Die-on-Tab for Compound Semiconductors:

Enabling Advanced RF Power Systems

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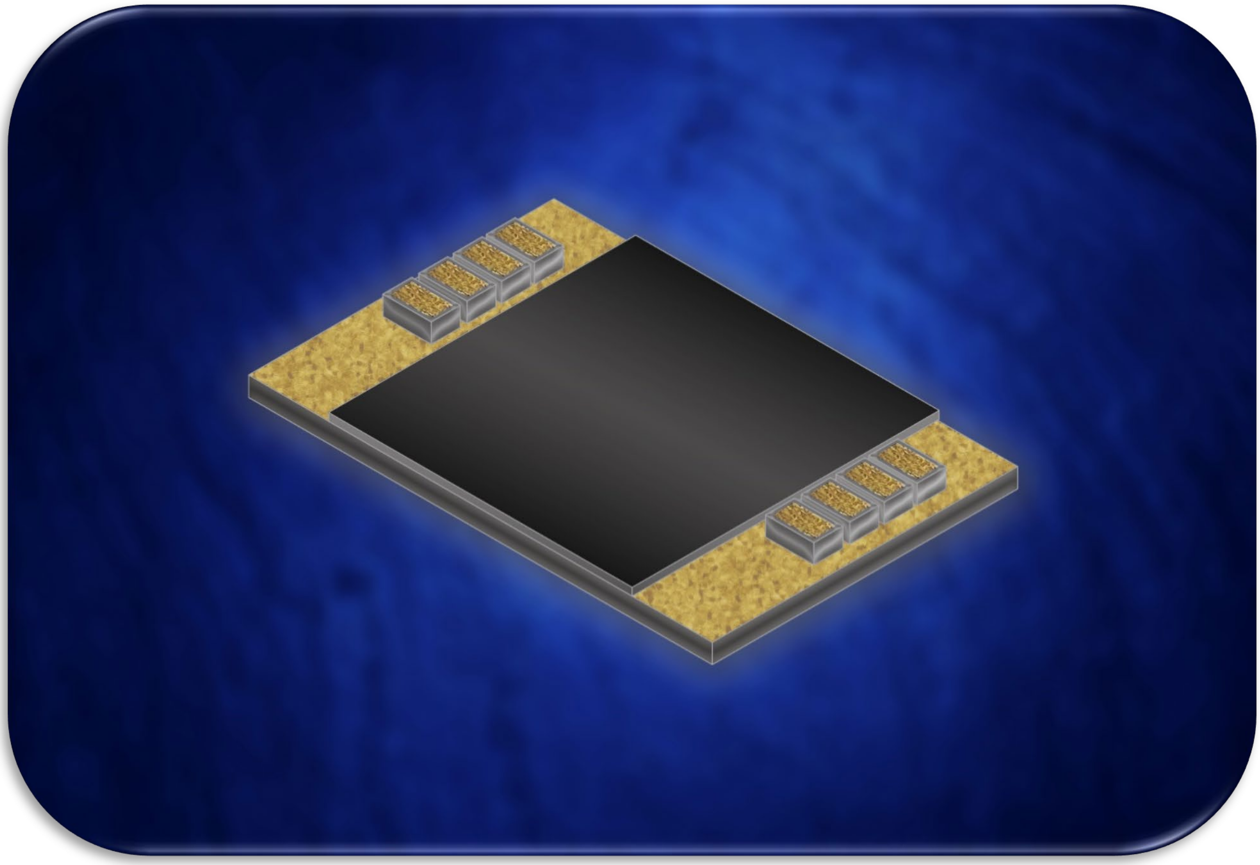

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Introduction

Compound semiconductors such as gallium nitride (GaN) and gallium arsenide (GaAs) are driving innovation in high-frequency and high-power applications, from 5G base stations and radar systems to satellite communications and power electronics. These materials, especially GaN, offer superior electron mobility, high breakdown voltage, and exceptional power density. However, the same properties that make them valuable also introduce significant challenges in packaging and thermal management.

Among the emerging packaging techniques addressing these challenges, the die-on-tab approach has gained particular attention. By mounting the semiconductor onto a metallic tab before attachment to the substrate or printed circuit board (PCB), this method enhances thermal performance and mechanical reliability, which are two key factors for compound semiconductor longevity and efficiency.

StratEdge has been providing packaging solutions for compound semiconductors for 40 years. This article explains what die-on-tab is, how it functions, and why it is especially important for compound semiconductor devices, with a focus on GaN-based RF power applications.

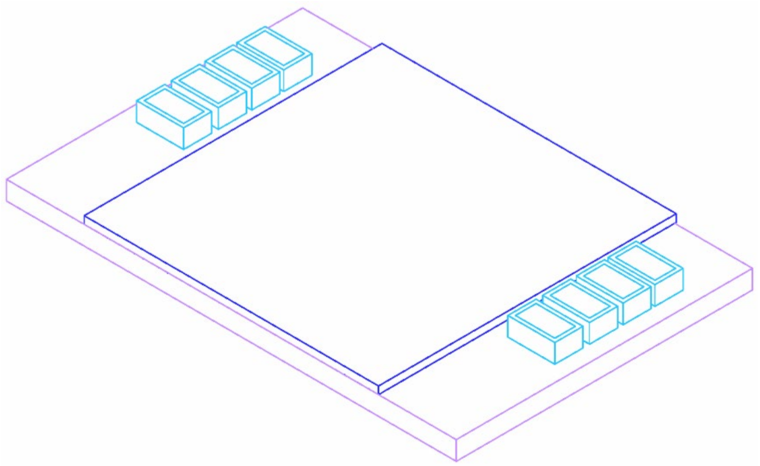
What Is Die-on-Tab?

In conventional semiconductor packaging, the device is directly bonded to a lead frame or substrate and is then encapsulated with plastic. A radio-frequency (RF) device is usually placed in a package because its performance benefits from having an air cavity above it.

In contrast, die-on-tab involves mounting the die onto a metallic tab, also called a heat spreader or submount, that serves as an intermediate layer between the device and the next-level assembly, which is usually the PCB assembly.

This metallic tab performs several crucial roles:

- It provides a high-conductivity thermal path to extract heat from the active device region.
- It acts as a mechanical buffer, reducing the effects of mismatched thermal expansion between materials.
- It offers structural support, ensuring the die remains planar and mechanically secure during assembly and operation.



Typical die on tab with chip and eight capacitors.

Common materials used for tabs include copper (Cu), copper–molybdenum (CuMo), copper–tungsten (CuW), and copper laminates. Each material is selected for its balance of thermal conductivity, coefficient of thermal expansion (CTE), and cost.

Purpose and Function of the Tab

The primary purposes of the metallic tab in compound semiconductor packaging are thermal management, CTE mismatch mitigation, and mechanical reinforcement. There can also be commercial reasons for mounting the semiconductor onto a tab.

1. Thermal Management

GaN devices, particularly GaN-on-silicon carbide (SiC), can handle very high currents and voltages, resulting in exceptional power densities sometimes exceeding 8 W/mm in RF applications. This level of heat generation requires rapid and efficient dissipation.

The metallic tab provides a thermal spreading layer that distributes heat more evenly and conducts it away from the active region to the PCB or heatsink. This reduces the junction temperature, keeping device temperatures within safe operating limits and preventing localized hot spots that degrade performance.

2. CTE Mismatch Mitigation

One of the main mechanical challenges in packaging compound semiconductors lies in the mismatch of thermal expansion between the die and its substrate. GaN and GaAs typically exhibit CTEs around 5-6 ppm/°C, while the underlying PCB materials, such as ceramic-filled PTFE, may range from 9-19 ppm/°C.

Without an intermediate layer, these differences can cause significant thermomechanical stress during thermal cycling, leading to solder fatigue, delamination, or even die cracking. The tab acts as a CTE buffer, providing a gradual transition between the die and the PCB to absorb stress and maintain structural integrity over thousands of thermal cycles.

3. Mechanical Support

The tab also reinforces the die mechanically. It maintains planarity during assembly, ensures uniform bonding pressure, and reduces the risk of chipping or cracking during wire bonding or mounting.

4. Commercial Purpose

GaN devices can generate enormous power densities. But GaN-on-SiC devices also have about six times greater thermal conductivity than GaAs, which means they can handle more power without increasing the device temperature, as long as the heat is removed efficiently from the device. This makes the quality of the first level interface between the GaN device and the mounting carrier extremely important.

A company that designs, fabricates, and sells GaN devices has a lot at stake if the quality of the first-level interface is poor. Rather than letting its customers assemble the device, it benefits the company to perform this step themselves. In extremely critical applications, a tab material can be selected that allows the solder joint quality to be analyzed by X-ray before installing it onto the board. Die-on-tab as a product is an outstanding way to add value and eliminate potential disappointment if the customer fails to properly install the device.

Die-on-Tab for GaN-on-PCB Applications

Mounting GaN devices directly onto a PCB, also referred to as chip-on-board (COB), eliminates the package and all the costs associated with it. However, COB attachment poses risks due to thermal and mechanical incompatibility. GaN and the substrates they are grown on have CTEs significantly lower than PCB materials. When operated under high power, thermal expansion differentials can degrade solder joints and cause premature device failure. It is particularly advantageous if the GaN device is attached using Gold-Tin (AuSn) eutectic solder, but the high reflow temperature of AuSn is incompatible with organic PCB technologies.

The die-on-tab configuration solves this issue by introducing a metallic intermediate layer between the die and PCB. This tab absorbs mechanical stress while maintaining excellent thermal conduction. The tab also allows for optimized heat spreading, ensuring that heat is distributed across a larger surface area before it reaches the PCB or heat sink. It also allows AuSn solder attachment to be used prior to installing the device onto the PCB, which would be a separate operation performed by either the device supplier or other die-on-tab assembler.

COB eliminates the use of a stand-alone package to protect the device. This may seem like a simplification, but it actually adds complexity to the installation of RF amplifiers. When a package is used, the device is typically assembled in Class 1000 or better cleanroom with controls on particulates, electrostatic discharge, and other things harmful to the bare device. The packaged device can then be assembled onto the board in a less controlled environment. Package-level testing can also be performed prior to PCB mounting. As a designer and manufacturer of packages for high-frequency, high-power, and high-reliability devices for over 40 years, we at StratEdge certainly are proponents of the use of packages.

Designers of systems operating in Ku through E bands may decide the advantages of COB outweigh the disadvantages. Eliminating the package can reduce parasitic inductance and signal loss and simplify routing of the RF circuitry, particularly for power amplifiers used in telecommunications and defense systems. Special handling and controls must be implemented in the PCB assembly area if bare RF devices are installed without the protection of the package. For RF GaN amplifiers, where devices operate in pulsed or continuous high-power modes, the die-on-tab approach can enable higher output power, stable gain performance, and improved mean time to failure (MTTF).

Tab Material Selection

Selecting the appropriate tab material is a trade-off between thermal conductivity, CTE compatibility, mechanical rigidity, and cost.

Material	Thermal Conductivity (W/m·K)	CTE (ppm/°C)	Key Advantages
Copper (Cu)	390	17	Highest thermal conductivity; cost-effective; best for low-stress applications and very small devices.
CuMo	~190	8–9	Balanced CTE and conductivity; widely used for GaN and GaAs devices; allows X-ray analysis.
CuW	~190	8-9	Balanced CTE and conductivity; widely used for GaN and GaAs devices.
Copper laminate	~190 (z-direction)	8-9	Customizable properties and lower cost for large-volume production; superior thermal spreading capability; typically allows X-ray analysis.

Copper composite materials, like CuMo and CuW, are often used for high-power RF GaN devices because their CTE closely matches that of the GaN-on-SiC device, reducing stress while still offering good heat dissipation. By varying the percentage of copper, the thermal conductivity and CTE can be adjusted. The properties of copper composite materials vary between manufacturers, so the exact percentages and thermal conductivities are not provided.

Like copper composites, the thermal conductivity and CTE of copper laminates can also vary. Layer thicknesses and stiffener composition of the laminated structure will determine the net thermal conductivity in the z-direction. At the device interface, copper with its 390 W/mK will spread the heat away from the device transistors more efficiently. StratEdge recommends Cu-Mo-Cu in a thickness ratio of 1:3:1 as the best solution for tabs used to mount GaN-on-SiC.

Interface and Assembly Considerations

The performance of a die-on-tab assembly depends heavily on the quality of the interfaces between the die, tab, and substrate. The choice of die-attach material influences both thermal and mechanical performance.

Common attachment materials include:

- AuSn eutectic solder (80Au/20Sn): Excellent thermal conductivity and high-temperature stability.
- Silver sinter paste: Superior heat conduction and robust joint strength at lower processing temperatures.
- Conductive epoxy: Economical and simple to process, but with significantly lower conductivity and temperature limits.

Proper control of voiding, bondline thickness, and surface planarity is critical. Voids or uneven bondlines can introduce localized thermal resistance and stress concentrations, reducing overall reliability.

Benefits of Die-on-Tab Packaging

The adoption of die-on-tab structures offers numerous benefits, especially for compound semiconductors:

1. Enhanced Heat Dissipation

The tab acts as a heat spreader, lowering junction temperature and improving both performance and device reliability.

2. Reduced Thermomechanical Stress

CTE mismatch mitigation prevents cracking and delamination, extending device lifetime.

3. Improved Electrical Performance

By allowing the die to be mounted closer to the PCB, parasitic inductance and resistance are minimized.

4. Mechanical Robustness

The tab provides structural support, improving assembly yields and survivability under vibration or shock.

5. Design Flexibility

Different tab materials and thicknesses can be selected to meet specific thermal and cost targets.

6. Ensured Performance

Die-on-tab allows the device manufacturer to prevent mistakes made during die attach from degrading device performance.

Future Outlook

As RF and power electronics push toward higher power densities and operating frequencies, packaging technologies must evolve in tandem. The die-on-tab concept continues to advance with new composite materials, improved sintering processes, and material and process maturation that further enhance heat removal.

Emerging materials such as diamond-copper and diamond-silver composites are being explored to deliver even better thermal performance while maintaining mechanical compatibility. Whether the die-on-tab is used as an insert in a package or as a COB, the extraordinary thermal conductivities of these materials may make the added cost worthwhile. The cost can be minimized by making the tab close to the size of the device rather than making an entire package base or PCB-coin out of these expensive materials.

For next-generation GaN and GaAs devices used in 6G communications, radar, and satellite communications, die-on-tab will remain an essential packaging strategy, bridging the gap between high-performance semiconductor devices and practical, manufacturable systems.

Conclusion

The die-on-tab approach represents a critical enabler for the continued advancement of compound semiconductor technology. By introducing a thermally conductive, mechanically compatible intermediate layer, this structure efficiently manages heat, mitigates CTE mismatch, and improves reliability, all while maintaining electrical performance.

As the demand for higher efficiency, smaller form factors, and greater power densities grows, die-on-tab packaging will play an increasingly vital role in realizing the full potential of GaN and other compound semiconductors.

Key Terms and Definitions

AuSn eutectic solder (80Au/20Sn) – High-conductivity, high-temperature die-attach solder.

Chip-on-board (COB) – Bare die mounted directly on the PCB without a package.

Coefficient of thermal expansion (CTE) – How much a material expands or contracts with temperature.

Compound semiconductors – Multi-element semiconductors such as GaN and GaAs.

Copper laminate – Layered copper-based structure engineered for tailored CTE and thermal performance.

CuMo (copper–molybdenum) – Engineered composite material created for high power devices; tailored CTE/thermal performance, lighter and more X-ray transparent than CuW.

CuW (copper–tungsten) – Engineered composite material created for high power devices; tailored CTE/thermal performance, denser, stiffer, less X-ray transparent than CuMo.

Die-attach – Process of bonding the semiconductor die to its mounting surface.

Die-on-tab – Die first attached to a metallic tab, then mounted to the PCB or package.

E band – Millimeter-wave frequency around 60–90 GHz.

GaAs (gallium arsenide) – Compound semiconductor used widely in RF and microwave devices.

GaN (gallium nitride) – Wide-bandgap semiconductor enabling high-power, high-frequency operation.

GaN-on-SiC (gallium nitride on silicon carbide) – GaN devices grown on SiC substrates for superior thermal performance.

Heat spreader (tab, submount) – Metallic intermediate that spreads heat and buffers mechanical stress.

Ku band – Microwave frequency around 12–18 GHz, common in satellite links.

Mean time to failure (MTTF) – Average expected operating time before device failure.

Printed circuit board (PCB) – Substrate with copper traces that interconnect and support components.

PTFE (polytetrafluoroethylene) – Low-loss fluoropolymer used in high-frequency PCB laminates.

Radio-frequency (RF) – Electromagnetic signals used for wireless, radar, and high-frequency systems.

Silver sinter paste – High-conductivity die-attach material using sintered silver particles.