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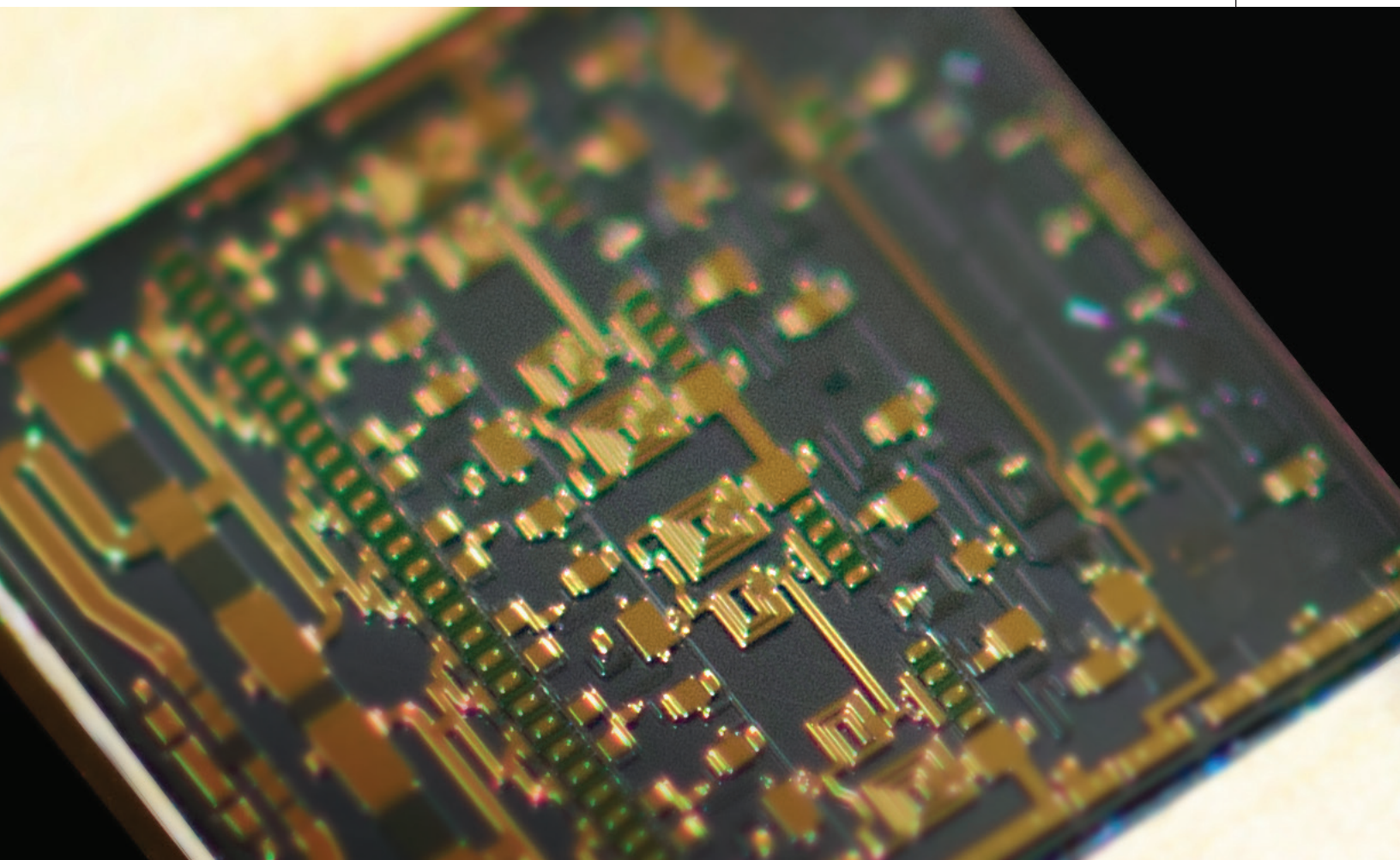
TECH BRIEF

Eutectic Die-Attach of GaN and GaAs MMICs



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ABSTRACT

The latest GaN and GaAs circuit chips (die) are providing higher power levels than previous solid-state technologies. These new-generation devices require incredible precision and consistency throughout the die-attach and assembly process to ensure that the thermal flux from these devices is efficiently conducted to the heat spreaders and away from the transistor-gate regions. There are many metal-quality and thickness challenges to overcome when developing a repeatable eutectic die-attach process, including avoiding contamination, the quality of the pickup collets, and efficient but accurate screening procedures. This technical brief details the key factors in determining if a eutectic die-attach process is sophisticated enough to serve the mission-critical applications of today's aerospace, military, Satcom, and telecommunications applications.

INTRODUCTION

The latest military/defense, aerospace, and space applications are continuing to see a growth of adoption of gallium arsenide (GaAs), and now gallium nitride (GaN), RF power electronics and monolithic microwave integrated circuits (MMICs). Where previous generations of RF, microwave, and millimeter-wave (mmWave) technologies relied on discrete components and traveling-wave tube amplifiers (TWTAs), modern defense and aerospace electronics leverage the reduced size, weight, power, and cost (SWaP-C) of solid-state amplifiers (SSAs), solid-state power amplifiers (SSPAs), and MMICs based on GaAs and GaN semiconductors. These new devices have become essential in achieving mission-critical performance and cost targets for new phased-array antenna and complex modulation technologies, enabling low probability of intercept and low probability of detection (LPI/LPD) for active electronically steered array (AESA) radar, and ever more capable communications that can intelligently respond to the warfare theater or the environment.

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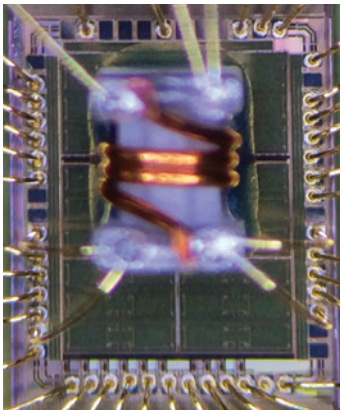

GaN and GaAs transistors, modules, and MMICs are now incorporated into the designs of both critical transmitter and receiver components in communications and radar transceivers, transmitter/receiver (TR) modules, and satellite communications (SatCOM) links in land, sea, air, and space. Though able to power the highest performance microwave electronics for the world's military, commercial, and space applications, GaAs and GaN transistors, devices, and MMICs must be handled and assembled with incredible care and precision to unleash the broadband, high-power, and high-linearity performance for which they are needed. Even slight mishandling, contamination, assembly process flaws, or process variations could dramatically reduce the performance and life of a GaN and GaAs device. One of the key areas of assembly for these high-performance devices is the die-attach process, where the GaN or GaAs semiconductor die is electrically, mechanically, and thermally bonded to the substrate, chip carrier, heat spreader, or heat sink.

Though there are many methods of die-attach and die bonding, one of the preferred methods for high-performance applications is eutectic die-attach (eutectic bonding or eutectic soldering), which leverages a precise heating and cooling method to cause a liquefied eutectic solder between the die base and substrate to transition directly from a liquid to a solid. While liquid the eutectic solder is designed to permeate the die metal-base layer and substrate, which is maintained during the solder's solidification. The eutectic die-attach process enables a very reliable mechanical connection and an optimized thermal and electrical connection, which are essential for the extreme power and heat produced by the latest GaN power amplifiers (PAs), and which ensure optimized grounding for electrical performance.

Due to the sensitive nature of SSAs and MMICs, and the precise process control necessary to achieve high yields from a eutectic die-attach, there are several common requirements used to determine optimal eutectic die-attach and also several eutectic die-attach process pitfalls that plague many fabrication facilities. In order to ensure SSA and MMIC modules help to achieve mission-critical success, an OEM must be sure their in-house, or contracted, eutectic die-attach and assembly process is both precise and reliable. There are few facilities capable of maintaining the required quality assurance to achieve reliable eutectic die-attach, and the following guide to the requirements and pitfalls of the die-attach process is intended to provide a foundational instruction on how to evaluate a eutectic die-attach process and enhance the confidence of a manufacturing partner in delivering success.

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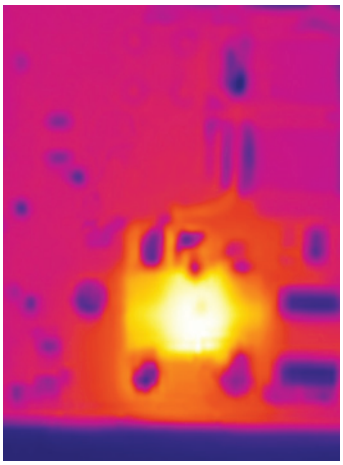
KEY EUTECTIC DIE-ATTACHMENT FACTORS



1. Thermal Considerations

A quality eutectic die-attach process allows for the lowest thermal and electrical resistance from the die base layer to the substrate, die carrier, or heat spreader, as well as a strong mechanical connection. Even small issues with the eutectic die-attach process could lead to a lack of coverage, voids, adhesion problems, and challenges with maintaining process repeatability, which is essential for a consistently performing product line, TR modules, radar, and SatCOM links.

Many of the base metal materials for GaN and GaAs die and substrates are plated with gold, and a common eutectic solder alloy for die-attach is gold-tin (AuSn 80/20). AuSn demonstrates good compatibility with gold-based devices, and also demonstrates excellent long-term reliability. Solder preforms of a precise size and thickness are commonly used during eutectic die-attach to ensure consistency of the die-attach process. The eutectic solder attachment is done using a reflow process that brings the eutectic solder to its melting temperature and then cools the solder down over an exact vacuum reflow process profile. The temperature and timing profile of the reflow process is specifically engineered to achieve optimum results, and varies based on the eutectic solder material, die and substrate metal, materials, and other furnace, assembly, and thermal-mass considerations. Fixtures are used to prevent the die from shifting during reflex, as die floating is possible when the solder temperature reaches its liquid point and forms a meniscus under the die.

Having a good match of the coefficient of thermal expansion (CTE) of the die, solder, and substrate is important to prevent mechanical damage during thermal cycling. This is especially true as a GaAs die is very brittle, and can easily crack during die-attach, or during operation under extreme temperatures if there is a discrepancy between the substrate or base plate of a heat spreader. GaN devices, such as GaN on silicon carbide (SiC), are typically more robust then GaAs, but care must still be taken to avoid substantial CTE mismatches as stress fractures can still develop under the extreme operating temperatures and thermal cycling GaN power devices undergo during use.

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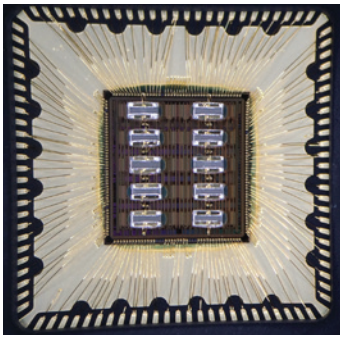

2. Scrubbing vs. Flux

Fluxes can't typically be used with GaN or GaAs devices, as fluxes tend to lead to electrical and mechanical degradation of the device materials upon contact. As such a forming gas composed of a mixture of nitrogen and hydrogen is used during reflow. With such a forming gas, the necessary reducing atmosphere can be developed around the devices and substrate, preventing oxide formation during the die-attach process. If the reflow process is performed appropriately, the resultant visible areas of the solder joint should appear to shine with a silver coloration, as opposed to a duller gold appearance, which is often a sign of excessively high temperatures during vacuum reflow.

The technique that is commonly used with eutectic die-attach is scrubbing. With a scrub process, the die, held by a pickup collet with some head force, and the substrate are "scrubbed" against each other while the solder is in its liquid state. Scrubbing can help to ensure a conformal solder layer and greater solder adhesion with the die base layer and substrate/spreader. There are many key parameters to successful scrub, which include head force, scrub direction and path, scrub cycles, scrub time, and where in the reflow process the scrub is done. The pickup collet must be specifically designed for each die-attach process, and a consistent and reliable pickup collet is crucial in the die-attach process of the highest performance and precision devices.

If the eutectic die-attach process is performed properly, the result will be a die-attach with adequate coverage, minimum voids, and optimal adhesion, and will present these characteristics among die in the same batch, and from batch-to-batch. Typical coverage specifications are greater than 99%, with no voiding greater than 1 mil in diameter. Maximum void specifications can be found in MIL-STD-883 J TM 2012.9, though this test method is under review in JEDEC due to the new real-time X-ray equipment that is available. Also, this specification may be less stringent that what is necessary to achieve long-term reliability and a high mean-time-before-failure (MTBF) for a mission-critical component.

These die-attach parameters are not easily achieved, and require exceptional process development and quality control to ensure the best adhesion and repeatable performance. X-ray inspection is a method that aids in evaluating the results of a eutectic die-attach process, as is acoustic microscopy imaging (AMI) equipment, such as Sonoscan devices. These imaging techniques are able to reveal delamination and voiding. For thicker material-layer applications, AMI can be used to illuminate errors in a process, like whether enough solder was

applied, if the solder was properly heated, if the preform was properly applied, and if the die and solder are level relative to each other, as well as improve overall process quality and yield. Proper screening and quality-control measures can add confidence that each pallet, module, or assembly delivered after die-attach meets stringent military, aerospace, and space specifications.

EUTECTIC DIE-ATTACH PROCEDURES TO AVOID

A eutectic die-attach process is prone to many potential complications. Of these complications, there are many associated with contamination, plating integrity, and condition of the die and substrate, die carrier, or heat spreader/heat sink. One such complication is the contamination of the die during packaging, handling, shipping, storage, and preparation of the die for die-attach.

Typically, GaN and GaAs die and MMIC are packaged in an inert atmosphere, likely nitrogen, in a clean-room environment. If the die-attach process, or any handling, was done with the die outside of the package, or not in a clean room, then the die is likely to become contaminated. Contamination can be from oxide film formation due to atmospheric exposure, or organic debris could be accumulated from the environment. These types of contaminants form a passivation barrier between the base-layer or substrate and the eutectic solder, preventing wetting.

It is more common that the substrate, die carrier, heat spreader/heat sink, or solder preform has been contaminated, and these often require cleaning prior to eutectic die-attach. Plasma or chemical cleaning can be done to the die and/or die carrier to improve wetting if contamination occurred. This effort would be fruitless, however, if the carriers, fixtures, and handling equipment used prior and during eutectic die-attach have debris, or are otherwise contaminated. Cleaning of all surfaces that come in contact with the die, including pickup collets, can be a critical stage in repeatability of a eutectic die-attach process.

The wetting and adhesion quality of a eutectic die-attach process depends on the integrity of the plating of the die and die carriers. If the gold plating on a die carrier is of poor quality, is inadequately thick, contains pits, dips, scratches, or flaking, coverage quality may be reduced and voids may be developed during die-attach. Indicators of the quality of gold plating is the bright and smooth appearance of the gold. This is also true for the solder preforms, though depending on how they were fabricated they may not be perfectly smooth.

POINTERS ON PICKUP COLLETS

For many applications an operator will use tweezers or dual-side vacuum collets for MMIC placement. Semi-autonomous and autonomous eutectic die-attach machines more often use vacuum collets. The preferred tool is the use of an inverted-pyramid, or four-sided vacuum collet, which grips the die on all four sides without adding pressure to the top surface of the die. Avoiding added pressure to the top surface of a GaN or GaAs die is important to avoid damaging land bridges and other delicate 3D structures on the chip.

As most pickup collets must be specially manufactured per die, it often takes several weeks of turnaround, and increased the cost and development time of a eutectic-die attach process. Using such a collet is still the preferred method of achieving the highest quality and most reliable die-attach. Collets need to be designed specifically for each die, taking into account die geometry and air bridges that may lay close to the edge of a device. Four-sided, three-sided and two-sided collets are commonly used in this process to achieve void-free eutectic attach. Preform size and thickness also play a role in this success, and using a specifically sized collet to bring the die down onto the preform allows for perfect centering on top of the preform prior to solder flow.

CONCLUSION

Eutectic die-attach is an essential process in manufacturing RF, microwave, and mmWave modules and assemblies for high-power and high-frequency applications critical for mission success. Military, aerospace, and SatCOM applications all benefit from the high-quality electrical, mechanical, and thermal connections between the latest GaAs and GaN transistors and MMICs and their substrates, die carriers, and heat spreaders/heat sinks that eutectic die-attach enables. In order to achieve a quality eutectic die-attach that enables reliability per device and batch-to-batch, there are many technical and supply-chain parameters that must be addressed. SemiGen is a trusted manufacturing partner that has aided many customers in developing precision eutectic die-attach processes and enabled these customers to offer ultra-reliable die-attach for devices deployed in land, sea, air, and space missions conducted around the globe.

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