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Successful Void-Free Die Attach Using Vacuum Reflow Systems

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Introduction

There are many factors to consider when it comes to achieving desirable die attach; one of the most important of these factors is solder interface voiding. Voids in the solder interface contribute to various failure modes including overheating via non-uniform dissipation of heat and high mechanical stresses.

Vacuum reflow systems offer solutions to achieve low solder interface voiding through chamber pressure manipulations and surface treatment options. In addition, the correct solder material selection is key to achieving excellent bond quality. Each application is unique and requires careful consideration when it comes to solder material selection.

Selecting the proper material, solder, and process/tooling selection are essential to provide a successful void-free die attach using a vacuum reflow system.

Void-Free – What is it and Where is it Needed?

Void-free bonding is defined as voids in the bonding material interface, for example solder, that are equal to or less than 5% of the interface area.

Figure 1: Example of a die with many voids and one with less than 5%, or void-free.

Creating a void-free bond can be critical because voids in the interface bond degrade product performance and reliability. The more demanding the application (either in terms of higher power or improved specifications), the greater the need is to have as little void as possible in the bond.

Void-free is critical where ever high-power, high-performance, high efficiency and long-life reliability are important. For example, some specific applications include devices for aerospace, defense, submarine, life-critical medical devices, high power electronics, high performance sensors in EV Vehicles, high power transmission products lasers & LED's. Even devices, like HVAC systems or escalators, require void-free solutions.

In terms of the market growth, there are two principles drivers. The first driver is the need for higher power or higher performance, such as IGBT power modules. The second key driver in this market also requires standard application vacuum processes, and in large numbers too, which are devices such as laser modules. The challenges here are to provide a good quality void-free product within a cost-effective commercial framework.

Systems, Tools, Processes Necessary for Void-Free Die Attach

Using the correct system, tooling, process, and making wise material choices while considering material preparation are all factors and important points that need to be considered when looking to achieve void-free die attach.

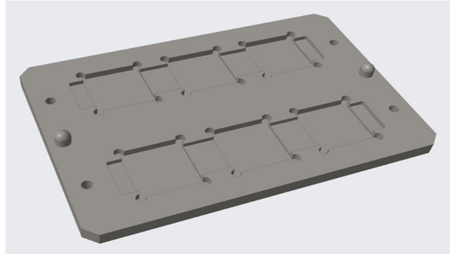


Figure 2: Typical example of a tooling boat.

Vacuum reflow systems is one solution that can provide the perfect controlled environment to start and by utilizing optimum tooling design and tight process parameters that control vacuum, heat, forming gases, formic acid and most important of all, overpressure. It's a combination of all these factors working together to achieve the very best void free results.

The devices to be assembled are located within custom design tooling and placed within a vacuum reflow chamber. Once the chamber is sealed the profile is commenced. This profile consists of multiple stages, typically including vacuum, pressure, pre-heat and reflow temperature along with cool down.

Nitrogen purging is typically done to assist this process. Essentially the aim is to remove air, particulates and moisture to create as inert an atmosphere as possible. The reflow chamber contains the heating elements that should be either graphite resistive heating elements to create a radiant heat and edge heating elements, also of graphite, to create a very stable and uniform temperature within the chamber. Inserted into the chamber is a graphite target plate. This is where the completed tooling assembly is placed.

Custom tooling is absolutely key to the success in achieving virtually void-free die attach using a vacuum reflow system. The purpose of the device tooling is to fix or stabilize the position of the components to be assembled. This may of course be for various potential reasons. One may be to ensure alignment and positional accuracy.

Case Study: Vacuum Reflow for a Butterfly Package

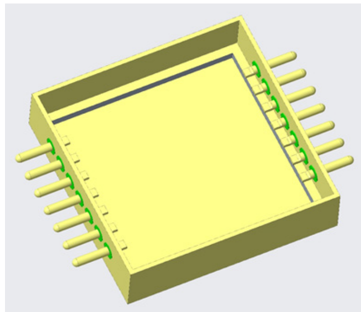


Figure 3: 1-inch square butterfly package.

This case study outlines how a vacuum reflow process is used in a fictious example of a butterfly package. The aim here is to place two components, first a form of substrate and second, in this example a semiconductor die. This package as seen in Figure 3 is 1-inch square with a deep access tub complete with an array of glass insulated gold plated pins for the wire bonded interconnects. The plan is to align both the substrate and die centrally within the package and use a single-pass vacuum reflow profile.

In Figure 4, a primary custom graphite insert is shown. Its purpose is to align the substrate and subsequent following components as required. This is placed into the package observing the correct orientation. Customer specific applications may require multiple inserts or apertures and observation of keep-off areas or pre-existing components.

Once the primary graphite insert is placed into the butterfly package, the first preform which has been pre-cut to the required dimensions is placed inside the insert (Figure 5). These dimensions would have been determined by various factors including previous materials experience, DOE trails and suppler recommendations. Achieving not only virtually void-free die bond but also correct and consistent bond line thickness, outflow and mechanical/electrical integrity. To ensure consistency, placement of this preform is ideally performed by precision Pick & Place equipment, such as a Palomar® 3880-II die bonder. In this example all components beyond the initial primary insert could by assembled in this manner, rapidly increasing throughputs, improving consistency and yields whilst reducing potential failure modes.

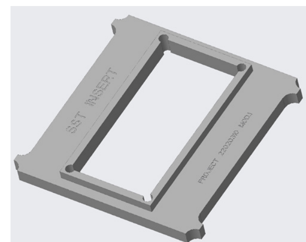


Figure 4: Custom graphite insert to be placed inside the butterfly package.

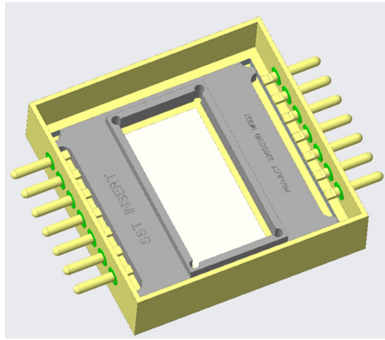


Figure 5: Preform eutectic alloy preform inserted in graphite.

After the first preform has been positioned within the primary insert aperture, the substrate is placed (Figure 6). This is now captured within the tooling and its position fixed.

Now that the substrate is placed, it is necessary to locate and fix the position and orientation of the next component, the semiconductor device. To achieve this, an additional, secondary insert is placed into the assembly. Its purpose as with the primary insert is to fix the die bond position within the substrate. SST Vacuum Reflow Systems have the capability to create extremely small precision-machined custom inserts designed for any application. In this example, wire bond positions between the butterfly package pins and the substrate design itself need to be considered.

A second preform of the same eutectic alloy as the first preform (80Au/20Sn preform) is placed into the secondary insert. Once the preform is positioned, the semiconductor device, a GaN RF component is placed.

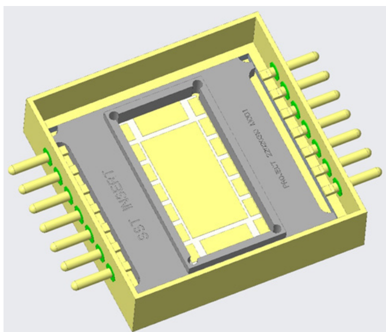


Figure 6: Substrate installed into insert aperture.

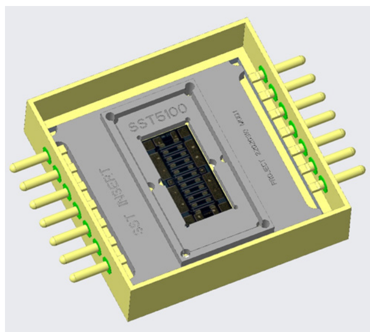


Figure 7: A Gan RF component shown placed into the secondary insert.

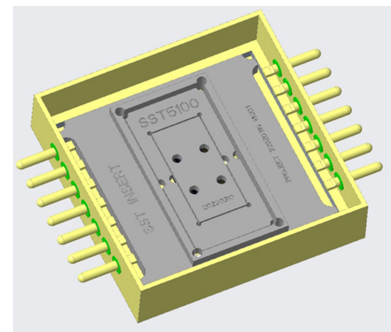


Figure 8: Weighted bezel placed on top of the semiconductor device.

In order to achieve the proper combination of vacuum, pressure and temperature, the next component placed is a "weight bezel" which ensures that all of these are able to work together in harmony to help achieve virtually void-free die attach. A weight bezel's intended purpose is to enable a downforce to be applied to the die, substrate and both layers of preform. The bezel, again application specific and custom designed, safeguards the surface of the semiconductor device.

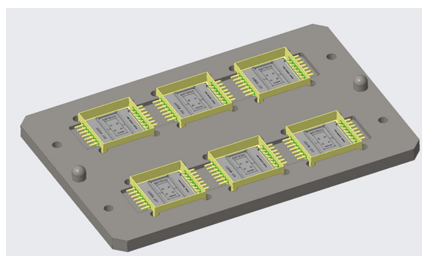


Figure 9: Weighted bezel placed on top of the semiconductor device.

Now that the devices are fully assembled, they need to be placed into the reflow tooling commonly referred to as a base tooling plate or a "boat".

Once the boat is populated, a top plate is installed to encapsulate the assemblies. This top plate as has holes relating to the device positions. These holes serve to locate metal weights which align to the "weight bezels" that were placed earlier within the individual devices. These are typically machined from stainless steel, again application specific. It would be standard to perform trails in respect to this to ascertain the optimised level of weight and subsequent downforce. The principle here comes back to the vacuum, pressure and temperature combination.

Application of weights and downforce brings all of the materials into contact to ensure that elimination of voiding occurs and therefore pockets of trapped space between the materials is prevented. Vacuum is applied initially, along with nitrogen purging to remove air, particulates and moisture. Ensuring that the materials are not "floating" helps tremendously in reducing the likelihood of voiding. This is also critical for conduction of heat transfer throughout the tooling and assembled components. Uniform and appropriate process temperatures are again key to success here. Pressure is applied by the vacuum reflow system to "squash" and collapse voids as part of a typical standard profile. These weights and downforce help to provide a significant helping hand to that principle.

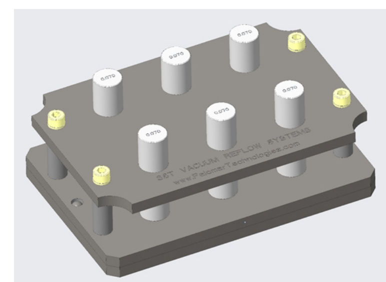


Figure 10: Top plate with weights located over the weight bezels.

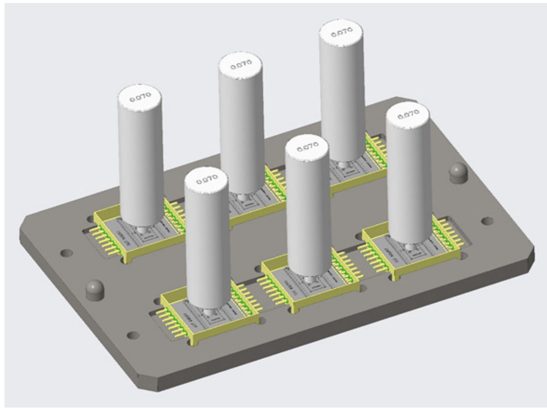


Figure 11: Example of how the weights relate to the weight bezels.

Continuing the assembly with offset support posts and a top “weights plate” again for alignment purposes, the assembly is bolted together. The weights are installed. In this example, 70g per device. Through a DOE trial and prototyping this was determined to be the optimized level of downforce required to provide the most consistent die bond with lowest virtual void-free results attainable. For this analysis CSAM and X-Ray techniques for void measurements would be employed.

The final stage of the reflow tooling assembly is the insertion of the individual weights. Once the reflow tooling is fully assembled it is placed into an SST Vacuum Reflow System chamber onto the graphite target plate.

Considerations for Successful Void-Free Attach

Selecting the correct solder can determine the success of the application. Before any other aspects of the solder can be determined, temperature limitations of the application must be specified. The melting point of the solder must fall within the limitations of the device components maximum temperature along with any other solders used.

Solder preforms are absolutely crucial to achieving void free soldering. Preforms can be cut to specific sizes and shapes, depending on the application. Solder preforms do not contain any organics or other compounds that can hinder the die attach soldering process.

Figure 12: Commonly used solder preforms.

Lastly, flux should be avoided when selecting solder for a die attach application because flux can cause process issues and also mechanical equipment issues with flux getting caught in gas lines.

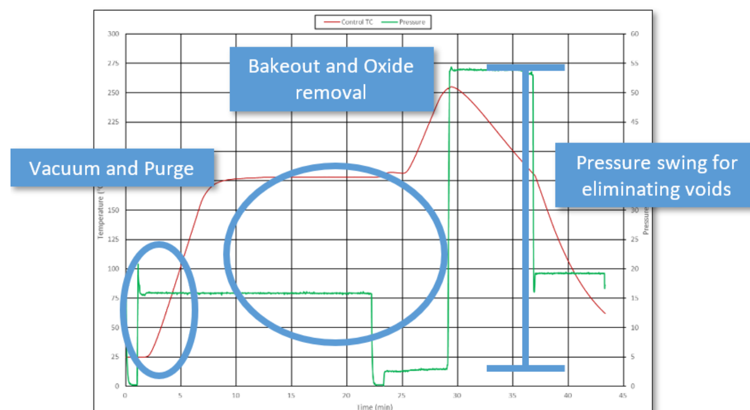


Figure 13: Typical reflow system profile for an SST Vacuum Reflow System.

When executing a successful void-free soldering application, tight temperature control is extremely important. Large temperature fluctuations during the reflow stage of a soldering process can contribute to insufficient solder wetting, solder splatter, and overall increase in voiding.

Using the ability to vary pressure within SST’s vacuum reflow equipment, the “vacuum and purge” step removes oxygen or moisture in the chamber. The bakeout and oxide removal allows for continued moisture removal at an elevated temperature.

At this moment in the profile, an oxide removal agent (e.g. formic acid) can be introduced into the chamber. Lastly, the pressure is aggressively increased while the solder is still in a liquidus state to ensure that maximum void elimination occurs.

Tooling Considerations – Graphite is the Best

Tooling or fixtures hold solder and dies in place when conducting die attach soldering. Graphite tooling offers characteristics that other materials cannot e.g. low thermal expansion. Thermal expansion goes hand in hand in soldering applications. Typically, different materials are being soldered together and naturally, there will be competing thermal expansion coefficients; this is why graphite is a good option with its low expavnsion rate.

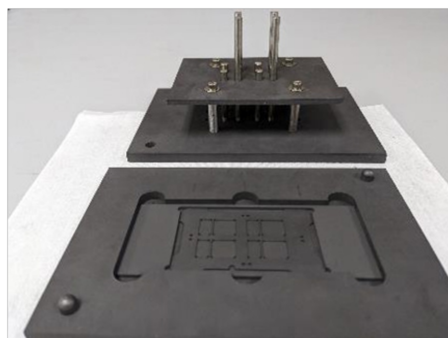


Figure 14: Example of graphite tooling, weights and inserts.

Additionally, graphite can withstand most, if not all, die attach soldering applications. It is not degraded through thermal cycling as long as it is used in an inert environment. Benefits of graphite:

- Excellent thermal conductivity and low thermal expansion
- Withstands high temperature (up to 2000C) while increasing strength
- Great for high current densities and aggressive ramp up times
- Low vapor pressure and is not degraded by thermal cycling
- Lightweight and easily machined

Conclusion

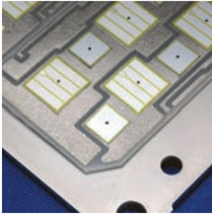
There are many factors to consider when it comes to achieving successful die attach; one of the most important of these factors is solder interface voiding. Voids in the solder interface contribute to various failure modes including overheating via non-uniform dissipation of heat and high mechanical stresses. Using the proper material, solder and process/tooling is critical to achieving low-void.

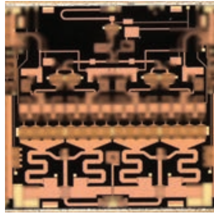
Vacuum reflow systems offer solutions to achieve low solder interface voiding through chamber pressure manipulations and surface treatment options. In addition, the correct solder material selection is key in achieving excellent bond quality. Each application is unique and requires careful consideration when it comes to solder material selection.

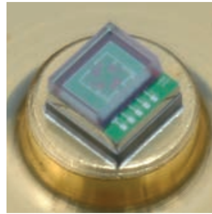
SST 5100

VACUUM PRESSURE FURNACE

The SST 5100 is a programmable vacuum/ pressure furnace that creates void-free solder joints without the use of flux, resulting in high reliability electronic components.







QUIKCOOL™

QuikCool™ is an auxiliary cooling unit designed to rapidly reduce the temperature of the target plate to enable a faster production process. The entire process takes place in one chamber to reduce handling and increase speed of production.

CHAMBER WITH EDGE HEAT

Unique edge heating elements enable the chamber to achieve temperature uniformity over the entire target plate.

USER-FRIENDLY SOFTWARE

User-friendly, Windows-based software makes it easier for operators to use the machine and for programmers to efficiently develop profiles and perform real-time process analysis. Intuitive HMI.

- **Programmable Vacuum Furnace**
  Precise control of soldering process profile
- **Creates void-free, flux-free joints**
  Consistent, highly reliable solder interface
- **Temperature up to 500°C**
  Wide range of solder alloys & other interconnect materials
- **Vacuum Level**
  <50 mTorr or .067 mBar
- **Edge heat systems**
  Optimizes temperature uniformity across the entire thermal work area
- **Single chamber process**
  Minimizes maintanence and lowers cost of ownership
- **Pressure to 40 psig**
  Collapses solder voids across larger surface areas
- **Graphite heating element**
  Higher quality and more consistent results
- **Precise heat and cool controls**
  Higher quality and more consistent results
- **Distributed logic control system**
  Automatic control with real time graph & data logs
- **Proprietary Run Analyzer Software**
  Run analyzer provides ability to graphically review data from logged profiles and export data

SELECTED 5100 OPTIONS

- QuikCool™ system
- Formic Acid
- Oil-Sealed or Dry Vacuum Pump*
- Multiple Temperature Zone Measurement
- Mid-Vacuum ($<10^{-5}$ Torr) system
- Barcode reader
- Water chiller/Recirculator
- Custom Component Fixtures/ Tooling
- Status Light
- 3rd Process Gas Input
- Moisture and Oxygen Analyzers
- Alternative Heated Target Plate Materials
- Illuminated Chamber Viewport
- Casters

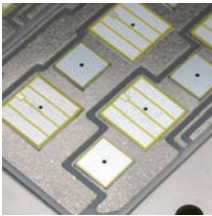
TYPICAL APPLICATIONS

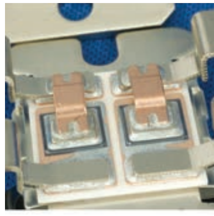
- Flux-less Soldering
- MMIC Die Attach
- Power Module Assembly
- Lead-Free Soldering
- Hermetic Package Sealing
- Fiber Optic Packaging
- Hybrid Assembly
- High Intensity LED Attach
- Eutectic Die Attach
- PV Solar Cell Assembly
- Flip Chip Assembly
- Automotive Device Assembly

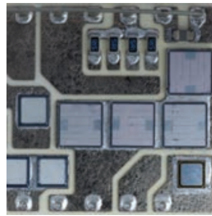
SST 8301

AUTOMATED VACUUM PRESSURE SOLDERING SYSTEM

The SST 8301 Automated Vacuum Pressure Soldering System is setting new industry standards for flux-less soldering by providing highly reliable and reproducible solder interfaces with industry leading void rates.







QUIKCOOL™
QuikCool™ is an auxiliary cooling unit designed to rapidly reduce the temperature of the target plate to enable a faster production process. The entire process takes place in one chamber to reduce handling and increase speed of production.

AUTOMATION ROBOT
A Cartesian gantry automation robot efficiently moves part carriers from conveyors to/from the chamber.

CHAMBER WITH EDGE HEAT
Unique edge heating elements enable the chamber to achieve temperature uniformity over the entire thermal process area.

USER-FRIENDLY SOFTWARE
User-friendly Windows-based software makes it easier for operators to use the machine and makes it easier for programmers to efficiently develop profiles and perform real-time process analysis.

- **High Accuracy and Precision**
  A Cartesian gantry system automatically shuttles part carriers in/out of each chamber, performing each movement with high accuracy and precision.
- **Graphite Heating Element**
  Precise temperature control; no warping; absorbs thermal shock
- **Temp. Up to 500°C**
  Wide range of solder alloys & other interconnect materials
- **Formic Acid System**
  Reduces metal oxide layer for fluxless, low-void soldering
- **Positive Gas Pressure in Chamber**
  Effective means to collapse solder voids over larger surface area
- **Maximum Flexibility**
  Can operate as a stand-alone unit or integrated into an automated production line. SMEMA compliant.
- **Single Chamber Process**
  Minimizes maintanance and lowers cost of ownership
- **Remote Maintenance**
  Remote support for the equipment through LAN connection
- **Traceability**
  Equipment stores all profile runs and logs system events

SELECTED 8301 OPTIONS

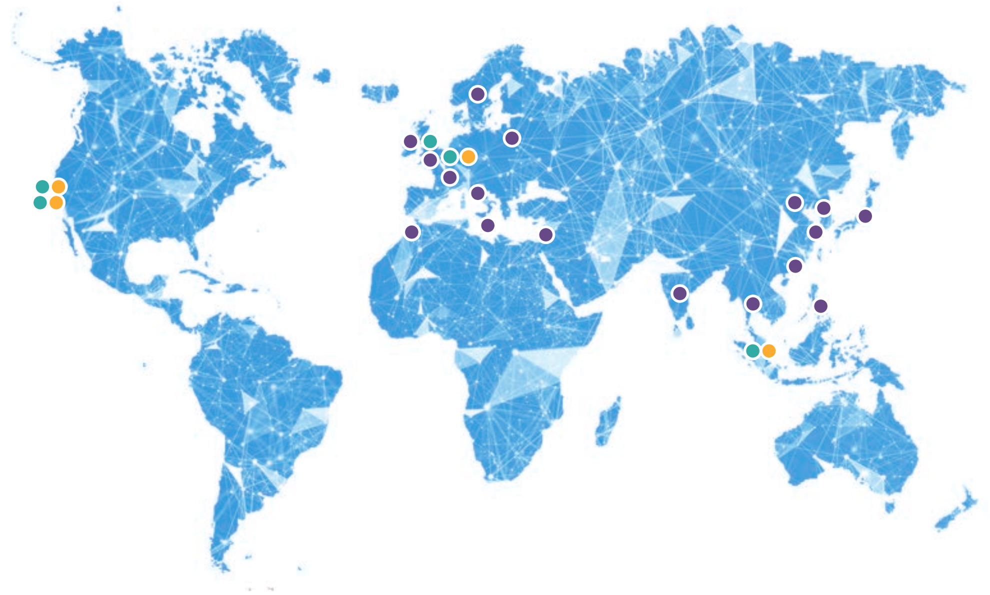
- Formic Acid
- Flux Trap
- Moisture Analyzer
- Oxygen Analyzer
- Up to 6 Monitoring Thermocouples
- Water Chiller/recirculator
- Dry Vacuum Pump
- Mid-Vac $< 10^{-5}$ Torr (1.33 x 10-5 mBar)

TYPICAL APPLICATIONS

- IGBT Modules
- GaAs/GaN/SiC Die Attach
- High Intensity LED Attach
- CPV Solar Cell Assembly
- Copper Clip Soldering
- Multilayer Ceramic Capacitors
- Power Module Assembly
- Die Attach for Pressure Sensors
- High Power Laser Module Assembly
- Hermetic Sealing of IR Image Sensors
- Hermetic Sealing of Hi-Rel Packages

Making the connected world possible™

Making the connected world possible by delivering a Total Process Solution™ for advanced photonic and microelectronic device assembly processes utilized in today's smart, connected devices. With a focus on flexibility, speed, and accuracy, Palomar's Total Process Solution includes die bonders, wire and wedge bonders, vacuum reflow systems, along with Innovation Centers for outsourced manufacturing and assembly, and Customer Support services, that together deliver improved production quality and yield, reduced assembly times, and rapid ROI.



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