Efficient Manufacture of IR Sensors – Combining Bonder and Vacuum Reflow Technology

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Authors: Alex Voronel, SST Vacuum Reflow System
Kyle Schaefer, Palomar Technologies

Introduction

The market for the IR sensing devices has been growing steadily, but in recent years, the market experienced a rapid growth. Several factors drove the market. Among them, the sharp increase in the need for surveillance cameras and, with COVID-19, remote temperature sensing. The growth of smart building technology added more demand for IR sensors as well.

Six megatrends are responsible for this growing demand for IR sensors. While they are independent, each impacts the other, for example, artificial intelligence (AI) requires input from IR sensors as part of harvesting more and accurate sensor data, that leads to improved algorithm competence, thus extending into other ecosystems, such as autonomous drive technology. Extended use in one sector, leads to increase use in the other. Assuming these six megatrends, we have thirty-six such iterations. The net result is significant and exponentially rising demand across all sectors.

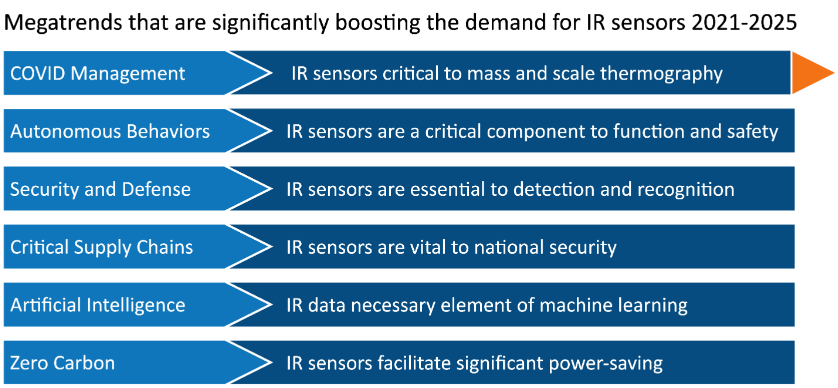


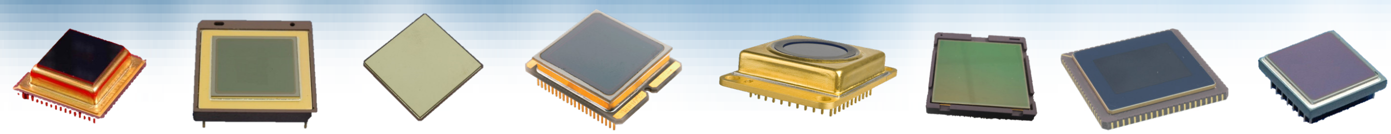
Figure 1: Six megatrends are shaping the IR sensor market.

While we have all felt the inconvenience of COVID management, the 168% increase in demand for uncooled IR sensors in 2020, especially once stated in dollar terms, really drives home the extent and importance of that impact. That COVID is here to stay suggests continued growth in demand, though not on this scale.

Looking ahead, the important trends are beginning to surface. We are witnessing the following: Increased demand from the automotive sector (despite the chip shortage); large increases in military and security expenditure on devices that require IR sensors (such as drones, surveillance, etc.); continued demand because of COVID management, and finally, rising demand from within agriculture and green power sectors.

The IR sensor market is divided into two main groups, IR imagers and IR detectors. Using a range of assembly equipment, specifically die and wire bonders, along with high vacuum reflow systems designed to work together will enable meeting the key parameters required to achieve the specified performance for both IR imagers and IR detectors. While there are a number of applications that can be addressed with wafer level packaging technology, this article focuses on high performance discrete or chip scale packaging technology for IR microbolometer and IR thermopile sensors.

IR Microbolometers



IR imagers use a technology called uncooled IR microbolometers, and as the name indicates, create an infrared image of an object. The technology to create a thermal image of an object is quite complex compared to the IR detector. The number of pixels for IR imagers ranges from 80x80 to 1024x768 (XVGA) and will soon reach HD resolution, with the pixel size ranging from 17 to 12 microns and eventually reaching a single digit.

The key benefit of an IR imager is to provide a clear thermal image of an object(s) regardless of the light condition or presence of smoke or fog that may obstruct the view. Since an IR imager displays the thermal image of an object, it offers considerably better visibility than the human eye can see, regardless of the light condition or presence of fog or smoke.

IR Imager Applications

There are a number of typical applications where IR imagers (IR microbolometers) are used. The largest portion are used in IR surveillance cameras used for area monitoring outside of buildings, street traffic monitoring, just to name a few. IR cameras provide an accurate and efficient way to monitor specific areas of interest. It isespecially powerful in rugged terrain where using traditional ways, like patrols, is not possible. There are many other applications for IR microbolometers, such as, Personal Vision Systems (PVS) for firefighters, which allow them to see through smoke as they enter the burning building. They are also used for industrial applications where the thermal image of the object can precisely indicate if there is escaping heat or overheating.

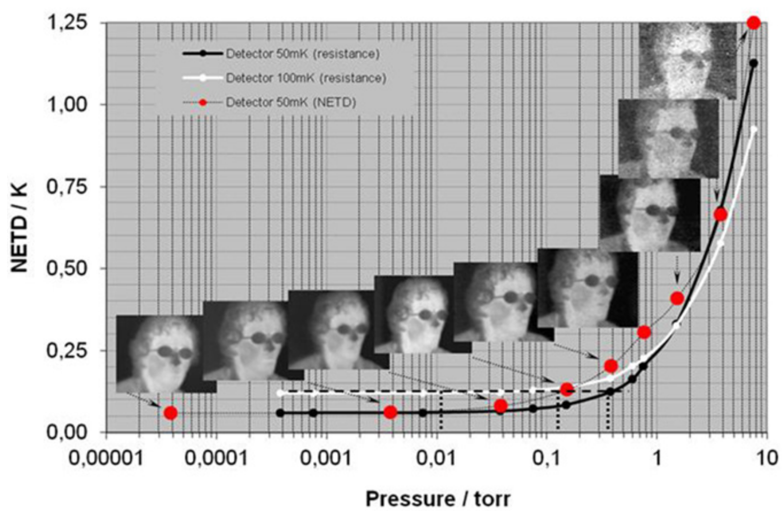


Figure 2: The quality of the image changes as the vacuum level (Pressure / torr) scale changes. The lower the vacuum in the chamber, the lower vacuum will be sealed in the package.[i]

Other typical applications are medical temperature monitoring of people. In addition, night vision cameras for cars enhances the safety of the driver and the pedestrians by allowing the car safety system to see the obstacles on the road in poor lighting and/or fog or smoke.

Key Parameters

Like any device that produces an image, the clarity of the image/high contrast and the resolution are the key parameters. As stated earlier, modern microbolometers can achieve a resolution of 1024x768 (XVGA) and soon HD, with the pixel size ranging from 17 to 12 microns. The pixel size and the resolution are part of the ROIC (Read Out IC) or sensor die manufacturing technology.

To achieve the contrast of the image, the sealed environment inside the microbolometer plays a key role. Figure 2 shows the impact of the sealed vacuum inside the microbolometer package on NETD/K (Noise Equivalent Temperature Difference per degree in K) which in simple terms, is a thermal contrast.

Over the years, packaging variants for IR microbolometers evolved as the assembly technology, processes, and materials have become available for viable manufacturing of the uncooled microbolometer. When uncooled microbolometer devices were introduced to the market some 20 years ago, the main market for them was defense and aerospace applications. The cost of materials and manufacturing was high and the volume was low. During the early days, microbolometers were assembled using a metal package, which had a vacuum port, in the shape of a tube. Getter was supplied in the form of a resistor that was attached to the leads of the package. The process involved the hermetic sealing of the window (Si or Ge) to the metal package, which was followed by a pump down of the vacuum by connecting the vacuum pump to the vacuum port (tube) of the microbolometer. Once the specific vacuum level was achieved, the getter was electrically activated. After the activation was finished and the required vacuum level was achieved, the tube was pinched off to capture the vacuum level inside the package.

In the last 5-10 years, new packaging variants became more common due to the available materials and assembly equipment able to manufacture uncooled microbolometers at a lower cost and with higher UPH. The introduction to the market of low permeability ceramic materials, and thin evaporable getter material that is deposited onto the window of the microbolometer and thermally activated, are just a few of those advancements. The current packaging technology of uncooled microbolometers lends itself to automating the thermal getter activation and the hermetic sealing of the microbolometer in high vacuum all in one assembly process.

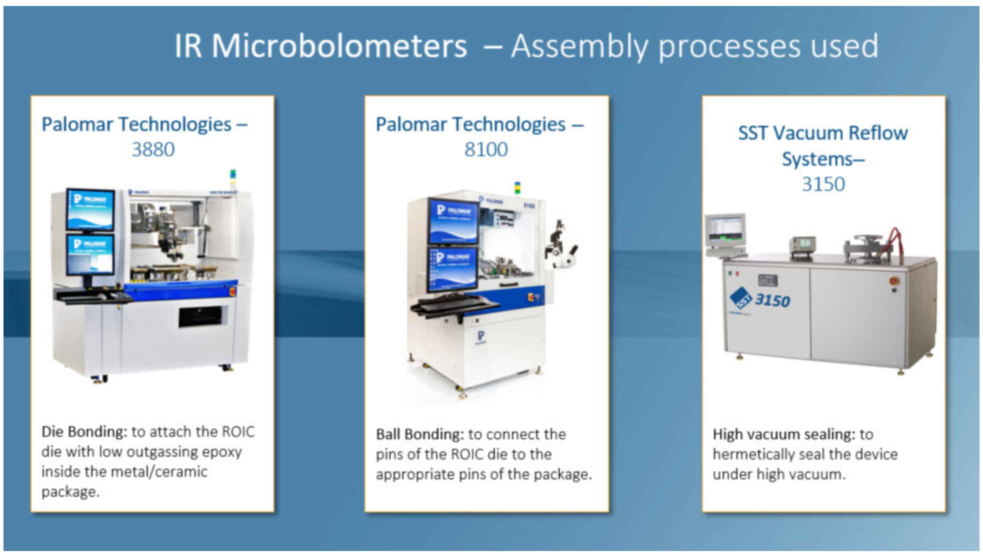


Figure 3: There are three main assembly processes utilized for the assembly the IR microbolometer: die bonding, wire bonding and vacuum sealing.

Assembly of IR Microbolometer Sensors

There are three main assembly processes utilized for the assembly of an IR microbolometer. First, is die bonding where the MEMS ROIC die is attached to the ceramic package, either with low outgassing epoxy or with eutectic solder alloy. Then, wire bonding, either ball bonding or wedge bonding is used for connecting the ROIC contacts to the appropriate pins on the ceramic package. The last process is the hermetic lid sealing under high vacuum of the Si or Ge window to the ceramic package.

For the die attach, Palomar's Model 3880 offers a robust and flexible system with a variety of options for the die attach materials and component presentation options. The 3880 Die Bonder has the flexibility to attach the MEMS dies in the microbolometer package with either epoxy or solder preform. The 3880 is an ideal fit for MEMS devices, as the main objective is to assure repeatable die placement and to assure the lowest vacuum level in the device after lid sealing.

The 3880 offers several component presentation options, including 2" and 4" waffle pack or gel pack, tape and reel, wafer die ejectors, and custom die presentation stages. Various die pick up tools are available or can be designed to handle a wide range of die sizes up to 3" for sensitive MEMS or similar dies.

For the package handling, edge belt conveyors are available to bring in up to 6” boats. A heated conveyor can be utilized to bring in packages and boats should preheating be necessary during the die bonding process. For the adhesive dispensing, the 3880 offers time/pressure, auger pump, or epoxy jetting. An Auger pump can be used for the precise volume control of the dispensed adhesive, while a jetting pump for more precise temperature control during dispensing.

The 3880 die bonding system offers a comprehensive suite of process control capabilities. The control of the assembly process is an extremely important feature when dealing with high reliability and high cost devices. A complete view of the assembly process is available – storing images and data from the beginning of die bonding process to finish. Among the stored information are placement accuracies, pattern recognition images, dispense pattern images, temperature profiles, die surface quality checks; and all of them are tied to each program execution and the IDs of each component used for that execution.

These components can be tracked through several means of identification – 2D barcodes, 3D barcodes, QR codes, and even individual character strings on the actual components.

For wire bonding, the Palomar 8100 Ball Bonder and the Palomar 9000 Wedge feature a large X-Y table for assembly of a wide range of packages introduced in various carriers. Both models are designed for seamless integration into various automatic assembly lines or with handlers/indexers for the stand-alone operation.

The 8100 excels at handling challenging bonding surfaces, unconventional loop shapes with the options to use stand-off-stitch, and security bumps, respectively. The 9000 can bond Au and Al wires at an extremely fine pitch with various wire feed angles.

Both wire bonders have options to deal with material variations and ensure robust wire bonding process when assembling high reliability devices that do not have the option to use epoxy wire encapsulation for strengthening the rigidity of the wire loops. Comprehensive monitoring and detailed bonding data allows for process optimization to ensure proper device quality from the outset and for the process control to assure the long term bonding results stability.

The construction of uncooled IR microbolometers is based on a MEMS sensor with a specific number and size of pixels to generate the thermal image. The key requirement for the functionality and the image quality of the thermal imager (microbolometer) is based on a sealed high vacuum level, typically 0.1 mTorr or lower. To achieve such a vacuum level, a powerful vacuum system and properly designed chamber need to be employed as a part of the sealing furnace. The SST 3150 High Vacuum Furnace meets these requirements.

In addition, to maintaining the vacuum level sealed in the package, the getter must be activated, before the package is hermetically sealed. The 3150’s in situ system with servo-driven lid and package separation, along with the highly reflective retractable shutters provide a precise thermal environment for the getter activation.

Just as important is the heating components in a high vacuum environment. It is a challenging task. Convection heating and conduction heating are not effective, while component materials and process chamber emmissivities affect the infrared heating. The thermal uniformity requirements, along with the desired heating and cooling rates present additional challenges.

The 3150 features in-chamber resistive graphite heating plates can address most of these issues. High quality, semiconductor-grade graphite tooling is precisely machined to nest and locate package components relative to each other. Low voltage current flowing through these heating plates is directed and controlled to minimize thermal gradients. Infrared and conductive heating is applied directly to components located in pockets in the graphite heating plates.

IR Thermopile Sensors

The technology to measure the temperature of an object remotely or from a certain distance, offers many end use applications. All these applications fall in the realm of thermally detecting an object or IR detection. IR detectors use a technology called IR thermopile, and as the name implies it serves the function of detecting/measuring the temperature of an object.

Hence, the technology is designed for only determining the temperature of an object. The complexity of sensing the heat is relatively simple since a few pixels of an image is sufficient to determine that there is a temperature difference between the ambient and an object's temperature. Typically, 4x4 to 64x64 pixel sensing is utilized for the IR detectors, with the pixels sizes ranging between 90 to 200 microns.

IR Detector Applications

Among the most common applications where the IR thermopile sensors used are include:

- Non-contact temperature measurement using hand held devices.
- Counting the people as they walking in and out of the buildings.
- Detecting the presence of the people in the room and their relative position in the room for more optimized energy use of the Air Conditioning and/or Lighting.
- Kitchen appliances are readily using IR Thermopile sensors for more precise temperature control in stoves and induction ovens.

Key Parameters

High performance IR thermopile sensors have specific packaging technology requirements to assure the performance of the detector and its longevity. One of the key parameters is the chamber vacuum where the thermopile sensor is sealed. The vacuum level needs to be between 0.1-0.01 Torr inside the device, which means that the chamber vacuum level should be 1x10-5 Torr or lower.

Just as important is the hermeticity of the package or the leak rate. The hermetic package ensures that the vacuum level stays constant for the long term thus assuring the stable performance of the thermopile sensor. Typically, the package must comply with the MIL STD 883E specification.

Some IR detectors devices are based on less complex technology where only a limited number of pixels need to be monitored and the sensing distance is quite short. On the other hand, there are higher performance IR thermopile sensors with a higher number of pixels and extended sensing range and other improved specifications. As a result, different packaging variants were developed based on the end use application and the expected performance of the IR detector.

There are several packaging variants for IR thermopile sensors; the least expensive and simplest is typically used for the low-end performance sensors (low pixel number and short range). These are TO style packages where the thermopile die is bonded to the base of the TO package and the wire bonds connect the die pads to the contacts of the package. The metal cap with the IR glass window is then seam-welded to the base of the package. Another popular low cost packaging is ceramic SMD. The die is bonded to the ceramic base and then wire bonds connect the die pads to the appropriate contacts of the package. Then the IR window lid is glued over the package to protect the die. There is no requirement for achieving and maintaining a specific vacuum level inside the detector.

For high-performance IR thermopile sensors, a specific vacuum level and hermeticity level are required to achieve the performance specs. In order to achieve the vacuum level inside the IR thermopile sensor in the range of 0.1-0.01 Torr, the vacuum level in the vacuum reflow oven should be 1x10-5 Torr or lower. Low permeability of the ceramic material for the ceramic package must be used to ensure the sealed vacuum does not leak through the pores of the ceramic. A eutectic soldering process is used for the lid-sealing, which provides higher hermeticity seal than seam welding.

Typical high-end IR thermopile sensor packaging solutions include a standard SMD package where the die is bonded to the base of the ceramic package. The wires, either Au or Al are bonded to connect the die pads to the appropriate contact of the package. Then the Si window (lid) is soldered under chamber vacuum to achieve a Mil-Std 883E leak rate. In addition to thermopile die, there is an ASIC die packaged in the sensor. For the assembly of this variant, the same assembly steps will be used as described earlier, the die attach process will be used to bond the dies to a ceramic base and the wire bonding will be used to connect the bonding pads of both dies to appropriate contacts of the package.

Then, the metal cap with the integrated Si window is soldered under chamber vacuum to achieve Mil-Std 883E leak rate.

Assembly of IR Thermopile Sensor

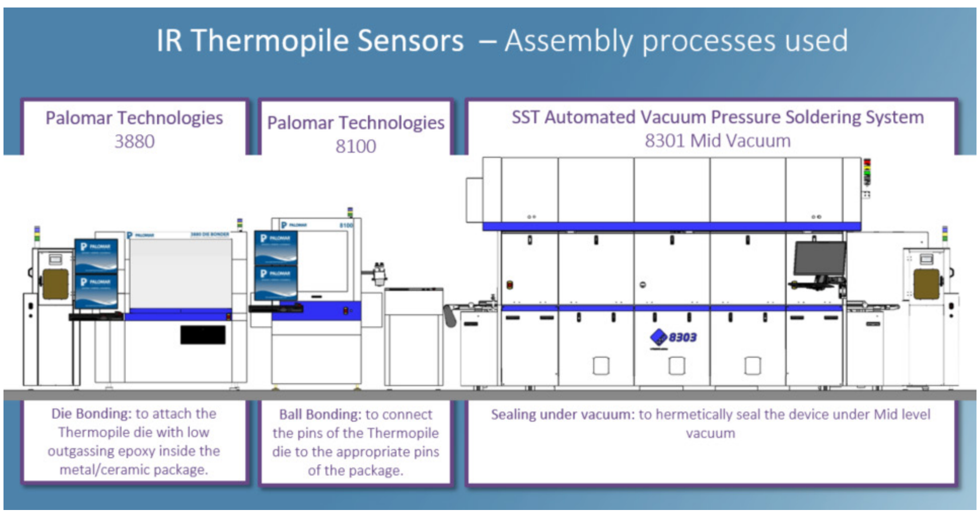


Figure 3: There are three main assembly processes utilized for the assembly the IR microbolometer: die bonding, wire bonding and vacuum sealing.

There are three main assembly processes utilized for the assembly of high performance IR thermopile sensors. First, die bonding is used to attach the MEMS thermopile die to the ceramic package, either with the low outgassing epoxy or with eutectic solder alloy. Then, wire bonding, either ball bonding or wedge bonding is used to connect the thermopile die bonding pads to the appropriate pins on the ceramic package. The last process is the hermetic lid sealing under vacuum of the Si window (lid) or metal cap with the Si window already attached to the ceramic package. All three of these systems can be seamlessly integrated into a robust automated assembly line as shown in Figure 4.

For die attach, as with IR microbolometer assembly, Palomar's 3880 Die Bonder offers a robust and flexible system with a variety of features for die attach materials and handling options. In addition to the features mentioned earlier, high volume/continuous production operation is achieved with automated conveyors with optional heating. Tape and reel feeders are available for robust and rapid delivery of components. The tray feeders are available to handle a variety of the assemblies and packages. The input and output magazines are available for easy loading and unloading of the standard trays, custom trays or lead frames. The robust process control and monitoring options are available for high volume production as well.

For wire bonding, either the Palomar 8100 Ball Bonder or the Palomar 9000 Wedge Bonder are excellent solutions. As mentioned earlier both bonding systems have a large X-Y table allowing the assembly of wide range of customer packages introduced in various carriers/trays.

Both wire bonders are set up for the high volume/continuous production operation by offering automated conveyors with optional heating. The 8100 is an extremely fast ball bonder, achieving 0.115 sec/wire (nearly 8 wires/sec). The 9000 wedge bonder can bond Au and Al wires at an extremely fine pitch with either deep access or various wire feed angles.

There are a number of available options to both systems, which provide the necessary data collected during the wire boding process for the process optimization and process monitoring. The Adaptive Bond Control monitors the bond height variation and adapts the Z coordinate of the bond for optimized bonding speed. For the 8100 the controller feedback of the NEFO, offer the precise formation of the ball for higher quality of ball bonding process.

One of the key parameters is the chamber vacuum where the thermopile sensor will be sealed. A vacuum level between 0.1-0.01 Torr needs to be achieved inside the device. To achieve such a vacuum level, an appropriate vacuum system and the chamber are employed as a part of the sealing furnace. Both the SST 5100 Vacuum Pressure System and SST 8301 Automated Vacuum Pressure Soldering System can achieve a chamber vacuum level of 10-5 Torr or lower.

The process section of the SST 5100 and 8300 is housed in a custom-built aluminum chamber. A target plate, typically made of graphite, is heated from below and at the perimeter with radiant flux emitted directly from graphite heating elements. The main heating element is machined from a single sheet of graphite, minimizing unheated areas, resulting in a uniform flux field. Secondary graphite heaters, located along each edge of the target plate, improve overall temperature uniformity by compensating for edge and sidewall heat losses and provides the temperature uniformity of +/-2% over entire heated area. Large size chambers provide high volume production of the IR Thermopile.

High quality, semiconductor-grade graphite tooling is available to nest and locate package components relative to each other. The RunAnalyzer software provides the real time monitoring of the assembly process and ability to record the key parameters of each production run to be used for the process development and the process control. The 8300 automated vacuum reflow system offers a fully automated, lid sealing process for large-scale production.

Conclusion

The market for the IR Sensors, divided into two main groups, IR imagers and IR detectors, continues to expand, as new end use applications are being addressed by the advantages of each. The key parameters required to achieve the specified performance, can be reached by using the appropriate assembly equipment.

The assembly of high performance discrete or Chip Scale Packaging technology for the IR microbolometers and IR thermopile sensors can be achieved using a range of assembly equipment, specifically die and wire bonders, along with vacuum reflow systems.

Palomar Technologies and SST Vacuum Reflow systems offer the complete suite of such equipment. The Palomar 3880 die bonder offers unmatched flexibility and mass production capability for wide range of packages and die attach materials. The 8100 and 9000 wire bonders provide all of the necessary features and options needed for the robust wire bonding process. The 3150 offers unique lid sealing process with in-situ the thermal getter activation capability that can achieve chamber vacuum level 10-7 Torr or lower required for the lid sealing of high performance microbolometers. The 5100 and 8300 systems provide all of the necessary features for the lid sealing of the IR Theromopile sensor by featuring large chamber size, tight temperature uniformity and the chamber vacuum level of 10-5 Torr or lower.

Whether the need is for a fully automated assembly process or semi-automated/batch assembly process of IR sensors, Palomar Technologies has a suitable assembly solution.

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[i] Image courtesy of INO, the largest centre of expertise in optics and photonics in Canada. https://www.ino.ca/en/

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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.

Palomar Technologies, Inc.
6305 El Camino Real
Carlsbad, CA 92009
+1 (760) 931-3600

Palomar Technologies GmbH
Am Weichselgarten 30 b
91058, Erlangen, Germany
+49 (9131) 48009-30

SST Vacuum Reflow Systems
9801 Everest Street
Downey, CA 90242
+1 (562) 803-3361

Palomar Technologies (S.E. Asia) Pte Ltd
8 Boon Lay Way #08-09
Tradehub 21, Singapore 609964
(+65) 6686-3096

Innovation/Demonstration Centers
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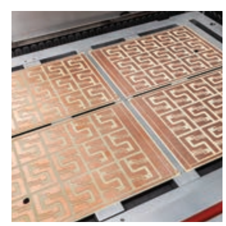

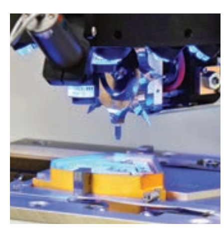

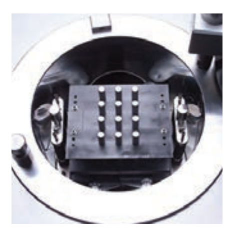

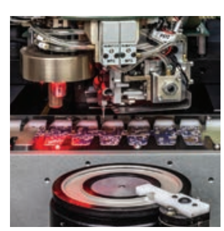

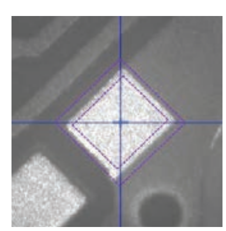

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