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# GaAs and GaN Die Assembly and Handling Procedures

**Qorvo Applications Engineering Staff**

## Executive Summary

This White Paper outlines methods for proper handling, component placement, optimum attachment methods, and interconnect techniques for use with GaN and GaAs microwave monolithic integrated circuits (MMICs) in electronic assemblies.

# GaAs and GaN Die Assembly and Handling Procedures

## Component Placement

Note that GaAs and GaN MMICs are sensitive to electrostatic discharge (ESD). Precautions should be taken with properly grounding equipment, environment, workstations, and operators to minimize/eliminate ESD during die handling, assembling, and packaging. Operators should wear proper ESD grounding straps. Test and assembly equipment and stations should be properly grounded and periodically tested for ESD compliance.

Component placement involves the pick-up and placement of components in the assembly of circuits and microwave modules. MMICs, both GaAs as well as GaN, should only be picked using an auto or semi-automated pick system and an appropriate pick tool. Vacuum pencils and/or vacuum collets are the preferred method of pick up. Although tweezers can be used, chip-outs of the edge of the MMIC can take place. These chip-outs may propagate cracks through the MMIC, causing reliability concerns. Pick parameters will need to be carefully defined so as not to cause damage to either the top or bottom of the MMIC surface. In any automated placement, avoidance of air-bridge locations should be practiced to prevent deformation and other air-bridge damage. Force impact is critical during pick up and placement in an automated mode of operation because of the brittle nature of the GaAs device. GaN MMICs are a little more robust, but care should still be taken when handling bare die for the reasons outlined above. An evaluation should be conducted prior to implementation of auto pick-and-place on GaAs and GaN products to define the acceptable force profile on the specific piece of equipment.

**Component placement assembly notes:**

- Vacuum pencils and/or vacuum collets preferred method of pick up
- Avoid air bridges during pick up and placement
- Force impact critical during auto placement

## Solder Attachment

Solvent cleaning of the solder preforms and substrates/packages is recommended, in order to remove any existing surface contaminants (from machining, packaging, handling, etc.). GaAs and GaN MMICs can be cleaned using an oxygen or plasma cleaning process prior to reflow; however, if the MMIC is stored properly in dry nitrogen, no cleaning should be necessary.

Solder attachment is performed utilizing a reflow process during which the solder preform is brought to its melting temperature and attaches the GaAs or GaN die to the substrate or base-plate material. The attachment is formed when the alloy and the two surfaces are heated, causing the alloy to melt at a specific temperature, depending on its elemental composition. Because of its metallic properties, the solder attachment alloy provides optimum electrical and thermal continuity between the two surfaces, as well as mechanical integrity.

Gold-Tin (AuSn 80/20) is the alloy most commonly used in the industry for GaAs and GaN soldered assemblies, due to its compatibility with gold-based components and its long-term reliability. Usually the AuSn solder is provided as a preform, usually 0.5-2 mils in thickness, and cut to a few mils undersized of the MMIC to be soldered.

Because it is a hard solder, and GaAs is a very brittle material, special care must be taken to ensure that the coefficient of thermal expansion (CTE) of the substrate or base-plate material matches the CTE of GaAs (5.73 ppm/°C). GaN on SiC is more robust to using AuSn solder than GaAs, but some attention should be given to the base CTE during the assembly design process. A typical CTE range that is acceptable places the GaAs in slight compression, with values of 6 to 10 ppm/°C. Some materials within this CTE range include $Al_2O_3$, Cu-W, Cu-Mo, and Alloy 46, which is a common Fe-Ni alloy. Materials that have a CTE lower than that of GaAs, such as Kovar or AlN, should not be utilized due to stress fractures that may develop in the device during assembly or during environmental exposure or conditioning. Base materials that are suitable for GaAs may also be used for GaN devices with no detriment. Materials with a wider range of CTE values can be used for GaN, but proper mechanical analysis must be performed to insure proper joint strength and robustness to thermal cycling with the approach used.

Most microwave assemblies are reflowed in a conveyor belt furnace which employs a forming gas atmosphere. Because of the reducing atmosphere within the furnace, there is no need to employ flux during the attachment operation. An atmosphere of forming gas or hydrogen adequately reduces the oxides from the surfaces to be attached. Many times, fixtures are used to align and/or weigh down the MMIC in place to prevent movement within the assembly during the movement through the conveyor system, and possible floating of the MMIC due to the formation of the meniscus under the die when the solder reaches its liquid point.

An ideal generic Au-Sn soldering profile for a conveyor belt furnace system is shown in Figure 1. Note that the profile is dependent on the type of furnace used, the size and number of die being soldered, and the thermal mass of the entire assembly, including carrying tray, fixtures, etc.; the final profile needs to be determined for a give assembly.
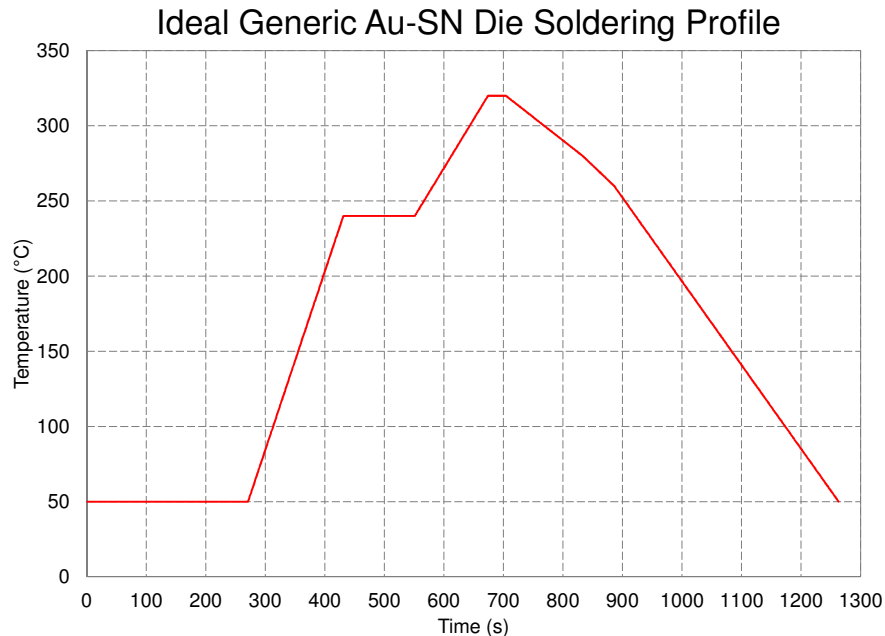


Figure 1. Generic Au-Sn Solder Profile.

Extended time at or above 320 °C is harmful to GaAs devices from a MTTF standpoint. For example, a 30 second exposure 320 °C is equivalent to approximately 545 hours of operational life at a channel temperature of 140 °C for Qorvo's 0.25 µm pHEMT process (similar examples can be shown for various GaAs processes and operating channel temperatures). Due to the longer lifetime and higher temperature handling capability of GaN devices, the impact of exposure to temperatures above 320 °C does not have as severe an impact to device MTTF. A maximum reflow temperature for GaAs and GaN of 320 °C for a maximum time of 30 seconds is recommended.

While the simplest method of producing heat for soldering devices is the use of a hot plate, typical reflow of materials using a hot plate in air usually requires flux. Flux is a rosin-based material that promotes wetting by cleaning the two surfaces to be mated, while removing oxides and contaminants and inhibiting oxidation of the mating surfaces during the attachment operation. Fluxes cannot be utilized in the assembly of GaAs and GaN devices due to electrical and mechanical degradation upon exposure. Fluxes may be eliminated through the use of a forming gas blanket over a hot plate. The forming gas atmosphere provides an adequate reducing environment to inhibit oxide formation during the reflow operation. It is for this reason that these types of alloy stations are commonly employed for rework when flux cannot be utilized.

Due to the flux-less soldering operation, post-solder cleanup is usually not required. AuSn solder joint visual inspection can indicate whether or not the soldering process was as desired. A shiny, bright smooth silver color indicates proper reflow time/temperature, while a dull, rough, or gold-colored appearance is indicative of exceeding the desired reflow temperature.

Achieving a void free solder attachment is important from both an electrical and mechanical perspective. A void free solder interface reduces the resistance between the MMIC die ground and the assembly housing. More importantly, achieving a void free die attach allows for optimum thermal conductivity through to the assembly heat sink, which insures that the die is operating at the lowest possible channel temperature. This optimizes device electrical performance at a given ambient temperature, as well as achieving best possible device MTTF. Voiding under the active device area in a power amplifier can result in a high enough operating temperature causing at least substandard output power performance, and possibly early device failure from overheating. Voiding under die bond locations can cause die breakage when the ultrasonic vibrations and pressure of the wire bonding tool is applied. The degree of voiding at the solder interface can be inspected using either x-ray or acoustic (e.g., C-SAM) inspection. The best method for inspection is a function of the assembly type and the materials used in the assembly.

**Solder reflow process assembly notes:**

- Gold-Tin (8020 AuSn) is by far the most commonly used alloy for MMIC die attachment
- Coefficient of thermal expansion matching is critical for long-term reliability, especially for GaAs MMICs
- MMICs should be stored in dry nitrogen atmosphere
- A conveyor furnace with reducing atmosphere is the preferred heat source for initial assembly; a hot-plate alloy station with reducing atmosphere can be used for assembly rework
- Flux should not be used
- Limit maximum temperature to 320 °C for no longer than 30 seconds

# Epoxy Attachment

Attachment of GaAs and GaN devices on substrates can be performed using an organic adhesive such as epoxy. In the past, these organics were recommended for use only in low-power applications where good heat transfer from the device is not an issue. Epoxy technology (e.g., AbleBond 84-1, ATROX D800HT5) has improved to the point where thermal management and electrical performance is approaching the performance of AuSn solder. The use of epoxies to attach high power MMIC devices is, however, not only dependent on the thermal conductivity of the epoxy, but also the dissipated power and heat flux of the device to be attached and the base material properties (thermal conductivity and CTE). The ability to achieve thin bond lines (< 0.001 inch) with epoxy helps mitigate the impact of the thermal conductivity of the epoxy. Achieving these thin bond lines requires careful design of the dispensing pattern, and die placement and fixturing during curing. A thicker bond line may help mitigate CTE mismatches between the die and the base CTE, especially for GaN die (that can handle a slightly higher mismatch), but the resultant increase in thermal resistance may not be an acceptable trade-off. A thicker bond line may not be nearly as much of an issue for parts with low power dissipations (LNAs, control components, etc.).

Coefficient of thermal expansion (CTE) matching of the substrate to the GaAs/GaN device remains a concern even with organic attachment. In an unmatched situation, initial failure might not be seen because of the ability of the organic to absorb the stress. Instead, failure may occur after environmental conditioning when changes to the organic, such as hardening due to additional cross linking of the polymer chains, promote stress transfer from the unmatched substrate. The preferred CTE range is 6–10 ppm/°C for substrate to GaAs/GaN attachment, as for AuSn soldering. Again GaN-on-SiC can withstand a little more CTE mismatch, but as the materials with CTE values used for GaAs devices is fairly common, the CTE values used for GaAs should also be used with GaN devices.

Epoxies cure at temperatures of 100 °C to 200 °C, which lessens the impact of high temperatures required for AuSn soldering. Curing should be effected in a convection oven with exhaust for the expulsion of diluents and solvents during the cure process. Follow the epoxy manufacturer's recommendations for dispensing and curing to insure optimum die attachment. Microwave or radiant curing techniques may result in differential heating of the assembly. This can potentially cause failure to the GaAs device due to excessive black body heating, where the device heats up faster than the surrounding components and absorbs all of the heat energy being generated.

Information provided above for material preparation/cleaning and void-free die attach considerations and determination applies to die attach processing using epoxy as well as for using solder.

**Adhesive attachment assembly notes:**

- Organic attachment can be used in low-power applications, and in some higher power applications with judicious selection of the epoxy, the base material CTE, the bond line thickness, the power dissipation and heat flux of the component to be attached, and consideration of the system operating environment
- Curing should be done in a convection oven; proper exhaust is a safety concern
- Microwave or radiant curing should not be used because of differential heating

# Interconnections

Assembly interconnection involves the electrical connection of components within an assembly through the use of wires and/or ribbons. For GaAs and GaN assemblies, the wires and ribbons are typically 99.99% gold. The most commonly employed technology is the thermosonic wire-bonding technique. In thermosonic bonding, the wire or ribbon bond is formed with pressure, heat, and ultrasonic energy. The heat is provided through the bonding stage (basically, a temperature-controlled plate on which the module/assembly is placed), the bond tool movement exerts pressure on the wire or ribbon, and ultrasonic energy travels from a transducer through the bond tool to the bond. This compares to the historically older thermocompression technique where the bond is formed primarily through heat, pressure, and time.

The bonding stage temperature in thermosonic bonding is usually kept at approximately 150 °C; a maximum stage temperature of 200 °C is recommended to minimize device degradation. Pressure or force, bond time, ultrasonic power, loop configuration, and bond locations are programmed parameters in automated bonding equipment. Force, time, and ultrasonic power are critical to reliability of the bonded device.

The majority of interconnections are formed through the use of ball-bonded wire. The circuit connection on one end of the wire is made by a ball with a wedge or stitch at the opposite end of the wire. In some cases, wedge bonding (wires with wedges on both ends of the wire, instead of a ball at one end), and ribbon bonds (using a rectangular-profile gold ribbon instead of a cylindrical wire) are used. Usually, wedge and ribbon bonds are used for situations where the lead inductance must be kept to a minimum (e.g., millimeter-wave applications) by reducing the loop height usually required with ball bonding, or for higher current requirements where a few ribbons can be used in place of a larger number of ball bonds. Electrical performance requirements need to be balanced with the number of wires required and the time required to perform the bonding operation. Automated ball bonding is usually faster per bond than wedge or ribbon bonding, and some time is required to change tooling if wire and ribbon bonding are both required.

Minimum bond-pad size for ball or wedge bonding with 0.001 inch (25 um) gold wire is 0.004 inch × 0.004 inch (100 μm × 100 um). Small discrete FET devices are generally wedge bonded with 0.0007 inch (18 um) wire because of pad size constraints. Ribbon bonding is usually performed with 0.001 × 0.003 inch ribbon, but other sizes can be used.

Since GaAs and GaN devices currently have gold-plated bonding pads, only gold wire or ribbon should be used for interconnection. Aluminum wire causes reliability problems, due to intermetallic growth and the resultant "Kirkendall voiding" within the bonded interface, and should not be used.

**Interconnect process assembly notes:**

- Thermosonic ball bonding is the preferred interconnect technique
- Force, time, and ultrasonics are critical parameters
- Discrete FET devices with small pad sizes should be bonded with 0.0007-inch wire
- Maximum stage temperature not to exceed 200 °C
- Aluminum wire should not be used