High Power Plastic Packaging with GaN

Quinn Martin

MACOM Technology Solutions, 523 Davis Drive, Suite 500, Morrisville, NC 27560
Phone: 919-424-5169 Email: quinn.martin@macom.com

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Abstract

The adoption of GaN devices, with their high power densities and operating temperatures, has created challenges for semiconductor packaging. Adding to these challenges is the drive to create cost-effective GaN products while still maintaining good RF performance and reliability. A solution to this is found in advanced plastic overmold packaging with new materials and processes that enable GaN products to be produced in high volumes with cost-effective production flows, while maintaining good device performance. This paper will describe a few of the key advancements in plastic packaging that have enabled this.

INTRODUCTION

For many years high power RF packaging has been dominated by metal-ceramic packages and assembly processes, with GaN being no exception to this trend. The resulting products have been reliable, consistent, and capable of dissipating heat out of the device. However, the material and assembly costs have been very high and throughput limited. Plastic overmolded parts, on the other hand, can be made at a fraction of the cost but have historically been limited to lower power applications and not considered seriously for high power GaN.

Recent advances in plastic packaging have enabled higher power dissipation of the device while maintaining a lower cost approach to the materials and assembly processes. This has been achieved through package design, material selection, and process optimization. This paper will show examples of packages that use these different aspects to overcome historical shortcomings of plastic packaging and enable high power GaN devices to operate with good performance and high reliability in plastic.

PACKAGE CONFIGURATION

There are two general package configurations used for RF devices, co-planar and multi-level (see Figure 1). The co-planar package is designed so that the source and pins are at the same level, usually on the backside of the package. This allows the part to be surface mounted onto a printed circuit board (PCB) along with all other components through a reflow process.

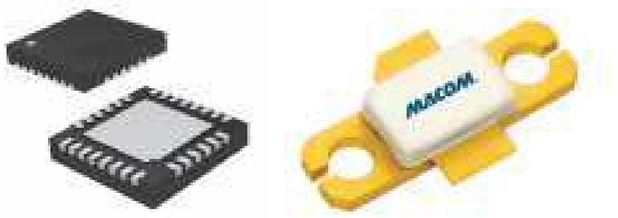

Fig. 1. Co-planar (left) and multi-level (right) package configurations

Most plastic overmolded parts, such as the QFN, are designed this way because it is a cheap and fast way to mount the part in the end user's application. However, this introduces a fundamental problem for high power devices. For heat to get out of the device it needs to travel through the package and also through the PCB before reaching a better heatsink in the form of a metal carrier (see Figure 2).

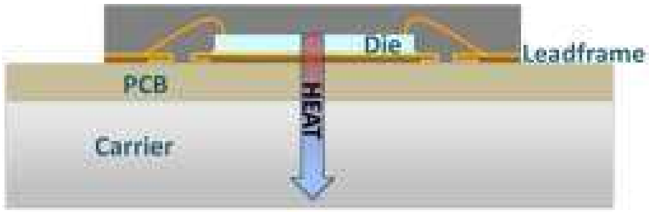

Fig. 2. Cross-section view of co-planar part on PCB and carrier

Considering the stack-up of materials and their corresponding thermal conductivities, the PCB material is by far the worst layer for thermal transfer, as shown in Table I, with thermal conductivities usually less than 1 W/m-K. No matter how thermally enhanced the packaged device is designed, the overall dissipated power is severely limited if the heat has to travel through the PCB as is the case with the co-planar package.

TABLE I

THERMAL CONDUCTIVITIES OF TYPICAL MATERIALS IN A CO-PLANAR PACKAGE SOLUTION

Material	Thermal Conductivity (W/m-K)
Die (Si)	150
Die Attach Epoxy	20-60
Leadframe (C194 Cu Alloy)	260
PCB (Rogers 4350)	0.69
Carrier (Al)	167-205

There are ways to improve the thermal resistance of the PCB by adding thermal vias, conductive filler materials, and reducing the thickness, but a GaN device in a co-planar package will typically reach a limit of ~15W power dissipated because of its inability to transfer heat.

Multi-level packages are designed with the source and pins at different heights so that the electrical connections can be made through the leads on top of the PCB while the source is resting directly on a heat sink near the bottom of the PCB. This design allows the device to dissipate heat through the package and directly into a metal carrier to which the source of the part is mounted, dissipating heat much more effectively out of the device (see Figure 3).

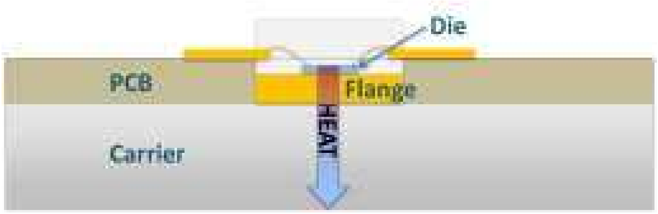

Fig. 3. Cross-section view of multi-level part on PCB and carrier

Metal-ceramic air cavity packages are usually designed in this multi-level configuration. Air cavity packages have been proven to be reliable, enable good RF performance, and dissipate heat effectively out of the device but they are also very expensive. The packaging material costs are high and the assembly process is often labor intensive and uses specialized equipment, leading to an expensive part with low throughput.

A blend of these two package configurations is the multi-level plastic package, as shown in Figure 4. This package utilizes the thermal benefits of a multi-level package while still following a plastic overmold assembly process. The multi-level configuration can be achieved by integrating a thick heat slug and a downset leadframe into the plastic body, creating a part with the leads significantly higher than the base of the package. The leadframe format enables the parts to be assembled through automated die bond, wire bond, molding, and singulation machines where high throughput translates into lower assembly costs.

Fig. 4. Multi-level plastic overmold part

The multi-level plastic package has been an enabler for low-cost high-power GaN devices. Products have been developed that achieve up to 200W in CW mode, while still operating below the maximum recommended junction temperature (T_j) of the device.

MOLD COMPOUNDS

GaN devices are capable of running at junction temperatures of 200°C or higher. Traditional mold compounds for plastic parts have a glass transition temperature (T_g) between 115°C and 140°C. As the plastic is heated above the T_g it transitions from a hard state to a soft "rubbery" state. The accompanying changes in coefficient of thermal expansion and flexural modulus can damage the device, wire bonds, or other features in contact with the plastic overmold material. There are multiple ways to overcome this with GaN devices.

New overmold materials with higher T_g values have been developed and incorporated in some packaging solutions. High temperature mold compounds are available from various suppliers with T_g's ranging from 170°C to 235°C. This allows the device to operate for extended periods at max T_j without the plastic mold compound ever transitioning and creating stress on the device or internal components.

There are limitations with high T_g mold compounds that need to be considered. Some have different mechanical properties, such as adhesion strength and moisture absorption, or electrical properties, such as dielectric constant and loss tangent, which may restrict their use in certain applications. In these cases a buffer layer can be used, along with a standard temperature mold compound, to isolate the mold compound from the device or any sensitive components within the overmolded part. A common material used for this buffer layer is a silicone elastomer die coat with a very low T_g, for example -120°C. With such a low Tg the material in contact with the device never goes through a transition and maintains its physical properties, thus minimizing stress on the device.

These theoretical limits are supported by various High Temperature Operating Life (HTOL) runs using various combinations of materials. In the first HTOL run a plastic overmold GaN product was developed with max T_j of 200°C and a mold compound with T_g of 115°C. After 902 hours there were 13/30 catastrophic failures, as can be seen in figure 5.

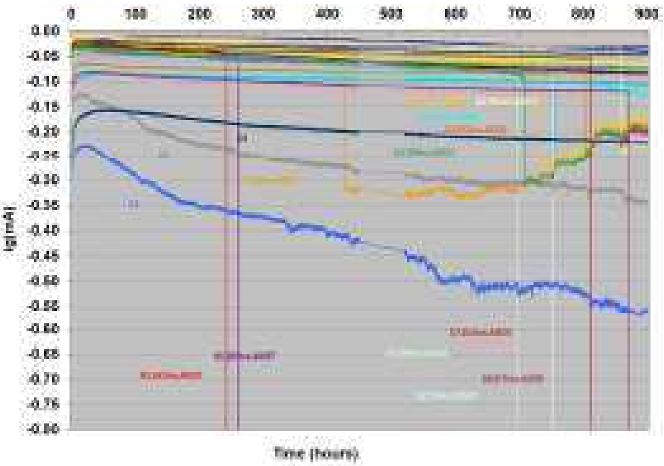

Fig. 5. HTOL in-situ data with T_j=200°C and T_g=115°C

Another plastic product was developed using a GaN device with max T_j of 200°C and a mold compound with T_g above 200°C. The results were much more favorable, with no failures out of 23 parts after 1000 hours of HTOL (see figure 6).

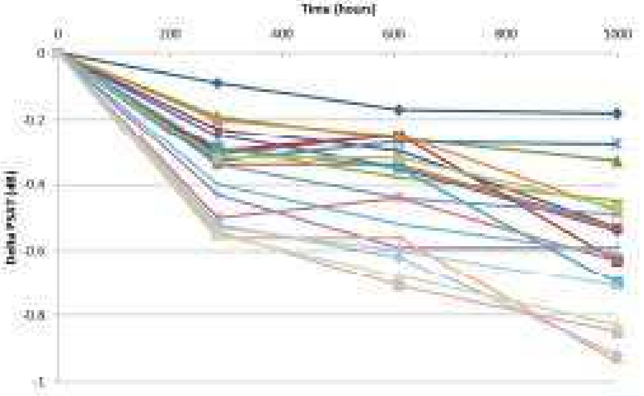

Fig. 6. HTOL down point data with T_j=200°C and T_g>200°C

A third HTOL was performed using a GaN die with T_j of 200°C, a mold compound with T_g of 140°C, and a die coat applied before molding. The results were also favorable with no failures out of 30 parts after 1000 hours of HTOL (see figure 7).

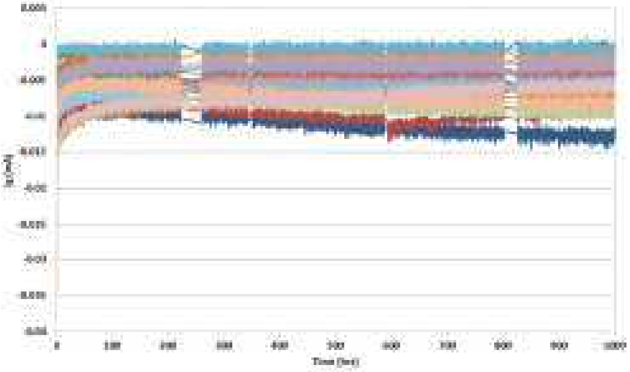

Fig. 7. HTOL in-situ data with T_j=200°C, T_g=140°C, and die coat

DIE ATTACH MATERIALS

One of the single largest advances in high power plastic packaging has come from die attach technologies. High power RF devices have historically required eutectic die attach, using AuSi or AuSn, to attach the die to a metal flange in an air cavity package. This has provided a reliable connection and low thermal resistance to get heat out of the device. The vast majority of plastic packages use epoxy die attach because the room temperature dispensing and pick and place process is more compatible with the leadframe format and equipment used to assemble plastic packages. Epoxies have generally been inferior to eutectic die attach in thermal conductivity resulting in plastic parts with lower performance than their air cavity counterparts. Recent advances in sintered die attach materials have changed this.

New materials from several manufacturers contain silver, gold, or copper particles embedded in an epoxy/organic matrix that, when properly cured, sinter together to form a strong bond with excellent thermal properties. These sintered epoxy materials have demonstrated thermal conductivities up to 200 W/m-K, exceeding even eutectic die attach (see Table II for a partial list of available sintered epoxy materials). These new materials also dispense and print like a traditional epoxy and can be incorporated in an automated leadframe-based die bond machine with little to no adjustments. This breakthrough enables GaN devices to be attached in a low cost plastic package without giving up any thermal performance

TABLE II
AVAILABLE SINTERED EPOXY MATERIALS

Manufacturer / Product	Technology	Thermal Conductivity (W/m-K)
Loctite Ablestik / SSP 2020	Ag sintering paste	>100
NAMICS / XH9890 series	Ag nano-particles in organic matrix	60-160
Tanaka / Aurofuse TR-191R	Au sub-micron particle paste	150
Alpha / Argomax, Fortibond	Ag nano-particle sintering	135-200
Heraeus / mAgic Sintering	Ag sintering	150-200
Reference	AuSn	59
Reference	AuSi	190

To validate the thermal performance of the sintered die attach material, several new products have been developed using the same GaN-on-Si device mounted inside an air cavity package with AuSn die attach and in a plastic overmold package with a Ag-sintered die attach material. The plastic parts also benefited from a Cu heatslug with higher thermal conductivity than the Cu-Mo flange of the air cavity parts. In each case the plastic parts with Ag-sintered die attach and Cu heatslug had significantly lower thermal resistance than their AuSn air cavity counterparts (see Table III). Thermal infrared microscopy showed a 26-30% reduction in thermal resistance between junction and case (Ɵj-c) from the air cavity parts to the plastic overmold parts.

TABLE III
AIR CAVITY AND PLASTIC OVERMOLD PRODUCT COMPARISON

Die / Power Level	Package Type	Die Attach Material / Thermal Conductivity	Theta J-C
14mm GaN 45W	Air Cavity	AuSn preform 59 W/m-K	2.3 °C/W
14mm GaN 45W	Plastic Overmold	Ag-sintered epoxy 160 W/m-K	1.6 °C/W
24mm GaN 100W	Air Cavity	AuSn preform 59 W/m-K	1.75 °C/W
24mm GaN 100W	Plastic Overmold	Ag-sintered epoxy 160 W/m-K	1.3 °C/W

CONCLUSIONS

The potential available market for GaN is much larger than the markets currently served by GaN devices, in large part because of cost. Traditional air cavity packaging and assembly is a big contributor to the cost of GaN products today. With advances in plastic overmold packaging and assembly, GaN products can now benefit from this lower cost structure and still maintain high standards of performance and reliability. This will enable GaN to enter into new markets with higher volumes, currently dominated by other device technologies, and thus further improve the process and manufacturing efficiencies.