Diamond-Metal Composite Package for High Power RF Device

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Abstract

There is a constant need for improved thermal performance in air cavity packages used for high power RF devices and this often leads to further scrutiny of the flange, or heatsink, material. This paper will show the research conducted to identify a material with greater than 2X improvement in thermal conductivity, resulting in a 40% reduction in total thermal resistance of the device. The material has also been demonstrated to be compatible with GaN-SiC die, can be formed into a flange and integrated into a functional package to enable very high power RF devices.

INTRODUCTION

GaN device technologies have been increasing in power and voltage to give end users an advantage in total system cost and performance for Aerospace and Defense applications, including RADAR and electronic warfare systems. As the power levels increase there is a greater burden placed on the package to dissipate heat out of the die and into the surrounding environment or heat sink. The GaN die is typically attached to the flange of the package, which is then mounted to a heat sink, making the flange the most critical component to dissipate heat from the die and into the system.

In addition to dissipating heat, the package flange also needs to be mechanically compatible with the other elements of the package, including the GaN/SiC or GaN/Si die, window frame, and leads. The flange also needs to accept plating and maintain specified surface finish and flatness specifications.

MATERIAL SELECTION

The most common flange type currently used for high power RF packages is a Copper-Molybdenum (Co-Mo) laminate material. This material is tailor made to have a relatively high thermal conductivity (TC) of 200-300 W/m-K and low coefficient of thermal expansion (CTE) of 7-9 ppm [1].

The first step in developing an improved thermal package was to outline the material requirements desired and compare to the traditional Co-Mo laminate material. These requirements included a TC above 600 W/m-K, CTE no more than 9 ppm, flatness of less than 1 mil per inch, roughness around 40-60 micro-inches, the ability to be plated, and withstand assembly temperatures up to 350°C. Many materials were first identified with compositions ranging from pure diamond to graphite to carbon fiber, and all manner of composites (see Table I).

Each technology was considered based on its technical specifications, stage of development, time to sample, stability of supply, and cost. Some technologies were early in development while others were being qualified or could already be supplied in production volumes.

Based on these criteria the list was narrowed down to 4 materials (referred to hereafter as material A, B, C, and D). These materials were all composed of a diamond-metal composite that could be formed into the desired flange size and readily available. Samples were procured of all materials plated with Ni/Au to enable die attach and subsequent assembly steps.

TABLE I
MATERIAL TECHNOLOGIES AND PROPERTIES

Technology	**Thermal Conductivity**	**CTE**
Cu-Diamond Composite 1	425-475 W/m-K	7-9 ppm
Ag-Diamond Composite 1	600 W/m-K	6-7 ppm
Ag-Diamond Composite 2	900 W/m-K	6.5 ppm
Al-Diamond Composite 1	500 W/m-K	6.1 ppm
Mo-graphite-Ti Composite	X-Y: 650 W/m-K, Z: 45 W/m-K	X-Y: 2.4, Z: 14.7
Cu-diamond Composite 2	432 W/m-K	8.6 ppm
Super CMC (High TC Variant)	X-Y: 381 W/m-K, Z: 362 W/m-K	14.8 ppm
Synthetic Diamond / Carbon Fiber Composite	Not available	Not available
Ag-Diamond Composite 3	600 W/m-K	9 ppm
Al-Diamond Composite 2	450 W/m-K	Not available
Cu-Diamond Composite 3	700 W/m-K	10 ppm
Thermal Pyrolytic Graphite	1155 (X), 130 (Y), 760 (Z) W/m-K	Varies
Cu-Mo Laminate (control)	*210-240 W/m-K*	*8-9 ppm*

ASSEMBLY EVALUATIONS

The first evaluation of the 4 different flange materials was to assemble them into a package with a high power GaN product design. The test vehicle chosen utilized 4 GaN-SiC die and a series of matching components, capable of producing up to 1300W of RF power (see Fig. 1).

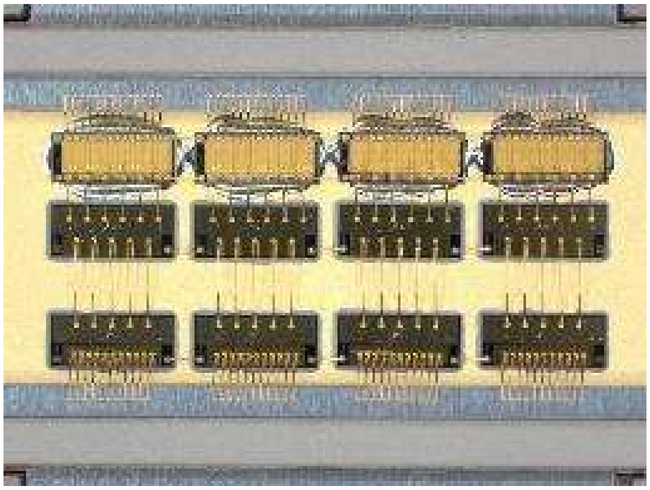

Fig. 1. Test vehicle with 4 GaN-SiC die and matching components attached to Diamond-Metal composite flange

Parts were first evaluated for die attach quality by measuring die attach voiding with CSAM, die shear testing, and visual quality. All 4 groups showed good attach with no parts failing any measurement criteria. This indicates the plating quality and adhesion to the underlying diamond-metal material was good.

The next process was to attach a window frame to the flange and measure again with CSAM, to look for voiding, and shear testing. All 4 groups showed good window frame attach with no defects.

Parts then proceeded through the remaining assembly process including wire bonding and lid seal. While these process steps don’t have a direct interaction with the flange, the measurements for wire pull and final internal visual quality were still performed and showed no issues. Finally gross leak testing was performed on all parts and there were no gross leak failures among the 4 groups.

Based on these results it was determined that all 4 diamond-metal materials showed equivalent and good results through the assembly evaluations. Control parts using Co-Mo laminate flanges were also assembled at the same time to be used during further testing.

RF TEMPERATURE TESTING

The next evaluation performed on the assembled parts was RF testing at different baseplate temperatures. RF drive-ups were performed at 1.06GHz and 65V with the baseplate temperature starting at 25°C and increasing to 125°C by 20°C increments.

RF performance was monitored while the baseplate was increased and used to calculate the estimated channel temperature of the device.

The results showed that the diamond composite flanges kept the device running about 60°C cooler than the Co-Mo control parts (see Fig. 2). All 4 test materials performed very similarly on average, but three materials; A, B, and C, showed consistently good results through all temperatures. Material D performed well at lower temperatures but once the baseplate reached 125°C the parts would consistently and catastrophically fail.

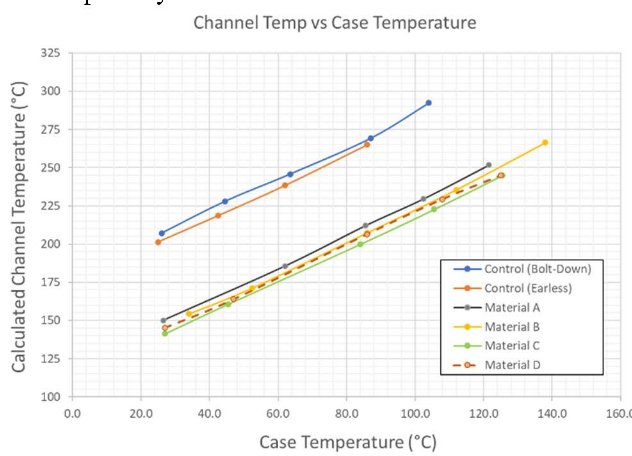

Fig. 2. RF Temperature Test Results

THERMAL IMAGING

All groups of parts were evaluated with thermal imaging using a QFI Infrared Scope under DC conditions. For this test the parts were mounted into a test fixture with a thermocouple in direct contact with the bottom of the flange to measure case temperature. The drain voltage was set at 50V and the gate voltage was adjusted until the junction temperature reached close to 200°C. The infrared camera was used to measure the junction temperature and then the total thermal resistance (Rjc) could be calculated.

The results were divided into 2 different groups because some of the groups were assembled with bolt-down flanges and others used earless flanges. The effect for this was taken out by comparing the diamond composite materials with their corresponding bolt-down or earless Co-Mo control parts only.

All 4 diamond composite materials showed similar results with a reduction in Rjc of 32-40%, see figure 3 below. Material A had the most improvement with an average 39.7% reduction in Rjc

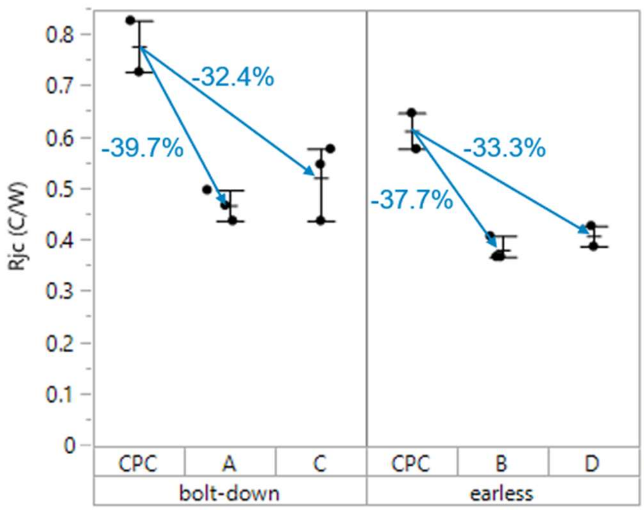

Fig. 3. Thermal Imaging Results

CONCLUSIONS

Based on the assembly, RF temperature testing, and thermal imaging results two materials were selected to continue with the packaging technology and ultimately product development. Additional factors such as cost, maturity of technology, manufacturing location, and ability to ramp in production were considered in this decision. Products are now in development using diamond-metal composite flanges capable of producing as much as 7kW of RF power in industry standard package outlines. This technology has great potential to enable next level performance of power products using GaN and other high power device technologies.

REFERENCES

[1] Torrey Hills Technologies (n.d.). Cu/Mo/Cu Heatsinks. https://www.torreyhillstech.com/hscmc.html

ACRONYMS

GaN: Gallium-Nitride
SiC: Silicon-Carbide
TC: Thermal Conductivity
CTE: Coefficient of Thermal Expansion
CSAM: C-mode Scanning Acoustic Microscopy