Next Generation High Powered RF and Optical Packages

Ramesh Kothandapani, Tan Sin Li, Tee Zhen Wei, Noel DeLeon, Chen Wang, Christopher Johnson
Materion Corporation
28 Woodlands Loop #01-00
Singapore 738308
Ph: 65-65594450
Email: ramesh.k@materion.com

Abstract

PACKAGES AND CIRCUITS FOR HIGH POWER RF, MICROWAVE AND OPTICAL DEVICES

RF signals are radio waves that are very crucial for telecommunications. Quality communications require reliable materials which are appropriately processed to house high-powered semiconductors such as GaN and GaAs. It is equally crucial to accommodate passive electronic components along with these semiconductors into the housings for the Next Generation RF package or GenPack™. Evolving semiconductor technologies demand fail-safe packages to protect the devices in all applications and environmental conditions. Future aircraft, EV cars, spacecraft, augmented and/ or virtual reality headsets, medical devices and many more technologies require operating at a higher power and frequency with a proper thermal and power management platform. The higher speeds of telecommunications hinge on the performance of semiconductors and their packages. Therefore, the GenPack™ and packaging process are becoming crucial pieces of the supply chain.

Rugged GenPack™ RF packages differ in several ways compared to the traditional air cavity packages. For instance, FR-4 or Flame-Retardant glass-reinforced epoxy laminate material can be replaced with Aluminum Nitride or Alumina Oxide, Silicon Nitride or even Sapphire. The switch offers mechanical bonding directly onto the thermal spreader. Traditional circuits created on printed circuit boards have limited ability to dissipate heat due to the low thermal conductivity of FR4. Circuits created on ceramic can dissipate higher amounts of heat. As in the organic FR4 boards, multiple vias can be formed in the ceramic substrates to create metal pads top the ceramic that are grounded to the flange beneath the ceramic.

A metal flange can be positioned beneath the ceramic to provide a heat spreader and electrical ground that can be bolted onto a heatsink. Flanges can be made from a diamond metal matrix composite instead of lower thermal conductivity materials to provide much more efficient thermal transfer. Furthermore, narrow leads offer optimized impedance at RF and microwave frequencies. A range of ceramic and flange materials can be selected to optimize GenPack™ RF Packages with cost, quality, and performance in considerations for the respective applications.

Keywords
Thermal Management Materials, CTE matching materials, GenPack™ RF Package, Insulators, **Radio Frequency, RF, Semiconductor, Optical Package, RF package, and Thermal Conductivity,** Photonics Sub mount and SIP Packages.

I. Introduction

Radio frequency packages with air cavities are used with Si LDMOS (Laterally Diffused Metal Oxide) Transistors, Doherty Amplifiers, GaAs FETs, GaAs MMICs, GaN FETs, and GaN MMICs. These packages include thermal spreading or thermally conductive flanges. Such packages are for high power circuits in telecommunications.

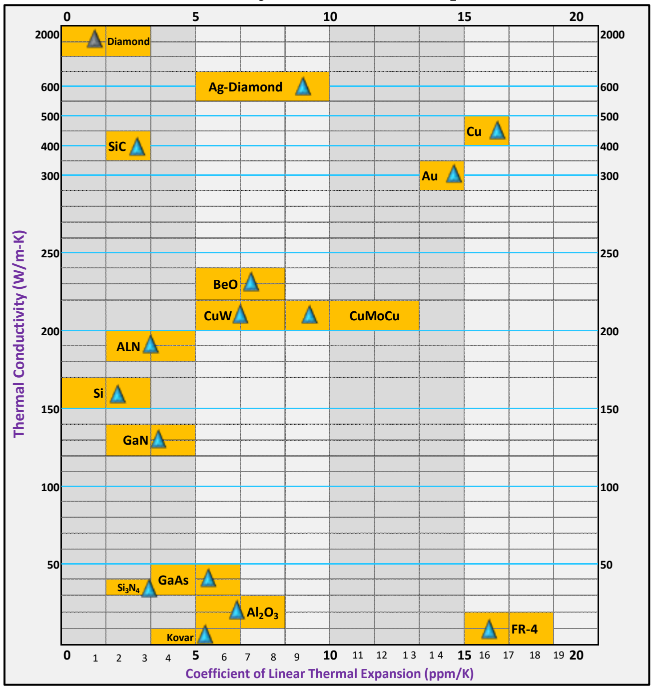
Semiconductor devices, in particular Gallium Nitride (GaN), have evolved with much higher power densities than previous transistor technologies. The higher power densities generate more heat in a smaller area due to internal dissipation. The smaller area of dissipation reduces the cross-sectional area of the heat dissipation path, which increases the junction temperatures. The junction temperature is determined by the power dissipation times the thermal impedance. The performance of a radio-frequency integrated circuit can be dramatically affected by the thermal impedance of the package. Demand for ever-changing and increasing requirements for high-speed digital and radio frequency applications requires packaging that takes into consideration RF performance, in addition to mechanical concerns. Packaging must be able to withstand higher junction operating temperatures for reliable operation. However, conventional packages have lower thermal dissipation properties and limited RF signal strength and power output. In addition, conventional package assemblies include more processing steps and demonstrate lower yields due to processing limitations, such as outgassing from epoxy die attach, which introduces organics and may result in lower RF performance than required for some applications, e.g., 5G applications and beyond. Organic materials reduce the shear strength between components, e.g., between the heat spreader and the insulator.

BOM (Thermal Spreader)

The GenPack™ RF package assembly contains a flange or thermal spreader and insulators that are compatible for bonding to the flange, organic-free high melting temperature bonding materials, organic-free electrical circuits traces, or patterns onto the top of the insulators including vias are added onto the insulator, specifically onto the circuit patterns. Multiple leads bonded to the electrical circuits are included for organic- free high melting temperature bonding alloy materials. Lastly, the package includes a lid to complete the bill of materials.

Thermal management is a critical issue in high-power packages. It is important to consider the correct materials for their respective applications and operating conditions. The heat spreader or flange is one of the crucial BOM for the GenPack™ RF package. The required applications could demand the thermal conductivity values possibly from 140 to 1000 W/(m-K) at room temperature, and a coefficient of thermal expansion (CTE) ranging from 2.3 ppm/K to 24 ppm/K. Cost, product durability, and environment are other factors to be considered before listing out of the selected materials.

Thermal Conductivity and Thermal Expansion Chart



Conventional flange materials include:

- Cu-CuMo-Cu,
- Copper tungsten (CuW),
- Cu-Mo-Cu, Cu, or combinations of each

However, the flange may be a copper diamond composite or a silver diamond composite for higher thermal conductivity.

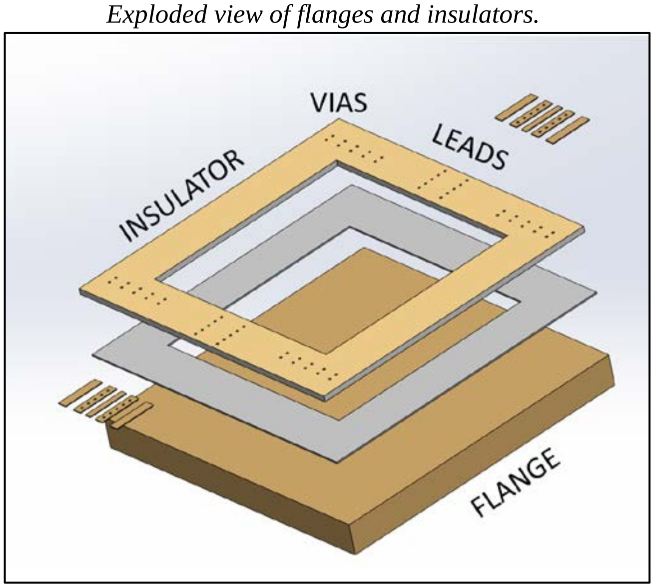
Thermal Conductivity and Thermal Expansion Chart

No	Materials	TC (W/m-K)	CTE (ppm/K)
1	FR-4	0.2	16
2	Al_2O_3	17	7
3	Si_3N_4	43	3.7
4	GaAs	46	5.7
5	GaN	130	3.2
6	Si	153	3.5
7	ALN	200	4.5
8	CuW	225	7
9	CuMoCu	210	8
10	Cu	393	17
11	SiC	430	4
12	Ag-Diamond	600	9
13	Diamond	1500	1.4

BOM (Insulators)

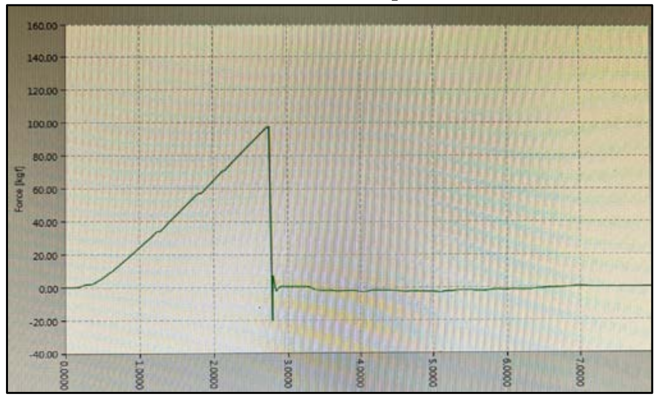
Available insulators include Sapphire, Alumina Oxide (Al_2O_3), Beryllium Oxide (BeO), Aluminum Nitride (AlN), Zirconia toughened Alumina (ZTA), Silicon Nitride (Si_3N_4), or combinations of each material. One common ceramic insulator is Alumina Oxide (Al_2O_3) having a purity of greater than or equal to 96%. The insulator may include a plurality of thru-holes through a thickness of the insulator. The plurality of thru- holes may be configured in a pattern along electrical circuits for the respective applications.

Exploded view of flanges and insulators.



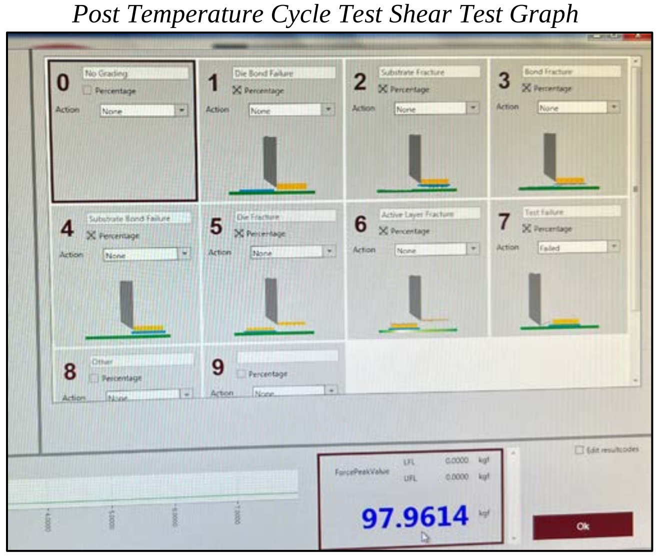
The first step of assembly bonds the insulators to the flange with higher melting braze materials. The insulator and Flanges post-bonding shear tests shows greater than 100 KgF bonding strength.

Shear Test Graph



Post assembly package was subject to Temperature Cycle Test. The Shear test was repeated after 1000-cycle tests. The shear strength results remained similar to the earlier shear force range.

Post Temperature Cycle Test Shear Test Graph

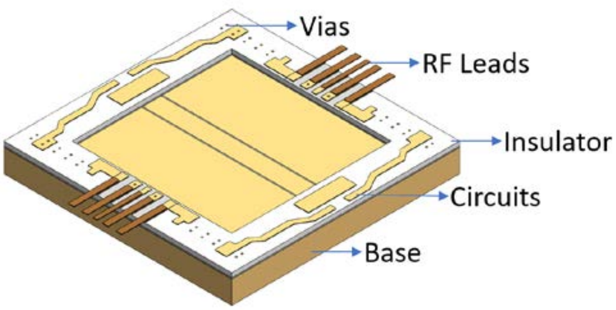


Post-shear failure modes consistently exhibit insulator cracks or shatters towards 100 KgF from the flange, which is almost the maximum value of the test equipment. The vias in the ceramic are used to reduce either the high-frequency electrical impedance or the thermal resistance between layers assists with additional vias fill to bonding strength. Metal-filled vias provide a low DC resistance path between layers for high current pathways. For the case of bonding strength, these vias add on more strength to the bonding in parallel.

BOM (Electrical Circuits on Insulators)

The insulators enable creation of custom designed electrical traces. The organic-free electrical circuits with greater than 2.5 micrometer-wide gold lines enable higher current pathways.

GenPack™ RF Package



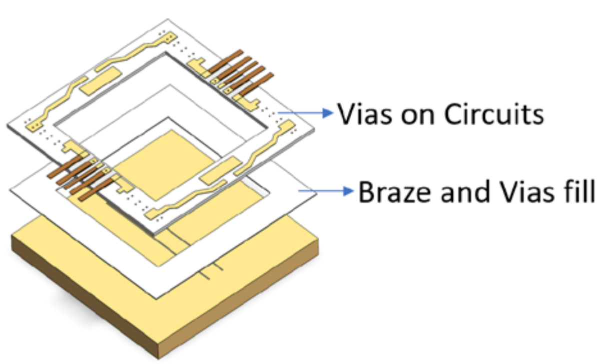
The insulator can be opted to deposit the electrical circuit patterns according to its applications, except the FR-4.

No	Materials	Dielectric Constant (1MHZ)
1	Al2O3	9.8
2	AIN	8.5
3	Si3N4	7.8

The Dielectric values for insulators

No	Materials	Dielectric Constant (1MHZ)
1	Al_2O_3	9.8
2	AIN	8.5
3	Si_3N_4	7.8
4	FR-4	5.0

Exploded View of Key Components

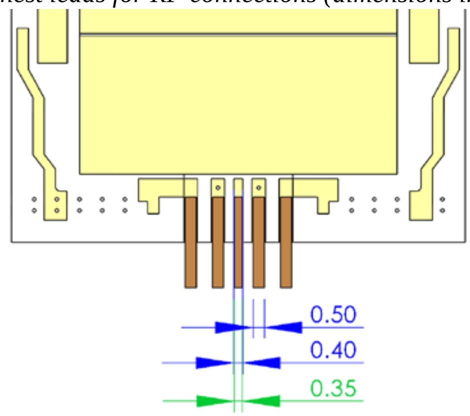


The exploded view of the package illustrates the organic-free braze alloy to attach both leads and electrical circuit bearing insulator onto the flange. The vias are also filled with bonding braze alloy.

BOM (Narrow Leads)

The GenPack™ RF packages utilize a refined process of attaching multiple leads with the higher melting temperature braze alloy. It is equally important to focus on the widths of the RF leads, as they are very crucial to the signal impedance. The narrow width leads are always desired for greater RF signaling with lower resistance. The narrow width leads are challenging to offer strong bond to the electrical circuits. The leads are bonded with the same concept as the insulator to the flange. Leads can be fabricated to taper down to a width of only 0.35 mm.

The finest leads for RF connections (dimensions in mm)



II. Helpful Hint

The RF world is experiencing a matured technology to service the next megatrend of evolving fail-safe telecommunications. The new material and processes available offer a market disruptive, yet reliable GenPack™ packaging solution. The design rules of GenPack™ packaging can support the next wave of microwave and optical high-power devices.

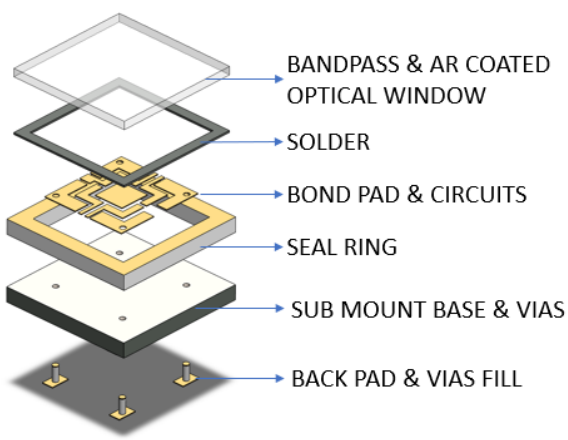
For an example the power management for LED, Photonics applications with the requirement to use GaN semiconductor could leverage the high thermal dissipating flanges and add on to the low resistance, higher temperature insulators such as Alumina Oxide (Al_2O_3) of Silicon Nitride (Si_3N_4) substrate to include very sophisticated electrical circuit pattens to achieve a lower resistance higher power performance. Moreover, the array of process development to offer lower cost and reliable product.

III. Photonic Packages

The materials could be mix and matched for any power device packages where low thermal resistance and high operating temperature are essential. The system in package or SIP accommodates many electronics under one roof. The SIP platform enables high temperature, high power circuitry to be formed on a ceramic frame surrounding the semiconductor chip.

This concept could be easily extended over to photonic power devices. Once again, with thermal spreader and electrical circuits both could be combined onto the insulator. For example, the Silicon Nitride (Si_3N_4) or Alumina Oxide (Al_2O_3) could have a design for light-emitting and receiving semiconductor with metal-filled vias for surface mounting. For this case, the thermal spreader is the insulator itself and the seal ring as an added feature could accommodate optical cover window with anti-reflective coating, with or without band pass filter coatings to offer a light-powered Next Generation Package.

Exploded View Optical Package



The optical package construction has many more materials for mix and match options. The number of vias could be increased within a small-sized package. The seal ring and band pass filter coated optical window could be combined to offer a cup-shaped hermetic cover. The bond pad and electrical component placement circuits are another added advantage to inbuild onto the respective sub mount base, with a wide selection of insulative materials. A wider selection of organic-free solder materials is readily available to choose from. The organic-free solder alloys such as Gold-Tin, Tin-based, or Indium-based alloys are dependent on the temperature constrained for the semiconductor die attachment.

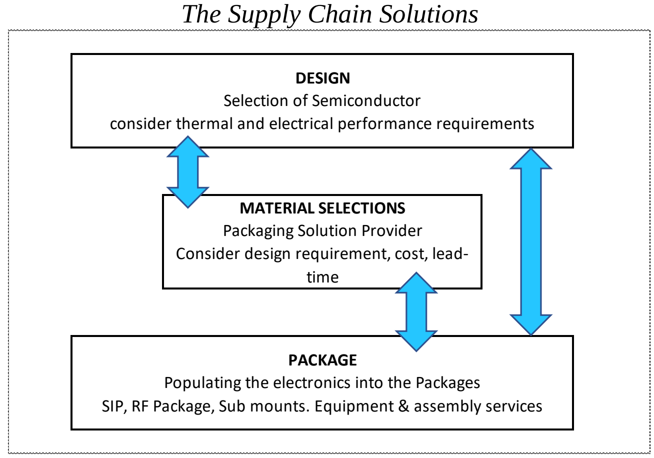
Outgassing of die attach adhesives could adversely affect the performance of the semiconductor. Getters and bake-out options could also be added in the design to make this package more effective.

Especially miniature sized RF packages could be very vulnerable to outgassing. This exploded option package having a cavity volume of 2.7 x 2.7 x 0.381 = 2.78mm^3 could contain organics that lowers the performance of the package or even malfunction the package within the short period of its operations. Optical components are also sensitive towards organic outgassing.

IV. Conclusion

The material selections begin at the end of the design stage. The design team collaborates with material suppliers who use packaging methods propose the respective solutions. The semiconductor is the center of focus for its efficiency, especially for higher-powered operations. The package materials and design must also reflect the type and design of the heatsink onto which the package will be bonded. The next crucial point is the collaboration with packaging team to process the assembling of these components, at an affordable time to achieve and cost goals.

The Supply Chain Solutions



Acknowledgment

Donna Tohme, Richard Koba

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