empfasis

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The EMPF is a U.S. Navy-sponsored National Center of Excellence focused on the development, application and transfer of new electronics manufacturing technology by partnering with industry, academia and government centers and laboratories in the U.S.

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Wide Band Gap Technology Transfer

The department of defense (DoD) has identified Wide Band Gap (WBG) materials, especially silicon carbide (SiC) and gallium nitride (GaN), as key semiconductor materials for the next generation of electronic sub-systems for military needs. However, what was yesterday considered to be a unique military application, has become today's commercial opportunities.

Application: Wireless Telecommunication and Military Sensors

With extremely high thermal and chemical stability, and electrical performance, WBG devices are used for high frequency, high temperature, and high power applications such as radar, jammers/decoys, communications, and data link. For example, wide band gap amplifier modules fabricated with GaN will result in lower costs because the system will require fewer modules. These modules are capable of generating 8-10 times the power of gallium arsenide (GaAs) based modules. It is also anticipated that commercial demands for WBG, especially GaN material, devices, and components will increase exponentially during this decade. Many of these commercial opportunities will be created as a result of advances in materials and devices for the less demanding optical applications including traffic control, large area full color display, automotive, medical, illumination, and consumer electronics such as the wireless telecommunications, mass data storage, computing, and power industries.[1]

In the commercialization of WBG devices, issues such as producibility, affordability, supply bases, and manufacturing infrastructure become very important. Currently, the largest market for WBG semiconductors is in applications that rarely experience high temperatures. However, the number of applications that can utilize the high junction temperatures and high frequency capabilities of WBG devices is growing exponentially as the industry realizes the potential these devices have in fulfilling niches that silicon could not fill. Furthermore, all the developers worldwide share the same fundamental material and

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Wide Band Gap Technology Transfer

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device problems that must be overcome if yields are to reach acceptable levels.

As Jay Baliga's studies (at North Carolina State University) have suggested, “the performance advantages of SiC over silicon, in terms of reduced parasitic, faster switching speed, and reduced thermal management, could perhaps displace billions of dollars of the silicon-based solid-state power business. But the wafer defects such as SiC micropipe and dislocation densities still need to come down by at least an order of magnitude or two on mass-produced SiC wafers before this can start to happen.”

Materials development, epitaxial skills, and advanced packaging play critical roles in the design and fabrication of most WBG devices. Improvement of reliable WBG materials is crucial to advancing viable devices. An open market supply chain with affordable, steady supply of WBG materials is needed to obtain high quality bulk substrates and EPI wafers. While silicon-based technologies are expected to dominate applications up to 200-250° C, GaAs and WBG semiconductors (WBS) which include SiC, diamond, and group III nitrides (III-N) will play critical roles beyond 250° C, accounting for 16 percent of the high temperature electronics demand by 2005. Therefore, packaging technology and thermal management solutions have to be ready to execute system integration and to WBG drive technology transition. Developing new packaging and interconnection materials, designing effective cooling packaging systems to meet the required user performance criteria must be addressed to assure the manufacturable, repeatable, cost effective packaging solutions. Even though most of the material characterization techniques are well known, the reliability test parameters used in an accurate lifetime assessment for WBG systems are still under development. Thus, different tests need to be formulated at the die, package, and systems levels. To accomplish this, new configurations are needed to accurately simulate operation in a high temperature environment and retrieve meaningful data. Failure analysis, reliability and device performance degradation mechanisms, and package integrity are important phenomena that must be understood to assure the insertion of WBG technology into DoD systems and to commercialize the WBG technology.

Transition Panel

Rapid improvement of wideband devices, thermal management, and packaging technologies requires concurrent development in each of these areas. To facilitate this, constant exchange of information must occur between device producers, thermal management experts, packaging developers, and end users. The American Competitiveness Institute has put together a series of Wide Band Gap Panel meetings to discuss the requirements of DoD systems, status of the technology, and other issues related to WBG development and implementation. These meetings allow direct interface between the end user and the supplier without divulgence of sensitive information. Some of the topics discussed during the panel discussions include immediate radar applications for wide band gap devices, the status of SiC MESFETs for power applications, and reliability testing methods for high temperature devices.

[1] *Edgar Martinez. “GaN initiative” 2001.*

About the EMPF

The Electronics Manufacturing Productivity Facility (EMPF) was established in 1984 to aid the electronics industry in improving electronics manufacturing processes required in the manufacture of military systems. Today, the EMPF operates as a National Electronics Manufacturing Center of Excellence deriving its resources from a consortium of industry, university and government participants led by the American Competitiveness Institute (ACI). The EMPF serves as a corporate residence of expertise in electronics manufacturing. The EMPF's principal goals are to: improve responsiveness to the needs of DoD electronics systems; ensure that deliverables make a significant impact in the electronics manufacturing industry; facilitate the development and transition of technology to the factory floor; and, expand the customer base to a national level.

The EMPF operates in a modern facility adjacent to the Philadelphia International Airport with easy access from I-95. The facility houses a 10,000 square foot demonstration factory; fully-equipped classrooms; an analytical laboratory for materials and environmental testing; conference and lecture rooms with video conferencing capabilities; and an easily accessible technical library. The EMPF offers many electronics manufacturing ser-

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MMIC Flip Chip

The next generation F/A-18 Radar and a number of other Department of Defense (DoD) programs require microwave subassemblies that are currently costly and difficult to assemble. If these programs are to meet their cost and schedule targets it is critical that new processes be developed to manufacture the required assemblies. This manufacturing process improvement project supports the Navy's F/A-18 Active Electronically Scanned Array (AESA) program for Low Rate Initial Production (LRIP).

ACI is starting the Monolithic Microwave Integrated Circuit (MMIC) Flip Chip MANTECH program. The F/A-18 Program Office PMA 265 and Raytheon Electronic Systems are also involved in this effort. ACI will manage the program and perform reliability testing on assembled test boards, the F/A-18 Program Office PMA 265 is the stakeholder and will insure that the project results will be acceptable, while Raytheon Electronic Systems, El Segundo, CA is the major subcontractor and will be bumping the flip chips and performing reliability testing at the bump and assembled board levels. The critical issue will be maintaining high tolerance with bumps in addition to reliability.

Figure 1. F/A-18 Hornet

A critical technology in the program is the direct attachment of MMICs to a substrate (usually low temperature cofired ceramic). The flip chip package allows the MMIC to be mounted on a substrate without further electrical connection such as wirebonds. This method will reduce the costs of these critical components by 15 percent. The flip chip method improves the reliability over wirebonding through lower operating temperatures, and also improves the performance by lowering parasitics by shortening the signal path.

A key reason for the undertaking of this project is that Raytheon has tested a new manufacturing process for bumping GaAs wafers. The bump process uses a plated silver "thermal bump" as the chip/substrate connection. This thermal bump lowers junction temperatures in power devices by 10^{o} C below the more traditional solder or gold bump connection materials. The bumping part of this project has already been demonstrated.

The direct attach or flip-chip approach has been developed but is currently limited to pilot scale production. To meet demand as the F/A-18 AESA radar moves to LRIP, as well as to support other programs, the process must be automated to increase volume by at least ten times and at the same time reduce cost. The desired rate of 48 systems per year cannot be sustained using the current pilot scale production. Another key aspect of this program is the licensing and transfer of the bumping technology to a commercial foundry. This will ensure that the Navy has an affordable, long-term supply of MMIC flip chips to support its future needs.

ACI, through the EMPF, will be verifying the manufacturability of the bumped flip chips and will be performing reliability testing on assembled test boards. Attachment of MMIC flip chips starts with printing solder paste on the substrate. Due to the small size of the bumps, a stencil with small apertures will be used. This may necessitate the use of type 4 solder pastes. After reflow, the solder connections will be inspected by transmission X-ray. The final step in the board assembly process will likely be cleaning. Manufacturing parameters to be investigated include placement accuracy tolerance, placement force, ability to rework, and cleaning method.

Environmental tests include thermal cycling (-55^{o}C to 125^{o}C), thermal shock, temperature/humidity testing and mechanical shock and vibration. Additionally, in situ monitoring of the connections will be done during thermal cycling, so that identification of number of cycles to failure of each flip chip will be known.

Failure analysis will follow to investigate failure modes and to determine methods to improve the manufacturing process of the MMIC flip chip assemblies. Flip chips will be micro-sectioned and examined with scanning electron microscopy and elemental dispersive spectroscopy to locate any failures and/or defects. Conclusions and lessons learned will be compiled and reported to the Navy as to improve future manufacturing initiatives using MMIC flip chips.

The potential cost savings of this program is $8.6 million per year for the F/A-18 AESA radar application alone. Other potential applications include programs supporting radar technology insertion, other DoD communications, and commercial communications.

Chemical Testing at the EMPF

Ion Chromatography

The EMPF performs ion chromatography (IC) analysis on electronic assemblies. This technique is used to measure cleanliness of assemblies, components, and bare board with precision. IC can determine the precise amount of F, Cl, Br, NO_2, NO_3, PO_4, and SO_4, down to 0.5 mg/cm^2. A common test method employed by the EMPF is the IPC TM-650 2.3.28. The EMPFhas analyzed thousands of assemblies, components, and bare boards using this technique.

Resistivity of Solvent Extract (ROSE)

The EMPF performs Resistivity of Solvent Extract (ROSE) analysis on electronics assemblies. This technique is used to measure the cleanliness of assemblies, components, and bare boards. Bulk ionics are measured according to their conductivity in solution and referenced to a sodium chloride standard. A common test method employed by the EMPF is the IPC TM-650 2.3.25. The EMPF has analyzed thousand of assemblies, components and bare boards using this technique.

Fourier-Transform Infrared (FT-IR) Spectroscopy

The EMPF performs FT-IR spectroscopy on a variety of sample types using both transmission and reflective modes as well as FT-IR microscopy on a routine basis. This technique is an excellent tool for examining organic materials such as adhesives, polymers, plastics, etc. The EMPF can obtain FT-IR spectra on surfaces, powders, liquids, and semi-solids. Common test methods include IPC TM-650 2.3.39B and ASTM methods. The spectra that are generated can then be analyzed against thousands of compounds in our spectral database and commercial spectral databases. This library search can be used to identify the compound being sampled.

Ultraviolet-Visible (UV-Vis) Spectroscopy

The EMPF performs both transmission as well as reflective UV-Vis spectroscopy on liquids and surfaces. UV-Vis spectroscopy is a technique that measures the amount of UV-Vis light absorbed by the sample of interest. Our spectrometer can operate from 230 - 1100 nm and is calibrated against a NIST traceable white reference standard. The EMPF has developed UV-Vis chemometric techniques that are applicable to the electronics and aerospace industries.

Sequential Electrochemical Reduction Analysis (SERA)

The EMPF has the equipment to analyze the surface oxides and sulfides on metals using sequential electrochemical reduction analysis (SERA). Any metal oxides or sulfides that are present on the surface can be identified and a thickness determined (within 50 angstroms). This technique can be used to identify and differentiate between SnO, SnO_2, Cu_2O, CuO_2, $Cu_xSn_yO_z$, Ag_2S, etc. The EMPF participated in the development of this technology and continues to employ this technology in failure analysis and surface analysis.

Reduced Oxide Solderability Activation (ROSA)

The EMPF has a process available that removes any metal oxides that may be contaminating a surface, Reduced Oxide Solderability Activation (ROSA). This technique was developed to remove the oxides and sulfides that inhibit solderability such as, tin (II), tin (IV), copper (I), copper (IV), and silver oxides and sulfides. The process is electrochemical and takes place in an aqueous solution. The process is rapid, a typical treatment takes less than one minute. The samples are rinsed in deionized water and are immediately available for processing. The EMPF has reconditioned thousands of components and printed wire boards that have been used in assembly of various military and commercial systems.

Wetting Balance Testing

Solderability is vital to producing quality electronic assemblies. The EMPF performs quantitative solderability testing as well as qualitative dip-and-look tests. The tests can be performed on leaded components, chip components, wires, and coupons, with the results compared to established evaluation standards such as the J-STD 002 and 003, as well as IEC-68-2-69 among others.

Optical Microscopy

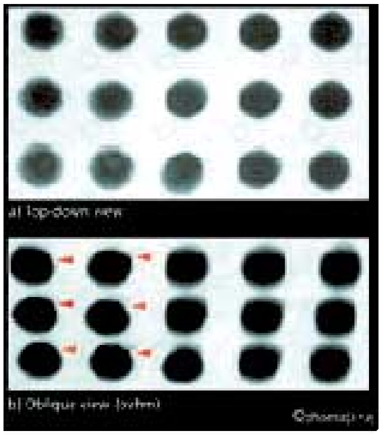
Optical microscopy at the EMPF is often coupled with digital imaging and analysis. ACI performs such tasks as dimensioning, annotation, archiving, and standardized inspections (e.g. IPC, MIL spec, and JEDEC). The EMPF specializes in bright field illumination and metallic contrast imaging using an inverted stage metallograph. Using various forms of optical microscopy, the EMPF examines components, circuit boards, solder, material microstructure, contamination, defects and anomalies, and other electronic materials at 2 to 1500 times magnification.

Metallurgy

Using SEM, EDS, optical microcopy, and SERA, EMPF engineers investigate many of the metallurgical issues involved in electronics packaging. Metallurgy is used to study diffusion, intermetallic formation and growth, contamination, morphology, thermodynamics, and kinetics involving a number of electronics related metals, ceramics, composites, and semiconductors. This information can be used to study failure modes.

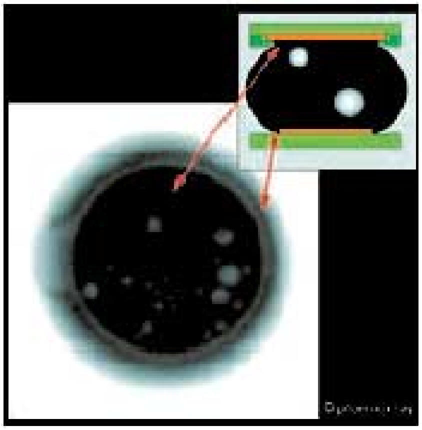
X-ray Inspection in Electronics Manufacturing

In today's electronics manufacturing, it has become common place for companies to use an X-ray inspection machine on a daily basis. The reason for this is that new packaging with small pitch components and BGAs makes it impossible to accurately inspect boards with a simple visual inspection. There are several different types of X-ray-based inspection systems including two- and three-dimensional, as well as X-ray laminography and tomography. This article will explore common defects and what to look for in an X-ray inspection.



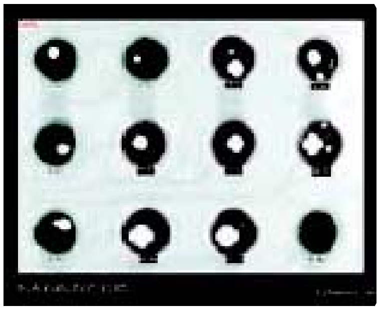
On the top there are 15 joints in the top-down view. Some of them at the lower left appear slightly brighter and broader showing signature of opens. At the bottom, the display in oblique view allows opens to be clearly identified.

Two-dimensional X-ray inspection systems, used by most manufacturers, are a viable and cost effective solution. These systems are suitable for accurate inspections. The two-dimensional inspection is done using a top down view that is fixed. The board is placed between the source and the image intensifier and inspected for shorts, opens, defective printing and insufficient reflow and wetting problems. The resolution is affected by the focal spot and its size. The magnification, which helps to resolve errors, is usually 200-400X and may go as high as 1,400X in ultra high resolution systems. Two-dimensional X-ray systems, with oblique view at highest magnification (OVHM), use an open tube source that provides a high irradiation angle vs. the narrow top down topology. This method maintains magnification during board rotation and tilting for BGAs and other fine pitch devices. The two-dimensional system is good for single-sided boards but has a problem differentiating components on a double sided board.



Dark rings at the edges of the pads pointing to additional solder in the area.

Three-dimensional X-ray imaging systems are used for the inspection of double sided boards. These systems are particularly useful when inspecting a double-sided board with BGAs directly across from each other on opposite sides of the board. Three-dimensional imaging systems use the same basic principals as the two-dimensional OVHM systems with the exception that a three-dimensional system allows the source and the detector to move simultaneously and lets a software engine capture several images to compile a three dimensional image. This action allows the image to be viewed in a slice-by-slice analysis. This takes a little longer but gives a more accurate image for inspecting solder joints and components. The three-dimensional systems magnification is not as good as the two-dimensional because the it is limited to 2-10X magnification.



The maximum accepted percentage of voids should not exceed 10%; more than 25% voiding are classified defect. Modern image processing software recognizes the number of joints affected and the size of voids to provide process control or improvement.

Classical laminography is based on a relative motion of the X-ray source, the detector, and the object. The X-ray source and detector are either moved synchronously in circles or are simply translated in opposite directions. Due to that correlated motion, the location of the projected images of points within the object also moves. The focal point will always be projected at the same location; therefore, a sharper image is the result. Objects either above or below the focal point will be permanently shown in different locations and with a less sharp image.

Digital laminography is the same as classical laminography with the exception that a digital X-ray can hold multiple images at one time, providing a clear image of the component overall, not just a slice at a time. Overall digital laminography is a suitable inspection technique for printed circuit boards with BGAs and other flat components.

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X-ray Inspection in Electronics Manufacturing

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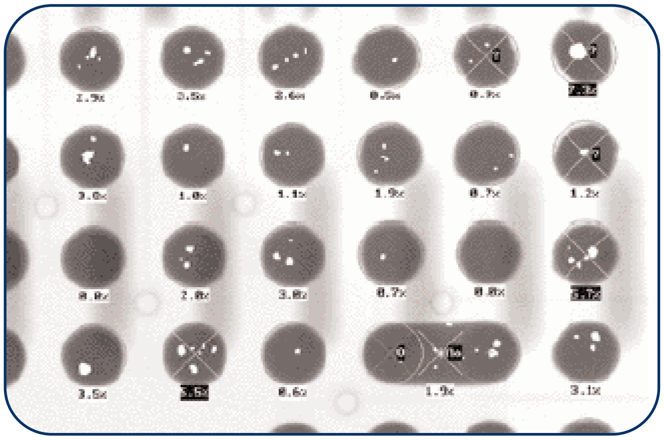
The types of defects found using X-ray systems include shorts, opens, defective paste prints, broken wire bonds, internally cracked components, broken traces and wetting issues on BGAs as well as misaligned or skewed parts. The most basic of these defects are the shorts and misalignment, which can be detected by an operator via the overview image. A short will show up as a dark line connecting two joints or more. The misalignment defect can be found easily by noting the angles of the ball joints in the corners of the component. The more difficult defects such as opens and broken traces can be found using a higher magnification and oblique angle views.



Typical results of an automated BGA evaluation (PBGA 352) after auto set-up: 3 solder joints deviate from a true circle by more than 13%, 1 solder bridge is present and 2 solder joints have over 5% voids.

The EMPF provides X-ray inspections with all of our manufacturing work and rework, as well as engineering functions such as reverse engineering, rapid prototyping, failure analysis and other testing needed in the electronics industry today. For more information on X-ray inspections, please call the EMPF Helpline at (610) 362-1320.

References

SMT magazine "3-D or 2-D: Choosing Today's Technology." Holger Roth, May 2001.

Digital Computed Laminography and Tomosynthesis, S. Gondrom, S.Schropfer, D. Saarbrucken, March 15, 1999.

Figures "More than counting black Dots" Dr. Holger, Roth Feb 2002.

About the EMPF

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vices and capabilities to DoD Program Managers and the U.S. electronics manufacturing industrial base. The EMPF's resident technical staff, most of whom have advanced degrees, consists of the nation's leading electrical engineers, mechanical engineers, materials scientists, chemists, physicists, instructors and technicians. The EMPF staff is dedicated to the advancement of environmentally safe electronics manufacturing processes, equipment, materials and practices; flexible electronics manufacturing technologies; and workforce competency in advanced electronics manufacturing technologies.

The EMPF maximizes its technology impact through the use of its successful national R&D and technical transfer/deployment networks who work with a variety of industrial, academic, and government organizations. This structure enables the EMPF to highly leverage these existing technical relationships to deliver innovations to a broad base; provide the key link to the factory floor; and, to systematically identify new ManTech requirements for the benefit of DoD.

The EMPF receives invaluable guidance from its Industrial Advisory Board, which consists of representatives from major Defense manufacturers. The Board provides important feedback to ACI ensuring that the key electronics manufacturing issues are identified, documented, and represented on the research agenda of the Center. This ongoing joint Industry/DoD participation is the cornerstone of the successful EMPF model.

The EMPF's modern Demonstration Factory is an important link to the factory floor. The Demonstration Factory is supported by many electronics manufacturing equipment manufacturers who supply millions of dollars of the latest in electronics manufacturing equipment for use at the EMPF. The EMPF's Equipment Advisory Board consists of representatives from many of the leading electronics manufacturing equipment firms in the country who provide guidance and resources to the EMPF. This partnership ensures successful technology transfer and deployment, which is a critical milestone of all research endeavors.

ACI American Competitiveness Institute

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TECH TIPS...

Implementing Lead-Free Soldering

Lead-free soldering is a technology that is gaining momentum in the electronics manufacturing world. Pending legislation in Asia and Europe have electronics manufacturers developing and implementing lead-free soldering. The American Competitiveness Institute (ACI) has performed research on this subject, having completed several lead-free production runs. The following is a brief primer on issues that one has to consider when implementing lead-free soldering processes.

Solder Alloy	Peak Reflow Soldering Temperatures
SnPb	220 ^{o}C
SnAgCu	235 ^{o}C
SnCu	240 ^{o}C
SnBi	160 ^{o}C

Table 1. Examples of Reflow Soldering Temperatures For Specific Solder Alloys

- **Lead-Free Solder Paste Alloys:** There is a wide range of lead-free solder paste alloys available. In general, lead-free alloys have higher soldering temperatures than SnPb (Table 1). The most popular range of alloys is in the SnAgCu family for SMT manufacturing. Eutectic SnCu has been recommended for wave soldering applications. SnBi alloys have shown promise in commercial applications due to their low soldering temperature. However, in high reliability applications with severe thermal requirements (-55^{o}C to 125^{o}C), SnBi does not perform as well as SnAgCu or SnCu. In addition, Bi when exposed to Pb can form a low temperature intermetallic which can reduce solder joint thermal reliability.

- **Moisture Sensitivity:** Due to the higher temperatures associated with many lead-free alloys, the requirement for baking out moisture sensitive components and board materials become even more important. Studies performed by Lucent and the Lead-Free Components Focus Group have found that plastic components will lose 1 to 2 levels of moisture sensitivity when exposed to lead-free reflow soldering temperatures up to 260^{o}C as opposed to 220^{o}C for SnPb solders. Failure to bake out moisture sensitive hardware will result in failures due to delamination ("popcorning") and measling.

- **Component & Board Finishes:** There are several component and board finishes available. Lead-free board finishes, such as OSP, NiAu, and Immersion Sn, are currently available from most board suppliers. Component manufacturers are beginning to offer lead-free component finishes. NiPd, Sn, SnCu, and SnAgCu are a few component finishes being offered. Component finishes are based on market demand placed on the component manufacturer. Depending upon the interaction between the solder alloy, component finish, and board finish, there is a possibility of material incompatibilities. However, the Lead-Free Components Focus Group found minimum thermal reliability effects from solder paste alloy, component finish, and PWB finish variable combinations.

- **Screen Printing / Component Placement:** Some good news. From a screen printing and component placement perspective, lead-free solders perform as well as their SnPb counterparts.

- **Reflow Soldering:** The peak temperatures for many lead-free solder alloys range from 240^{o}C to 260^{o}C (Figure 1). Thermal profiles with higher peak temperatures will be required. New reflow soldering equipment can support the higher temperatures associated with lead-free solders, but what about current reflow soldering equipment. Depending upon the equipment's vintage, current reflow soldering equipment may not be able to support lead-free soldering. Equipment that can support lead-free soldering temperature requirements will require additional preventative maintenance.

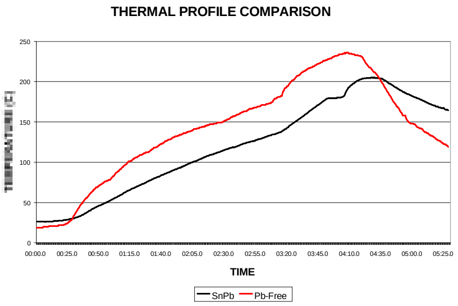

Figure 1. SnPb versus Lead-Free Reflow Soldering Profile

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Implementing Lead-Free Soldering

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An option would be to reduce the belt speed through the reflow soldering oven. The lower the belt speed, the higher the temperatures reached within the oven for a given thermal mass. However, the lower the belt speed, the longer the exposure to the higher reflow soldering temperatures. This longer exposure may damage the components and boards. The lower belt speed will also reduce the reflow soldering oven output.

Many lead-free solders do not wet as well as SnPb. Therefore, to improve wetting, reflow soldering should be performed in an inert atmosphere.

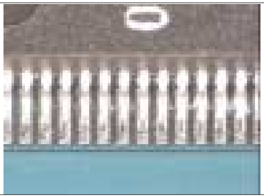
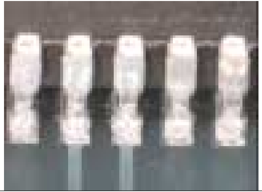
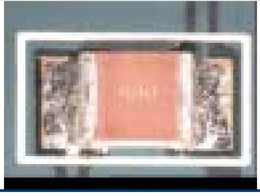
Production Conditions	Images
Leaded SMT Device • Alloy: SnPb • Board Coating: HASL • Reflow Atmosphere: Air	
Leaded SMT Device • Alloy: SnAgCuSb • Board Coating: NiAu • Reflow Atmosphere: Air	
Chip Resistor • Alloy: SnAgCu • Board Coating: OSP • Reflow Atmosphere: Air	

Figure 2. Visual Inspection Examples

- **Wave Soldering:** ACI soldered lead-free and SnPb hardware on comparable production quality wave soldering equipment. The lead-free solder required more aggressive solder flux than SnPb. While the solder pot temperature for both alloys were set at 260°C, lead-free solders required higher preheat temperatures than SnPb.

  Lead-free wave soldering should be performed in an inert atmosphere to improve solder wetting and reduce the amount of dross.

- **Cleaning:** It has been ACI's experience that no-clean lead-free solders leave minimum residues as their SnPb counterparts. However, many solder suppliers are using more active solder fluxes with their lead-free solder pastes to improve wetting. While these fluxes do open the processing window, the residues left on the hardware after soldering are harder to remove. To remove these residues, a more aggressive cleaning process may be required.

- **Visual Appearance:** Lead-free solder joints look different that their SnPb counterparts. Lead-free solders will have a dull grainy appearance. The IPC are beginning to change their visual inspection guidelines to take this feature into account (Figure 2).

- **Thermal Cycling Reliability:** Based on the Lead-Free Components Focus Group, it was determined that lead-free solder joint reliability is equivalent to SnPb solder joints for 2,000 thermal cycles, with temperatures ranging from -55°C to 125°C. Failure distributions for LCCC and area array component types found to be similar to other industry studies using similar test conditions. Of significance is that wave soldered hardware built by ACI, with a SnAgCuSb alloy, went through 2,000 thermal cycles without failure.

Despite these process differences, ACI successfully manufactured highly reliable hardware which meets IPC J-STD-001C Class 2 and Class 3 inspection criteria using lead-free solder. For additional information, contact the EMPF Helpline at (610) 362-1320.

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Manufacturer's Corner

VJ Technologies

The EMPF uses the VJ Electronix (a division of VJ Technologies, Inc.) X-ray system for all BGA device inspection and to pre-prep our samples for micro sectioning, SEM inspection and failure analysis. Analysis includes faults such as broken traces and wire bonds, cracked vias in a PCB, BGA/fine component alignment, shorts, voids, opens, wetting/de-wetting issues, etc. Using the 3D imaging software, we are able to pin point location and severity of voids and detect variations in BGA sphere sizes. In addition, by entering the proper inspection parameters, the BGA analysis software can compare sphere sizes and determine percentage of deviation of the size, percentage of voiding and number of voids.

The EMPF is using this system for the MEMS (Micro Electronic Mechanical Systems) project for the Navy and the Army's CECOM communication project.

The EMPF uses the VJ Electronix X-Ray system for all BGA device inspection as well as pre-preping samples for microsectioning, SEM inspection and failure analysis.

The Advantage

For years, production of through-hole assemblies included manual visual inspection after soldering, then electrical component testing (in-circuit) and finally functional testing to verify PCB assembly performs as designed. Visual inspection has become increasingly difficult with the implementation of surface mount technology (SMT). SMT allows for increased circuit density over through-hole technology on a printed circuit board by the use of smaller IC packages and smaller leads. With the use of Ball Grid Array (BGA) components, the solder joints are under the body of the device and are not visible for manual inspection. X-ray has become the industry standard for BGA solder joint inspection. X-ray images of solder joints can be analyzed to identify defects, such as insufficient solder, voiding, shorts, opens, etc. These solder type defects typically make up the majority of total defects found on a printed circuit board.

X-ray has a unique advantage over other test technologies: Materials absorb X-rays proportional to their atomic weight. Materials made of heavier elements absorb more X-rays and are easily imaged, while materials made of lighter elements are more transparent to X-rays. Solders used in electronic assembly are made of heavy elements, such as tin, lead, silver, bismuth and indium. Most other materials used in electronics are made of lighter materials such as carbon, aluminum, silicon, copper, etc. Therefore, X-rays have a unique advantage for generating images of solder joints: The solder shows up extremely well, while the PCB board, silicon IC and component leads become barely visible. This simplifies the analysis of the solder joints. A bonus comes from the transmissive nature of X-ray imaging. Unlike visible light used in automatic optical inspection, X-rays are not reflected to make an image but go through the board (and components), and form an image on a detector on the other side. This X-ray "Vision" allows hidden features to be examined, i.e., BGA's and other array style packages, the heels of solder joints on fine pitch packages, device wire bonds and the internal characteristics of the solder joints themselves.

The real advantage is the ability to find hidden defects. For instance, PCB assemblies with defects not optically visible are the obvious fit; specifically, products with Micro BGA's, BGA's, CSP's or components under RF shielding. Many PCB assemblies fall into this category due to the increasing popularity of array style packaging. Cellular phones and wireless communication products are placing RF shielding over unsoldered components at

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Manufacturer's Corner - V.J Technologies

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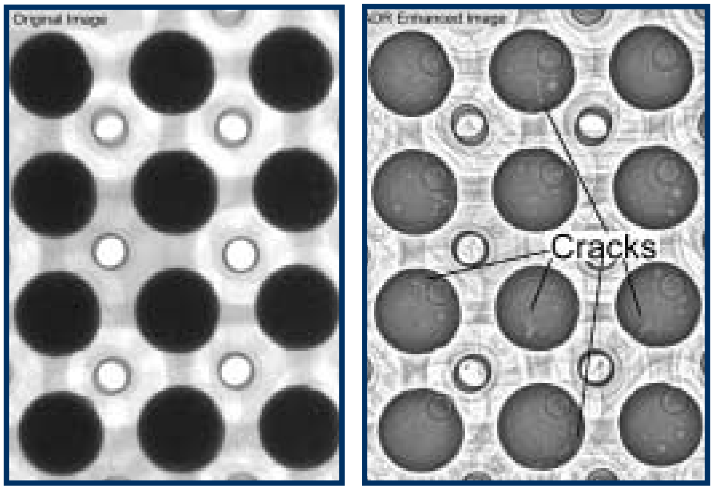
pick and place, using the reflow process to solder them to the PCB assembly. X-ray inspection is the best way to isolate soldering defects obscured by the shields.

Figure 1 depicts the same image; one without the enhancement of the X-ray image using Advanced Defect Recognition (ADR) and one with the enhancement. ADR produces an image that shows practically all defects automatically in a single pass.

How it Works

There are three primary components involved in an X-ray system that a potential customer must consider:



Figures 1 - The original picture shows the vias and solder balls. The ADR enhanced image shows all the voids in the solder balls, vias and details of the sample.

- The first is the X-ray source. The proper source must be compatible with the customer's specific need.
- The second element is the actual object to be X-rayed.
- The last item is choosing the proper detector, which must be appropriately suited to particular applications such as BGA, welds, castings, etc.

An X-ray system converts electrical energy into X-ray energy as specified by the user and it directs the X-rays toward the item under inspection. The system, in its simplest form, consists of at least the X-ray tube, the high voltage generator, and the control equipment containing a kilovolt meter and a milli-ampere meter.

The X-ray generator converts the electrical power (120, 208 or 240 VAC) into high voltage power. The X-ray tube requires the high voltage power to produce the X-ray beam, which is accomplished by imposing a high voltage between the (-) cathode and the (+) anode of the tube.

Whenever electrons are produced at the negatively charged cathode and accelerated toward the anode, they strike the positively charged target area of the anode to produce X-rays. The two crucial components in a generator are the transformer and the rectifier. A transformer uses the principle of magnetic induction to change the magnitude of an AC voltage. Most X-ray systems have an 'auto-transformer', which changes the voltage by a factor that is variable, usually controlled by a knob or an electric motor. The second crucial component, the rectifier, is a tube or semi-conductor device that lets the current flow in one direction only. The control panel happens to be one of the two places where the machine operator can control the X-ray beam. The operators find themselves in a position, which allows them to select predetermined settings of X-ray exposure and to initiate the exposure.

The second place where the X-ray machine operator can control the X-ray beam is at the beam intensifiers-filter, collimator, cone or compensatory filter. The operator is allow to direct and limit the X-ray beam to the area of interest but they also provide the capability of altering the X-ray beam by introducing devices or accessories to shield radiosensitive areas of the item under inspection. The simplest example of a beam modifier is the variable-aperture beam-limiting device consisting of one or more lead shutters that restrict the beam to the size of the cassette or to the area of interest

Historical Point

Industrial radiography began in the early 1920s and came of age during World War II due to better quality inspection requirements for high performance fighter planes. Film-less radiography in the form of fluoroscopy was successfully tried for the first time to inspect the aircraft's parts. The future of the non-destructive testing industry looks bright in view of the emphasis on achieving reliability in materials and processes for the space, medical and military industries in particular.

The EMPF will utilize this system for the MEMS (Micro Electronic Mechanical Systems) project for the Navy with L3 as well as the Army's CECOM communication project.
If you would like to see a product demonstration, please call Jeff Stong at (610) 362-1200 x224.

Ask the EMPF Helpline!

CUSTOMER ISSUE: A customer experienced intermittent failures of PLCC socket connections on PWB's. These failures appeared as open circuits corrected by force exerted on components/sockets or by exposing the PWB to a torsional (twist) force. The component leads and socket pins use a 95% tin (Sn), 5% lead (Pb) surface finish.

The EMPF Helpline Reccomendation

The initial investigation established that the mechanical connection between the socket and the IC lead were intact. No metallic contamination was detected. Microsectioning, scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS) and optical microscopy were used. Further examination of the lead revealed rough, scraped areas of the surface as well as a hazy undamaged segment of the surface, indicating normal mechanical interface characteristics in most cases. Mechanical failure (creep) and/or fretting corrosion were then considered as the failure mode.

Mechanical Failure (Creep)

Typically, upon insertion of a component into a connector, a normal (perpendicular) force is applied that prevents movement. The stress created by this force is translated to the lead. The leads (connector pin) bend in time to relieve this stress. This effect, termed creep, can reduce conductivity. Coplanarity of leads is used to test for creep.

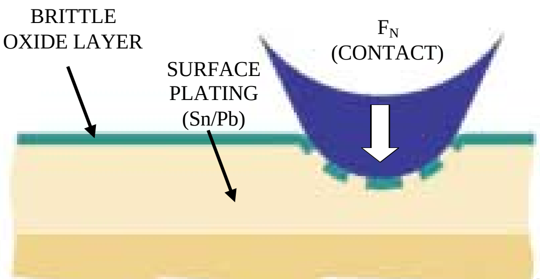


Figure 1. Illustration of the disruption of the oxide layer on a tin/lead surface.

PLCC packages were removed with an extraction tool. The components were photographed and planarity of the leads evaluated. None of the samples evidenced planarity defects.

Fretting Corrosion

Non-noble surface finishes such as Sn/Pb oxidize when exposed to atmospheric conditions, creating a non-conductive film which increases the resistivity of the junction. These oxide layers are brittle, but the Sn/Pb layer beneath remains ductile. When the component is inserted into the socket, the insertion forces disrupt the oxide layer and tin/lead is exposed, creating direct metallic contact. (See Figure 1)

Fretting corrosion occurs when repeated mechanical disturbance takes place. As the lead and socket pin displace relative to each other, an exposed area is formed that becomes oxidized. When the component returns to its initial location the oxide layer is again broken. As this cycle repeats, the oxide layers accumulate causing increased electrical resistance and eventual insulation at interface.

If you have an electronics manufacturing problem, call the EMPF Helpline at (610) 362-1320

The movement required for fretting corrosion may be extremely small. Sources of micro-movement in the circuit boards examined by the Helpline included cooling fan, environmental vibration and thermal cycling. The interface conductivity can degrade after only hundreds of cycles depending upon the environment and other factors. Macro-movement, such as pushing down on the component or twisting the circuit board may restore conductivity, but the cycle of fretting corrosion resumes.

Summary/Conclusions

Visual inspection of the solder joints revealed no cracks or exterior defects. The good quality solder of the joints focused the investigation on contact between the component lead and the connector pin.

After optical analysis and evaluating planarity of the components, fretting corrosion was determined to be the cause of the failures. The fretting is often corrected by flexing of the board or pushing on the components in the socket. These motions temporarily remove the build-up of oxide at the interface of the connector pin and the component lead. Auger analysis confirmed that fretting was present.

High component density may contribute to the fretting mechanism. This increases thermomechanical stresses resulting in expansion and contraction at the lead/pin interface, disturbing the surface oxide and accelerating the accumulation of tin oxide.

Recommendations

The Helpline recommended two approaches to preventing fretting corrosion:

1-Increase the connector mating force, thus increasing the friction of the interface and reducing displacement during thermal cycling or vibration.
2-The use of an anti-fretting lubricant to increase reliability.

To further increase reliability, noble finishes such as gold or palladium with a gold flash could be used for the pin and component finishes. These surface finishes are more durable than tin-based and are equally conductive.

American Competitiveness Institute - EMLC COURSE SCHEDULE

Electronics Manufacturing

Electronics Manufacturing BOOT CAMP A - Week 1
Oct. 28-Nov. 1
Jan. 27-31

Electronics Manufacturing BOOT CAMP B - Week 2
Nov. 4-8
February 3-7

Skills

SMT Soldering/Rework
Nov. 18-22

BGA Manufacturing, Inspection & Rework
Oct. 7-8
Feb. 24-25

Advanced Packaging Techniques
Oct. 9-11

Chip Scale Manufacturing
Jan. 22-24

Certifications

IPC J-STD-001 Instructor Certification
Oct. 14-18
Jan. 6-10
Feb 24-28

J-STD-001 Instructor Recertification
Nov. 4-5
Feb 10-11

IPC Challenge
Nov. 6
Feb 12

IPC-A-610 Instructor Certification
Oct. 7-11
Jan. 13-17

IPC-A-610 Instructor Recertification
Nov. 7-8
Feb. 13-14

IPC-7711/7721
Rework, Repair and Modification of Printed Boards and Electronic Assemblies
October 7-11, 14-17

Continuing Professional Advancement

Design for Manufacturability
Oct. 21-22
Feb. 10-11

Failure Analysis and Reliability Testing in Electronics Manufacturing
Nov. 13-15

Characteristic Properties of Materials in Electronics Manufacturing
Oct. 14-16
Feb. 19-21

For more information, please call (610) 362-1320 or e-mail: registrar@empf.org

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