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Michael D. Frederickson,
EMPF Director

Barry Thaler, Ph.D. • bthaler@aciusa.org
EMPF Technical Director
Empfasis Technical Editor

Paul Bratt • pbratt@aciusa.org
Empfasis Editor

In this Issue

ACI Technologies, Inc.

1 International Plaza, Suite 600
Philadelphia, PA 19113
610.362.1200 • *fax* 610.362.1290
Helpline 610.362.1320
www.aciusa.org • www.empf.org

Advanced Materials for Thermophotovoltaic Devices

Thermophotovoltaic (TPV) devices convert thermal energy in the form of black-body radiation into electricity in the same way photovoltaic (PV) devices convert solar energy into electricity. They can be packaged to fit easily into a variety of locations to capture waste heat from engines, motors, or other sources of heat and transfer that energy to a storage device where it can be made available for future use. A potential application for the U.S. Navy is to develop a manufacturing process to incorporate TPV systems in turbine generators used shipboard to generate power. The 550°C to over 800°C temperatures in these engines can generate enough waste heat to recycle using TPV technology on DDG 1000, LCS, and other platforms that use turbine engines. Potential commercial applications could include lining the engine compartment of an automobile where the excess energy would be held in storage until needed to run some other device such as a power steering pump. This concept can also be extended to any sufficient heat source providing a continuous supply of electricity[1].

Thermophotovoltaic energy conversion is a direct conversion process from heat to electricity via photons. The device converts secondary thermal radiation, re-emitted by an absorber or heat source, into electricity. The device is designed for maximum efficiency at the wavelength of the secondary radiation. Currently, TPV devices are more sensitive to infrared radiation (λ>1500 nm) from surfaces that are at temperatures from 950°C to about 1350°C. TPV devices are based on diodes with band gaps lower than 0.75 eV. They can contain a single type of semiconductor or several different types to cover a broad range of temperatures. The typical TPV device consists of four main parts; emitter or

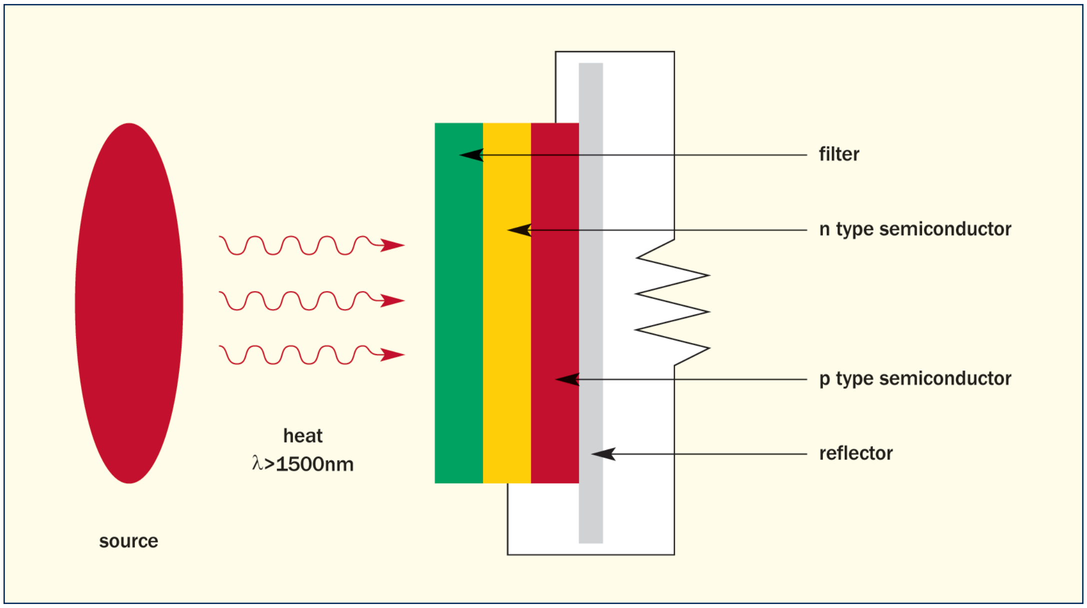

Figure 1-1: Schematic drawing of a basic TPV cell.

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Ask the EMPF Helpline!

Two Cases of "Line Down" Situations

Calls on the EMPF Helpline, asking for assistance are varied. Some require very simple answers, while others can be quite complex. This article covers a few examples.

The EMPF provides a Helpline service for anyone who has a question or problem to call a toll-free number and tap into the resources of this Navy ManTech Center of Excellence for electronics manufacturing. The questions may be as simple as identifying a typographical error in a printed wiring board specification to tackling a root cause analysis of a manufacturing defect that has shut down the production line of a major overseas contract electronics manufacturing services (EMS) provider.

Case 1

In the latter case, the EMPF was contacted by the EMS' customer, a major electronics original equipment manufacturer (OEM). An unacceptable level of manufacturing defects forced a production line shutdown in an overseas printed circuit board (PCB) manufacturing plant. The local engineers were unable to determine the cause, so the EMPF was contacted. Since this was a "line down" situation, time was of the essence.

Approach

An initial phone conference was set up with the EMPF's engineers and scientists to gather as much up-front information as possible. Design and process information was provided by the OEM and EMS, as well as the statistics for the failure rate. Several hypotheses were formulated, but until the PCB was examined, a final determination could not be made. The EMS shipped a couple of example PCBs overnight to the EMPF facility located near the Philadelphia airport. The boards were immediately examined under optical inspection and documented with photos. A number of diagnostic techniques were employed to confirm or refute the hypotheses. During the analysis, the EMPF staff maintained contact with the EMS and OEM to gain additional information and provide feedback.

Result

The root cause was determined to be marginal products from a second tier supplier whose process had drifted out of control. The corrective action was to purge and replace the stock at the EMS. The product line came back on line in just a few days.

Case 2

An automotive component manufacturer called with a similar problem in the engine control module (ECM) they supply for major car manufacturers (Figure 2-1). Inside is an electronics assembly that has been potted and sealed in a metal enclosure. At this stage the assembly is not reworkable. This manufacturer was also in a line down situation, but had already completed a root cause analysis and correction. Their problem was that they had a substantial inventory that contained an unknown number of defective parts. They knew that the defect was a cracked solder joint at a particular location on a ball grid array package. What they were seeking was a non-destructive screening method for the suspect inventory to find the assemblies with the defect.

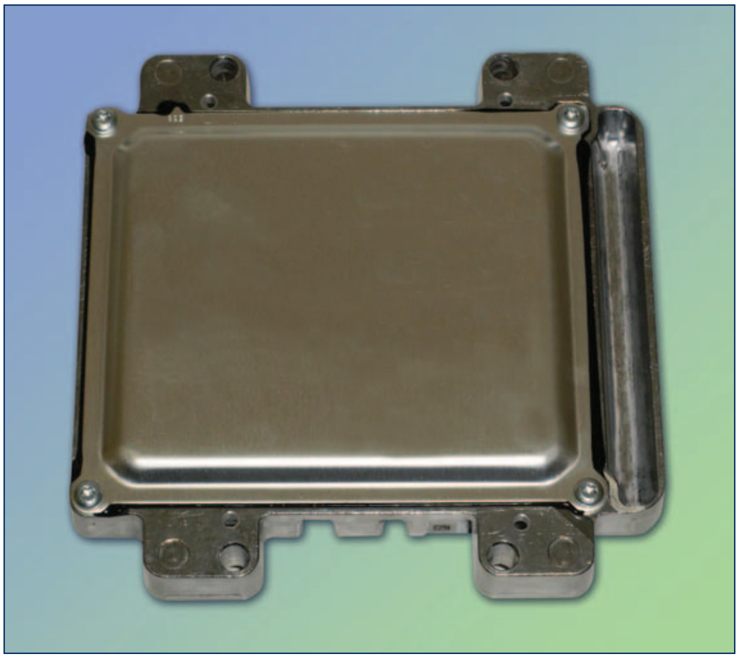

Figure 2-1: Engine control module (ECM) requiring screening for a cracked solder joint.

Approach

Electrical screening was ruled out because the cracked solder joint could make intermittent electrical contact until subjected to normal driving conditions. The next approach was to use the state of the art x-ray imaging system at the EMPF's Manufacturing Factory. The manufacturer had a slightly older model of the x-ray imager but was unsuccessful in identifying the defect due to a number features shadowing that portion of the assembly. They sent one of their modules to the EMPF to try on the newer machine along with drawings to provide a map to the defect area. This also proved unsuccessful. A relatively new technique being used in the materials analysis community is micro x-ray computed tomography (micro CT). The test is similar to medical CT using higher energy x-rays to penetrate harder materials. The EMPF contacted the micro CT manufacturers to explore that possibility. Unfortunately, the resolution needed to image the solder joint defect was not available for the size of the ECM (several centimeters). Micro CT is only effective for samples a few millimeters in size. Acoustic imaging is also available but does not have the resolution at the depth of penetration required to reach the defect area. The EMPF staff communicated this information back to the ECM manufacturer.

Result

The ECM manufacturer now had the information they needed to make the decision to proceed with scrapping the suspect inventory. They were very appreciative of the effort the EMPF provided on their behalf and the

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Materials Testing for High Efficiency Electronics

Materials used in high-tech electronics on Navy ManTech projects have been fully characterized to understand how electronic structure and properties are essential; the performance of these devices can be enhanced through various processing techniques. Crystalline structure, interfacial and surface roughness, layer thickness, crystalline defects, phase identification, elemental and impurity analysis are some of the important material properties to study. These material characteristics can be analyzed using techniques that can measure bulk properties or surface properties (Figure 3-1). Each of these techniques will be discussed in more detail in this article.

Both solar and fuel cells are constructed similarly using a heavily doped electron (n-type) semiconductor layer sandwiched with a heavily doped hole (p-type) semiconductor layer. Semiconductor materials used in these devices are grown as thin films with a preferred orientation for their atomic planes. X-ray diffraction (XRD) is a powerful technique that uses Bragg's law of diffraction to determine crystalline structure as well as atomic plane spacing. Incident x-rays enter the material at a specific angle and collide with an atom. The elastically scattered x-rays exit the sample at the same angle, resulting in constructive and destructive interference that is characteristic of the material. By searching a database, the orientation of the crystal can be determined from the x-ray diffraction data. Orientation of the semiconductor layer grown on another semiconductor layer is strongly influenced by the atomic plane spacing mismatch. With x-ray diffraction, scientists can determine if the crystal structure will lead to different performance of these devices.

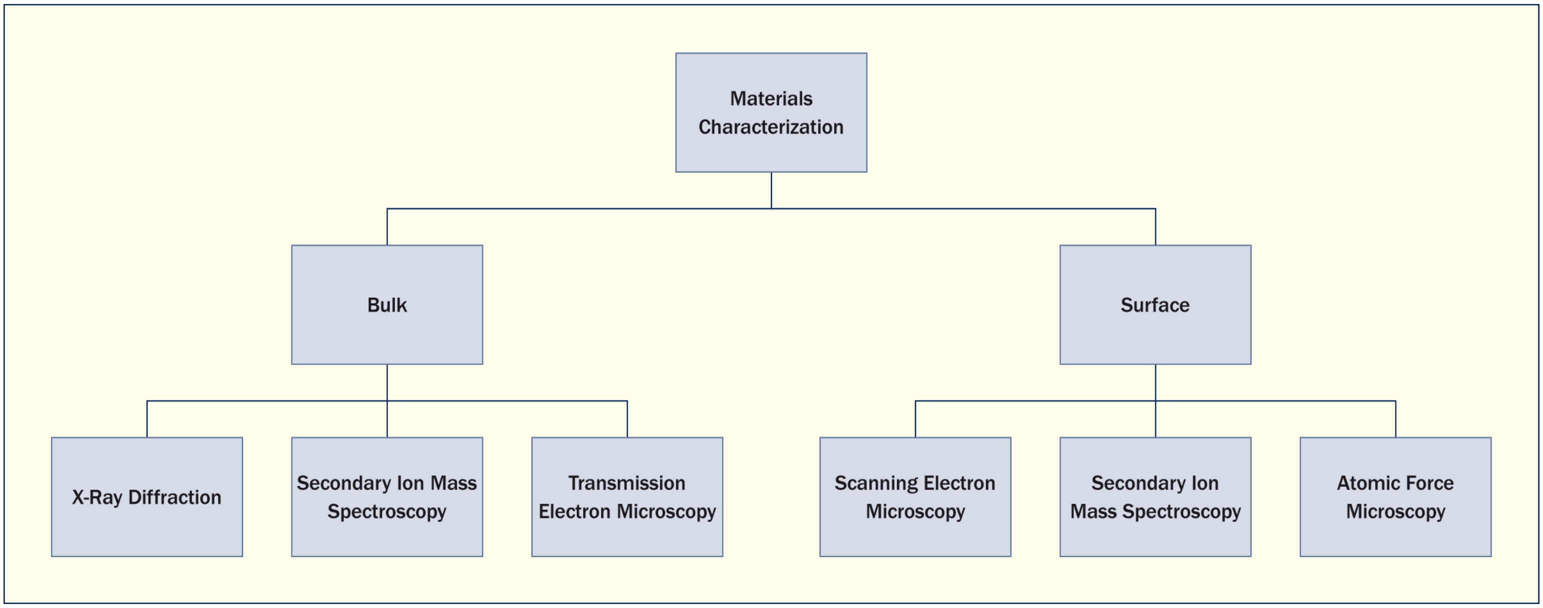

Figure 3-1: Materials Characterization - Bulk versus Surface Analysis

For layered structures, fitting the x-ray reflectivity (XRR) to the Fresnel equation can also provide information relating to the individual film thickness, density, and roughness at the interfaces. Below the critical angle total external reflection occurs while above the critical angle, reflections from the interfaces result in constructive and destructive interference. This information is important for determining and maintaining the quality of multilayered films. Also, film thickness, density, and roughness may play an important role in electronic transport across the film interface.

For exposed surfaces, atomic force microscopy (AFM) can be used to image an entire surface plane in all three dimensions. This technique uses a laser beam focused on a cantilevered, fine-tipped probe. By monitoring the reflected laser beam using a series of photodiodes, any deflection of the cantilever arm indicates a van der Waals interaction between the tip of the probe and the sample surface. As the probe approaches the sample surface from a distance, strong attractive van der Waals forces pull the probe closer to the sample. As the probe nears the sample surface, strong repulsive van der Waals forces push the probe away from the sample. These forces can be measured and correlated to height differences across the plane of the sample. Rastering the probe across the entire surface provides the surface roughness and an atomic level imaging of surface topology that would not be possible with x-ray reflectivity.

AFM has several modes of operation: contact, non-contact, and intermittent (tapping). In contact mode, the cantilever tip is touching the sample surface which results in strong, repulsive van der Waals forces between the cantilever tip and sample. As a result, the sample will be damaged as the cantilever tip is dragged across the surface. In non-contact mode, the cantilever tip is operated above the resonance frequency for amplitudes of a few nanometers. As a result, a strong, attractive van der Waals force is present with the cantilever tip less than 10 nanometers away from the surface. This can provide imaging without any damage to the sample.

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Tech Tips: Soldering Iron Tip Care

In today's cost-conscious environment, the ability to efficiently manufacture a product has driven the electronics industry towards more automated processes and streamlined production facilities. Despite this reality, the need for hand-soldering operations remains an integral part of most manufacturing processes. Whether it is the need to attach a large connector, conduct a field modification, or to rework a non-compliant item, hand-soldering operations require personnel with the proper skills to complete the job. The use of the proper, well maintained, equipment is paramount to completing the task in a timely manner while maintaining a high level of quality.

The proper maintenance of soldering equipment is often the most overlooked problem in hand-soldering operations. Fortunately, a few easy and repeatable practices regarding soldering iron tip care can eliminate a wide variety of issues before they become a problem. Proper tip care will extend the life of the tip and cut down on the need to frequently replace oxidized or pitted tips that are no longer usable.

The goal of any high quality soldered joint is the formation of a good intermetallic bond (Figure 4-1) between the solder alloy and the connection contact area (e.g., the wire or component lead, and the land, pad, or terminal).

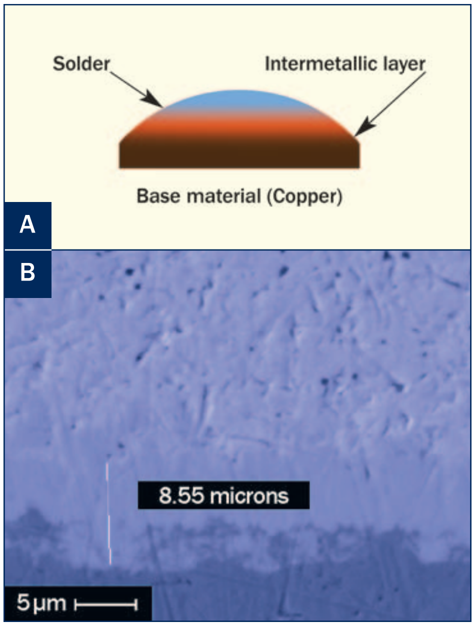


Figure 4-1: Typical solder joint.

The following practices will help ensure acceptable soldered connections and prolong the life of the equipment used in common hand soldering operations.

- First, select a tip that is the proper size and geometry for the connection to be soldered (match the width of the tip to the diameter of the pad). While this may seem like common sense, it is frequently the most overlooked practice. It is not uncommon that a technician will choose too small a tip size and try to compensate for poor heat transfer by increasing the temperature of the iron. The problem then becomes two-fold since you have an insufficient area for adequate heat transfer and increased oxidation by increasing the tip temperature. Use the correct tip size and temperature to yield better results.
- Select the lowest tip temperature needed to facilitate solder reflow. The correct temperature depends on the type of solder alloy being used. Lead-free alloys have higher melting points than tin/lead alloys and often have a frosted or grainy appearance (in the final connection). A grainy appearance on a tin/lead connection is a clear indication that the tip temperature is too high. If a connection is being made on a multilayer board with an internal ground plane, the ground plane acts as a heat sink. Auxiliary heating is needed to overcome the heat sink effects.
- "Idle the tip!" This term refers to the practice of coating the tip with a thin film of solder before returning it to its holder. This thin film of solder will be oxidized instead of the surface of the tip, dramatically extending the life of the tip.
  - First, wipe the tip on a clean, slightly damp sponge to remove oxidation and excess solder. A coiled brass wire pad can also be used to remove excess solder.
  - Only use sulfur-free sponges that are intended for electronics applications.
  - Use deionized water to slightly wet the sponge, never use tap water (the addition of fluorides to drinking water may be beneficial to public health, but causes a multitude of problems in electronics assemblies).
  - Replace sponges at regular intervals and when they become dirty. Replacement sponges are inexpensive and this simple practice will help avoid introducing contaminates.
- When soldering, do not apply downward pressure on the joint being soldered. Simply rest the tip of the iron on the joint to help establish a heat bridge (a small bead of solder on the tip will also aid in forming a heat bridge). Downward pressure will not aid in solder reflow. It will, however, cause undesired mechanical stress on the connection area and may result in lifting the pad.
- The solder should be fed to the connection, not to the tip. Once a heat bridge is established, the connection will melt the solder and the solder wire should be moved around the connection to ensure adequate coverage.
- Finally, always turn equipment off when not in use and never use tips for purposes other than what they are intended. Any breaks or cracks in the plating of the tip that results from improper usage will drastically reduce the lifespan of the tip, or at the very least, interfere with its heat transfer capabilities.

Contact the EMPF at 610.362.1320, via email at helpline@empf.org or visit the website at www.empf.org for more information or advice regarding proper equipment care and preventative maintenance.

Ross Dillman | Technician/Instructor

Manufacturer's Corner: Test Research, Inc.

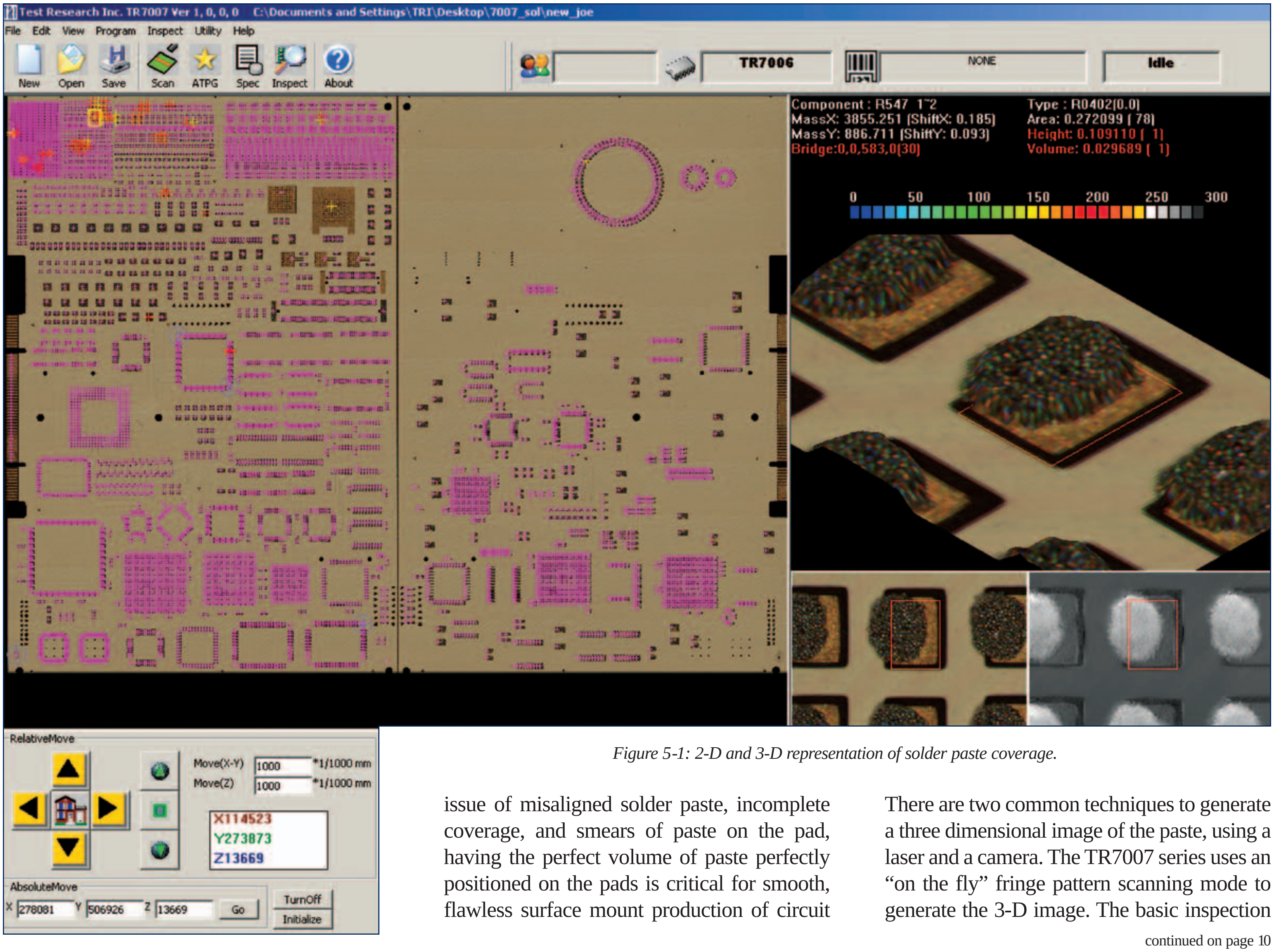
The TR7007 Ultra-High-Speed 3D Solder Paste Inspection System

The TR7007 automated solder paste system from Test Research, Inc. is an inline measuring system designed to provide very fast 3-D measurements of solder paste deposited on the pads of the circuit board. This inline machine is typically positioned between the stencil printer and the pick and place machine. According to studies, half of all surface mount build defects are caused by poor solder paste control in the stencil printing operation. The TR7007 machine inspects all of the paste placed on the pads of a circuit board. Since stencil printing is the first step in the surface mount assembly process, it is the correct place for inspections that can prevent poor connections as a result of small solder joints, lack of solder, and other solder paste errors.

This report will discuss the TR7007 in four segments: the performance justification, the technical requirements to perform a solder paste measurement on all the pads of a circuit board, the key technical elements of the measurement system, and the typical error conditions can be which identified.

High speed production lines can produce large quantities of expensive circuit boards very quickly. When you consider the reliability issue of misaligned solder paste, incomplete coverage, and smears of paste on the pad, having the perfect volume of paste perfectly positioned on the pads is critical for smooth, flawless surface mount production of circuit boards. The accurate measurement of the x,y alignment and volume of the paste is critical. Considering the operation of a high speed line two shifts a day, any rework can halt an expensive assembly line.

The process challenge is to assure that the paste is perfectly placed on all the hundreds to thousands of pads on a circuit board without slowing down the production line. Also, the operator must be provided with statistical process data to indicate trends in the coverage. To measure every individual pad requires a technology that can measure placement, coverage, and area at a rate of up to 171 cm^2/s with an accuracy of 14 µm.


Test Research Inc. TR7007 Ver 1, 0, 0, 0   C:\Documents and Settings\TRI\Desktop\7007_sol\new_joe

TR7006

NONE

Idle

Component : R547 1~2
MassX: 3855.251 (ShiftX: 0.185)
MassY: 886.711 (ShiftY: 0.093)
Bridge:0,0,583,0(30)

Type : R0402(0.0)
Area: 0.272099 (78)
Height: 0.109110 (1)
Volume: 0.029689 (1)

RelativeMove
Move(X-Y) 1000 *1/1000 mm
Move(Z) 1000 *1/1000 mm

X114523
Y273873
Z13669

AbsoluteMove
X 278081 Y 506926 Z 13669

Figure 5-1: 2-D and 3-D representation of solder paste coverage.

There are two common techniques to generate a three dimensional image of the paste, using a laser and a camera. The TR7007 series uses an "on the fly" fringe pattern scanning mode to generate the 3-D image. The basic inspection

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Electronic Packaging for Efficiency

The Navy has mandated cost reduction or cost savings for systems slotted for implementation on ships, submarines, and other naval equipment. Through the use of reliable and high efficiency electronics, the volume and weight can be reduced while increasing the power efficiency at a reduced cost to the taxpayer. The goal of the EMPF is to meet the warfighter requirements with innovative electronic manufacturing technologies.

Packaging technologies currently on the market offer some unique advantages over the older, larger, and more energy consuming devices on many of the naval platforms. This reflects not only the miniaturization trends of commercial electronics but also incorporates multiple functionalities.

System in Package (SiP)

Manufacturing technologies have made significant progress in areas of system in package (SiP) that maintain the same physical footprint of a single chip with equal power and performance, and at a competitive cost.

The advantages of SiP are:

- Combined mixed technologies by integrating several dies into a module such as logic, memory, mixed signals and passives
- Maximized interaction between the IC, interconnect, and the package

The SiP is able to accomplish this through high density integration - chip on chip technology and chip on substrate technology integrated into a proprietary silicon substrate or laminate. Essentially, SiP acts as a full sub-system enabling a modular architecture. Applications requiring radio frequency (RF) compatibility is an example where the modular approach produces benefits over the single packed IC. The current technology of applying packaged ICs and discrete components directly on the printed wiring board still exhibits the challenges of parasitics and isolation. SiP with integrated passive components and RF ICs, allow for high reactance to resistance ratio (Q) isolation substrates, which means low phase noise, lower power consumption, and excellent isolation, with fewer RF components. The result is a complete RF, baseband, and memory module that can be used in global positioning systems (GPS) and wireless local area network (LAN) cards.

Integrated Passives

The application of embedded passives as opposed to discrete components on modular assemblies has the added advantage of reducing the volume and weight. The array of devices can include resistors, inductors, and capacitors. Embedded resistors have the advantage of integrating custom shapes and sizes within the restive layers with values as high as 500 kΩ. Typically, a nickel chrome alloy is used as the material of choice for embedded resistors. In some cases, a tantalum silicon film is used. With a properly controlled lithographic process, a line width variability of ±2 µm can be achieved, giving tighter impedance control capability. Embedded high Q and choke conductors can push up to 200 nH of inductance with tolerances as low as 1%. There are now planar Marchand balun devices that can provide balanced inputs for low noise amplifiers (important for differential RF architecture). High Q metal-insulator-metal (MIM) capacitors can give a capacitance of 0.8 pF to 1600 pF with tolerances below 2%. Though these devices may not fully replace all of the discrete passives needed to achieve the performance criteria of many applications, they do reduce the weight and footprint of the assembly.

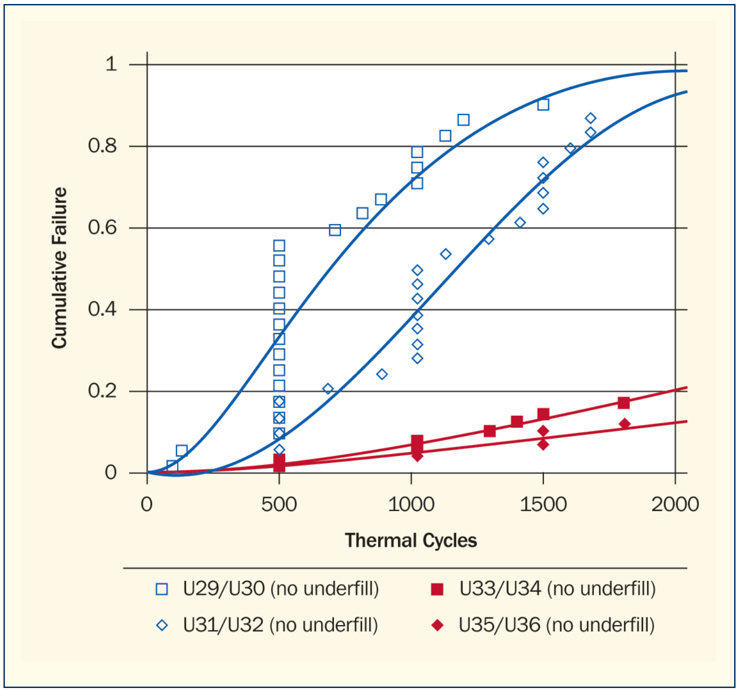

Figure 6-1: Thermal cycling performance of flip chips with and without underfill.

Flip Chip Technology

Flip chip technology has been around for some time, though its reliability in high stress applications where CTE (coefficient of thermal expansion) can play a major role in flip chip failure has impeded its acceptance as a substitute for wirebonding. With the advent of underfill materials (Figure 6-1), and alternate solder bumping methods of attachment, the prospects of failure due to CTE mismatch have diminished. Additionally, with the reworkable nature of the current underfills on the market, flip chip has become a more appealing option in applications where speed, RF performance, weight, and size are of consideration.

The EMPF training center has provided our valued customers important training, design, and packaging services to help them make the right electronic manufacturing decisions possible. For more information on training and engineering services, please contact the EMPF Helpline at 610.362.1320, via email at helpline@empf.org or visit our website at www.empf.org.

Carmine Meola | R&D Projects Lead

Advanced Materials for Thermophotovoltaic Devices

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source, radiator or filter, collector, and reflector (Figure 1-1). The radiator or filter control component acts to modify the emitter radiation to match the characteristics for the TPV diode. Proper matching between the emitter radiation and diode is essential for optimum efficiency of the system. The filter also reflects long wavelength photons back to the emitter to be reabsorbed. The radiator can be of two general types; broad or narrow band. Tungsten has been the choice in the industrial application because it is a refractory metal and it has good emissivity in the visible and near-IR range. Silicon carbide has been used for the broad band type because its emissivity is close to unity, it can withstand high temperatures, and it is inexpensive to manufacture. Several other materials such as ytterbium oxide, erbium oxide, and photonic crystals have been examined for use in narrow band radiators. While these rare earth materials have met with some success, more often a filter control of the source is used to select the wavelength for the diode. Photonic crystals are useful but right now are too expensive to manufacture and are not cost effective.

Since thermophotovoltaic systems have few, if any, moving parts they are small, quiet, and require low maintenance. They also have the potential for high energy densities, versatility in the choice of energy source, and will provide a continuous source of electricity if they are in contact with a steady source of heat. These properties make thermophotovoltaic systems suitable for use in the recovery of waste heat from consumer and industrial processes. The source of heat for a TPV device can theoretically be any source of heat, a flame, a concentrated solar array, or waste heat from a catalytic converter. However, since the most efficient devices operate at temperatures between 950°C to about 1350°C, there are limited sources of heat that can be utilized. Developing devices or systems that operate efficiently at lower temperatures will expand the uses of these devices.

The collector is typically manufactured from a low band gap semiconductor that produces an electrical current when exposed to infrared photons with energies that are above the band gap. Currently, the collectors with the lowest bad gaps are those made from indium phosphide arsenide antimonide (InPAsSb). InPAsSb have been manufactured by liquid phase epitaxy (LPE) and organometallic vapor phase epitaxy (OMVPE) but research into its use at lower temperatures is still being explored[2]. Early work on TPV diodes focused on silicon germanium diodes, however the conversion efficiencies were low. Recent work with gallium antimonide (GaSb) and quaternary gallium indium arsenide antimonide (GaInAsSb) have produced devices with band gaps from 0.4 eV to 0.72 eV. Currently GaSb diodes are the basis for most devices and are about 20% efficient. Indium gallium arsenide (InGaAs), another III-V semiconductor, has a band gap of 0.74eV when lattice-matched to an InP substrate. While not an improvement over GaSb, the band gap may be engineered by changing the ratio of In to Ga in order to absorb higher wavelength photons. This lattice mismatched InGaAs material with a bandgap of 0.55 eV provided the best experimental data for single junction cells. A sizeable efficiency improvement could be made in an InGaAs based TPV cell by monolithically combining two or more lattice mismatched InGaAs subcells on InP[3].

The large band gap lowering seen in low nitrogen fraction $GaAs_{1-x}N_x$ has led to the development of long-wavelength devices for IR lasers and PV cells. The lattice matched quaternary material $Ga_{1-y}In_yN_xAs_{1-x}$[4] has a band gap ranging from 1.42 eV to below 1.0 eV on GaAs and as low as 0.6 eV when strained to InP[5].

There are other lower band gap materials that are currently being developed are those using BiTe and quantum well technology[6]. Work with thin film, super-lattice, and quantum well materials currently holds the most promise for low band gap collectors. This would allow for harvesting at ambient temperatures in almost any application. The development of lower band gap semiconductors is essential for lowering the temperature range where these devices can be effective.

The filter/radiator serves to reflect the sub-bandgap photons back to the emitter and a mirror surface on the back of the diode reflects longer wave radiation back to the source, thus improving the system efficiency. It has been shown that TPV efficiencies of 27-28% can be achieved with the addition of back surface mirrors. The radiator/filter must be tailored to the collector in order for the system to operate efficiently. Work has been done using Yb_2O_3, photonic crystals, and rare earth materials but these must also be tailored to the specific collector. Work with the reflectors made from Zn diffusion process has improved the efficiency of the GaSb cells by recycling the energy in the long wavelength photons which occur in a higher percentage in low temperature applications.

The TPV system is a relatively simple one that has few components. Since the efficiency of the system depends on the efficiency of each part (radiator/filter, collector, and reflector), steps are taken to optimize each component. The technology in the semiconductor industry is close to making a device that can operate with some efficiency at lower temperatures, however, the materials and manufacturing costs are prohibitive at this point. Photovoltaic (PV) power has faced similar challenges in the past and still faces some of those challenges today. The start up costs of PV is high and the return of investment can take a long time. However, over the years advancements in manufacturing have driven down costs significantly while increasing the system efficiency. Materials such as hybrid solar cells and manufacturing techniques like roll-to-roll manufacturing will help PV become more and more competitive with other energy sources. The steps to making TPV efficient are similar to the ones facing PV today. Building on that technology and focusing on manufacturing an inexpensive TPV system holds the best hope for making this a viable technology.

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Mark Shinners | Senior R&D Engineer

Ask the EMPF Helpline!

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information on new technologies that could be used for diagnosing manufacturing defects.

For more information on our analytical and engineering services, please contact the EMPF at 610.362.1320, via email at helpline@empf.org or visit the website at www.empf.org.

Michael Barger | Senior Materials Engineer

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Materials Testing for High Efficiency Electronics

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Intermittent (tapping) mode is a cross between contact and non-contact modes where the cantilever tip is gently tapping across the surface. This mode is performed near the resonance frequency of the cantilever arm. Both strong attractive and repulsive forces are experienced by the cantilever tip as it approaches the sample. This is a compromise between the two extremes which results in minimal damage to the sample.

Electron microscopy is a valuable technique with high resolution for fracture analysis, elemental analysis, and phase identification. The scanning electron microscope (SEM) has an electron gun that provides a focused, collimated beam on the sample. Secondary and back scattered electrons are ejected from the surface of the sample to a nearby detector providing surface imaging on a resolution of one to 10 nanometers (depending on the instrument). Samples must be conductive or coated with conductive material to avoid surface charging.

When high-tech devices are under repeated use, failures may occur which must be examined under high magnification. Brittle and ductile failures can be easily identified by observing surface failure regions. Cross-sectioning is often used to provide even greater information for devices under repeated use.

An energy dispersive spectroscopy (EDS) detector can be attached as an accessory to the SEM. This detector can be used for elemental analysis of the sample. Phase identification can be made based on microstructure features and quantification of the elements present. Using a backscattered electron (BSE) detector, differences in atomic number (Z) can be identified by contrast in imaging. Atoms with larger cross sectional areas (high Z) have a greater tendency for elastic scattering to produce backscattered electrons. On the other hand, atoms with smaller cross sectional areas (low Z) have a lower tendency for elastic scattering to produce backscattered electrons. Therefore, the intensity of backscattered electrons will appear brighter for high Z atoms and darker for low Z atoms. During heating, materials in these devices will undergo various phase transformations. Using a BSE detector, one can determine phase transformation changes under different processing conditions.

Another electron microscope with even greater capabilities is the transmission electron microscope (TEM). Sample preparation is a time-consuming process which requires thinning the sample to hundreds of nanometers thick. The transmission electron microscope also has a collimated electron beam, but it passes through the sample providing a density based image below. Higher voltages are needed for TEM (than SEM) to enable the electrons to penetrate the sample and provide a higher resolution (0.2 nm to 0.5 nm). At this resolution, crystallographic defects can be observed such as dislocations (missing rows of atoms in a plane), stacking faults (a layered interruption in regularly ordered stack of atoms, i.e., ABCABABC), and twinning (boundary plane where two crystals of the same kind meet). Also, transmitted electron diffraction patterns can be obtained to understand the bulk crystallographic structure of the sample. Instead of being limited to an EDS detector, the TEM can utilize an electron energy loss spectroscopy (EELS) detector which can identify the element and the different oxidation states. An EELS detector can more easily detect lighter elements while EDS can be used to detect heavier elements.

Impurity levels are often important for layered structures. Secondary ion mass spectroscopy (SIMS) is an essential tool for examining trace elements in semiconductor thin films. The basic principle of this technique is to ion beam sputter the sample surface to examine the secondary ions. SIMS can operate using two modes: static and dynamic. In static mode, the sputtering rate is done slowly to examine an atomic monolayer on the surface. This mode allows for surface analysis with minimal sample damage. In dynamic mode, the sputtering rate is much faster allowing depth profiling and bulk analysis causing surface damage to the sample. As the primary ion source is sputtered onto the sample surface, some of the primary ions will ionize on the surface to produce secondary ions. The secondary ionization efficiency depends on the surface atoms. For electropositive surface atoms, an oxygen primary ion source will yield high secondary ionization efficiency. For electronegative surface atoms, a cesium primary ion source will yield high secondary ionization efficiency. Generally speaking, electropositive and electronegative atoms are on the left side and the right side of the periodic table, respectively. Therefore, it is important to use the appropriate primary ion source when analyzing the sample. The detection limit for trace element analysis is between 10^{12} to 10^{16} atoms per cubic centimeter.

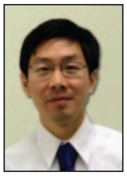
In summary, there are several techniques available to study the effects of processing on material properties in high efficiency electronics. However, all of these tools have their pros and cons which can determine which one will be more appropriate for the application. First, sample preparation must be considered prior to analysis. Some techniques require the sample to be sputter coated or sectioned. This will result in irreversible damage to the sample, but will yield information which may otherwise be unknown. Next, there are several different modes to operate each instrument which may or may not be applicable to the analysis. Knowledge of the sample is paramount in selecting the proper mode for each technique. Last, consistent analysis between samples is crucial to provide reliable data. Changing the mode, voltage setting, scanning area, or magnification between samples will make it difficult accurately compare all the data. It is recommended to determine the most suitable settings for analyzing the sample and keep them consistent. If a change is needed due to changes in sample composition, then it should be noted and documented for future reference.

continued on page 10

Materials Testing for High Efficiency Electronics

(continued from page 9)

The EMPF utilizes the latest equipment and techniques to study material properties such as those discussed here. For more information, please contact the EMPF at 610.362.1320, via email at helpline@empf.org or visit the website at www.empf.org.



Phillip Yu | Senior Materials Engineer

Manufacturer's Corner: Test Research, Inc.

(continued from page 5)

uses a camera based system with two lights to eliminate shadows. Using a triangulation principle and four-step phase shifting technology, the system measures the height, volume, and thickness of the solder paste and checks for bridging.

Visual images of the solder paste on the pads are presented in two ways: a 3-D grey scale image and a two dimensional color image. A microscopic version of the 3-D picture is also available, which is especially valuable for smaller components. For times when a problem condition may not show clearly in 3-D grey scale, a 2-D color image can convey stencil printing information very clearly (Figure 5-1).

The most common types of errors are slumped printing, bridging, scavenged printing, and peaking. Poor coverage is also common when the apertures of the stencil start to clog-up with solder paste (Figure 5-2). Without a measurement system, the task to examine each individual pad manually would be impossible.

Wherever possible, the precision, measurement, and repeatability of a production line should be built into the equipment rather than relying on operator inspection. Solder paste measurement was the last inspection to be automated because of the difficulty of a 3-D paste measurement at the high speeds required. The TR7007 has satisfied the requirement for a high speed inspection system with the necessary speed and accuracy.

For more information or demonstrations of the TR7007 ultra-high-speed 3-D Solder Paste Inspection System and other EMPF capabilities, please contact Mike Prestoy at 610.362.1200, extension 241.

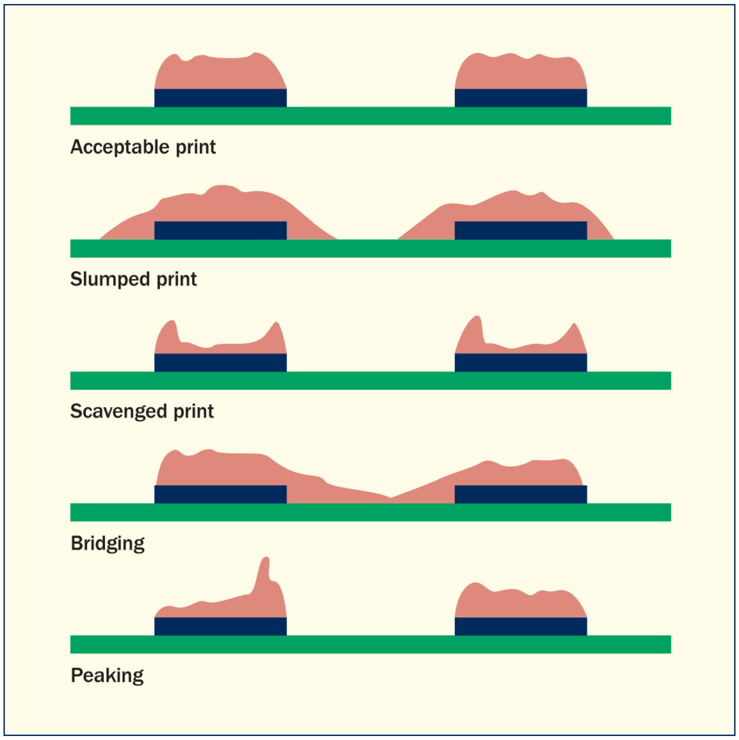


Figure 5-2: Solder paste conditions.

Mike Prestoy | Senior Applications Engineer

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Time: *8:30am - 3:00pm with complimentary lunch*

RSVP: *Katie Riggan by phone at 610.362.1200, extension 250*
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