid array) and the connection of the flip chip to diamond are possible points of failure. Simple stress analysis is not sufficient to determine the maximum thermal cycles before failure due to the build up of stress in the solder joint at the bumps and BGA. Therefore, experimental validation is required. Test results will be included in the final submission.

## Electrical Performance

An important part of this investigation is the performance of the MMIC flip chip to diamond attachment. Measured performance will be presented in the final submission.

## Conclusions

A new technique for attachment of diamond to flip chips is presented. This technique allows for use of low thermal conductivity motherboards due to the thermal spreading of the diamond. The electrical characteristics of diamond were measured and it was shown that diamond is a good microwave dielectric material. In addition, electromagnetic modeling is conducted for the transitions involved. Finally, measured electrical performance is shown for the flip chip on diamond.

## Acknowledgments

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