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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In This Issue

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LEAD FREE PROCESSING

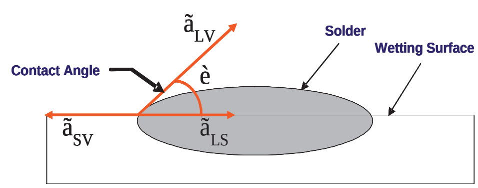
Lead Free soldering is no longer an esoteric concept. In Europe, the Waste Electronic and Electrical Equipment (WEEE) and the Restriction of Hazardous Substances (RoHS) Directives stipulate that consumer electronic equipment sold must be lead free by July 1, 2006. Members of the European Union have the option to accelerate this deadline. For example, Germany is considering banning lead from electronics by August, 2004. In Asia, the Japanese Ministry of Industry and Trade Institute (MITI) has stipulated that lead usage be reduced by 67% by December 31, 2005. As a result, electronics manufacturers have taken the initiative to start building lead free soldered hardware.

There are several technical issues associated with implementing the lead (Pb) free soldering process. In general, lead free solders require higher processing temperatures than their tin-lead (SnPb) counterparts (Table 1).

Alloy	Melting Temperature
SnPb	183^{o}C
SnBi	138^{o}C
SnAgCuBi	215^{o}C
SnAgCu	218^{o}C
SnAg	221^{o}C
SnAgCuSb	222^{o}C
SnCu	227^{o}C
SnSb	240^{o}C

Table 1. Solder Alloy Melting Temperatures

Pb free solders do not wet as well as SnPb. Typically, SnPb will have contact angles of between 4^{o} to 6^{o} on a copper surface. The Pb free solder alloy, Tin (Sn) Silver (Ag) Copper (Cu), generally has contact angles ranging from 6^{o} to 12^{o}. Soldering in an inert atmosphere will improve the contact wetting angle by 1^{o} to 3^{o} (Figure 1).



$\tilde{a}_{SV} = \tilde{a}_{LS} + \tilde{a}_{LV}$ cosè
$\tilde{a}_{SV}$ = The wetting force
$\tilde{a}_{LS}$ = Surface tension between liquid solder and wetting surface
$\tilde{a}_{LV}$ = Solder surface tension
è = Contact (Dihedral) Angle
Total Non Wetting: è =180^{o}
Total Wetting: è =0^{o}
Partial Wetting: 180^{o} > è > 0^{o}

Figure 1. Example of Contact Angle.

The processing variables for Pb free soldering are different from SnPb. Despite these differences, it is feasible to manufacture hardware that meets IPC-A-610 Class 3 requirements for high reliability hardware. It has been shown by the Lead Free Components Focus Group and NCMS that Pb free solders can pass aerospace thermal cycle testing from -55^{o}C to 125^{o}C.

HAND SOLDERING

Due to the higher soldering temperatures required for Pb free solders, the solder tip temperature has to be set higher. For example, with the solder alloys soldered, ACI found that the solder tip temperature had to be set at 343 ^{o}C for Pb free solders, as opposed for 315 ^{o}C for SnPb.

It was discovered that a longer dwell time, the time the soldering iron was in contact with the hardware, was required to promote adequate heat transfer during the soldering process.

It was ACI's experience that the soldering iron had to be removed quicker for Pb free than for SnPb. Icicles will be created if the soldering iron is removed too slowly. The size and frequency of solder icicles is dependent upon the purity of the alloy used and the soldering iron temperature setting (Figure 2). Also, pure metals have a narrow freezing range.

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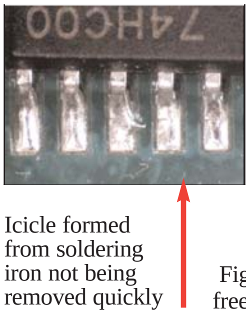
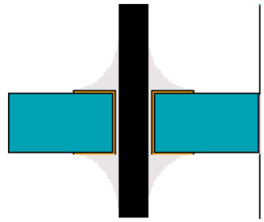


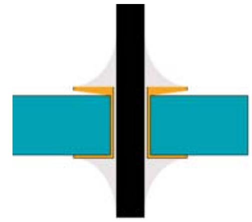
Icicle formed from soldering iron not being removed quickly

Pb free hand soldered solder joint

Figure 2. Pb free hand soldering examples



Cross section of acceptable solder joint



Cross section of solder joint with a lifted pad

Figure 3. Example of lifted pad phenomena

The higher soldering temperature requires that the soldering iron must remain clean and coated with the solder alloy. Pb free solders are more sensitive to the effects of a dirty soldering iron. The higher soldering temperatures can result in the soldering iron tip becoming oxidized if not cleaned and coated.

The resulting solder joint will have a grainy dull finish. Depending upon the soldering operation, a more active solder flux may be required to promote wetting. Using a more active solder flux may require a more aggressive cleaning operation.

Figure 4. Example of solder pot damaged from Lead Free solders.

WAVE SOLDERING
ACI wave soldered hardware for the Lead Free Components Focus Group. There were several process differences found when compared to SnPb wave soldering operations:

- The preheat temperature was much higher for Pb free solders (165^{o}C) than for SnPb (120^{o}C).

- Pb free solders create more solder dross when soldered in air. Nitrogen (N_2) reduces the amount of solder dross used.

- Due to the poor wetting of Pb free solders, N_2 and more active solder flux will have to be used to promote better solderability. It is documented that soldering in an inert atmosphere will improve solder wetting and reduce solder residues. Using a more active solder flux may require more aggressive cleaning.

The resulting solder joint will have a grainy dull finish. The solder joint will have more voids if the profile is not properly tuned.

It has been observed on SnBi alloys that there is a higher rate of lifted pads. This is caused by the cooling rate being too severe (Figure 3).

There is evidence that special tooling and tooling finishes may be required for Pb free solders. The high Sn content may damage sections of the solder pot (Figure 4). Companies are now beginning to coat solder pot fixtures with ceramic and teflon to reduce this damage. It is recommended that a wave solder pot not run continuously. To extend the life of the solder pot, the pot should not remain idle for an extended period of time. The solder pot should be on a rigid preventative maintenance operation, concentrating on the solder pot's impeller and wave solder fixtures.

SMT MANUFACTURING
ACI found that for screen printing operations and component placement operations, SnPb and Pb free solder pastes were equivalent. ACI technicians found Pb free solder paste easy to use. There were no changes in the stencil design and screen printing parameters to achieve good solder paste application. From a component placement perspective, the Pb free solder pastes used had equivalent tackiness and green strength to their SnPb counterparts.

For reflow soldering, the differences between Pb free solders and SnPb solders are wider. Typically, the peak reflow soldering temperature for Pb free solders can range between 240^{o}C and 260^{o}C. The thermal profile will be dependent upon the Pb free solder alloy used and the vendor. For example, ACI discovered that for the same SnAgCu alloy, two different vendors had each recommended different reflow soldering profiles and peak reflow soldering temperatures.

It is recommended that soldering be performed in an inert atmosphere, such as N_2. This will improve solder wetting and reduce solder residues.

With respect to the equipment, depending upon the vintage of the reflow soldering ovens used, current equipment can reach the reflow soldering temperatures required to process Pb free soldered hardware.

The equipment settings will be dictated by:

The solder alloy used
The hardware's thermal mass

To reach the higher reflow soldering temperatures, it is possible to reduce the oven's belt speed. The slower belt speed will reduce productivity. Due to the higher temperatures, more preventative maintenance - specifically belt lubrication and panel

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LEAD FREE MANUFACTURABILITY

The current movement in the worldwide electronics industry toward lead (Pb) free electronics is based on environmental and legislative, rather than technical, reasons. Pb is considered to be a toxic substance that should be eliminated from all electronics, just as the particularly harmful organic compounds of Pb have been eliminated from paint and gasoline. By 2006, Europe will require that all electronics be Pb free, and the U.S. banning of Pb in electronics is expected to be not far behind. However, the U.S. will be pulled along as other countries make the conversion. For details, see the article titled "Lead Free Soldering Processing" in this issue.

Pb is used in the existing electronic manufacturing process as a tin (Sn) Pb alloy solder to attach and electrically interconnect components such as IC (Integrated Circuit) chips and resistors to PWBs (Printed Wiring Boards). The vast majority of experience in electronics is with manufacturing processes that use SnPb solders to attach electrical components having SnPb plating on their leads to PWBs.

When Pb is banned, the electronic manufacturing industry will have to switch to solder that contains only Sn, and perhaps some small amount of silver (Ag), copper (Cu), bismuth (Bi), or antimony (Sb) to improve mechanical properties of the solder. These Pb free soldering alloys, such as SnCuAg, have much higher melting temperatures than the SnPb currently used. This higher melting temperature is the source of many manufacturing issues. One of the foremost DFM (Design for Manufacturability) issues is the selection of the base PWB material to be used in a design for Pb free electronic hardware. Figure 1 shows an example of the choices of substrate material available to the designer faced with the task of designing hardware that will use the Pb free assembly process.

Alloy	Reflow Soldering Temperature	PWB Laminate Material	Tg of PWB Laminate
SnPb (baseline)	220^{o}C	FR 4 (di-or Tetrafunctional epoxy)	125^{o}C-145^{o}C
SnBi	160^{o}C	FR 4 (di-or Tetrafunctional epoxy)	125^{o}C-145^{o}C
SnAgCu	237^{o}C	FR 4 (multifunctional epoxy)	170^{o}C
SnAg	240^{o}C	Thermount	240^{o}C
SnCu	247^{o}C	Polyimide	250^{o}C

Figure 1 - PWB substrate material choice concerns caused by Pb free manufacturing

FR 4 PWB substrate laminates of several varieties may be chosen for the PWB substrate to be used for Pb free manufacturing. These varieties of FR 4, with their corresponding Tg values, appear in Fig, 2.

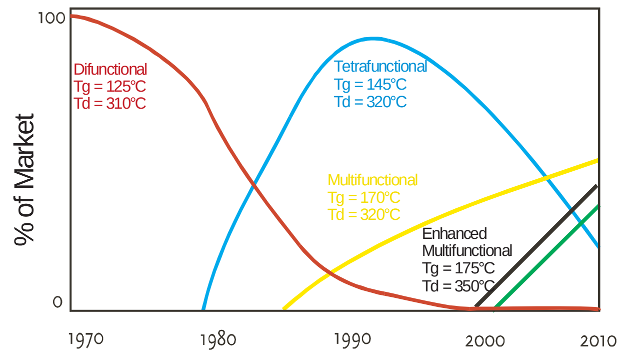

Fig. 2 FR 4 variations and their availabilities and use

Because of the close proximity to the Tg of the substrate PWB, Pb free soldering may cause the designer to call out a higher-Tg-substrate than PWBs used in SnPb processed assemblies. Extended time above the Tg of the PWB material in the reflow oven for SMT or in the solder wave for PTH manufacturing can cause the assemblies to warp. This makes the choice of PWB substrate materials a tougher challenge for the designer, especially since the higher Tg PWB materials tend to be more expensive.

"Popcorning" is the tendency for explosive outgassing of water vapor during the soldering temperature cycle. The moisture sensitivity rating for each component has, in most cases, been established based on SnPb soldering temperatures. Processing temperatures using the Pb free manufacturing process on the same hardware, depending on the solder alloy chosen, may be higher. It may be necessary to specify more stringent moisture sensitivity requirements for both the board and the components to compensate for these higher processing temperatures to avoid "popcorning", or delamination of the PWB or components.

Bake-out of the boards and components also becomes a more critical step with the higher temperature processes. For details on bake-out see the article titled ""Lead Free Soldering Processing" in this issue. The DFM requirement is to specify a moisture sensitivity rating for each component that has been based on the higher processing temperatures for Pb free manufacturing.

The PWBs currently have surface finishes that have been optimized to allow reliable solder attachment of those components using SnPb solder, but the new Pb free process will require that PWB finishes be qualified for the new alloys, pastes, and fluxes.

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LEAD FREE MANUFACTURABILITY (continued from page 3)

The most common of these surface finishes are:

HASL (Hot Air Solder Leveled)
ENIG (Electroless Nickel, Immersion Gold)
OSP (Organic Solderability Preservative)
Immersion Ag (Immersion Silver)
Immersion Sn (Immersion Tin)

At the EMPF, finishes have been tested using Pb free manufacturing methods in manual, through-hole and surface-mount modes. Pb free manufacturing has been found to be workable with relatively straightforward process accommodations except for the OSP finish.

Design and manufacturing processes are not the only complications in dealing with Pb free manufacturing. Manufacturing technology is also a concern. Component leads plated with SnPb solder will now be plated with pure Sn or other no-Pb alloys such as Ni, Pd, or Au. Unfortunately, pure Sn plating is known to grow spontaneous tin whiskers.
The Sn whisker is a filamentary single crystal growth that takes place some time (typically months or years) after the plating is done. It can grow to lengths that can easily bridge between features on a PWB, or even a bracket and other electrically grounded hardware in electronic systems, causing shorts.

Sn whiskers can also break off the Sn-plated component and re-lodge themselves between features causing short circuits. In the old SnPb solder world, the Pb alloying addition in the SnPb solder was known to virtually eliminate the possibility of whisker growth. The whole subject of Sn whisker growth, for which there is currently no industry standard test, must now be studied and controlled in the Pb free electronic manufacturing environment. For more information on the tin whiskering phenomenon, please see the article titled "Tin Whiskers" in this issue.

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Tin Whiskers

With Navy sustainment looking at 30 year lifecycles, the formation of tin (Sn) whiskers is a cause for concern. The micrograph of Sn whiskers shown in figure 1 was produced by the EMPF in only three days. Whiskers of this type are known to cause electrical shorting in electronic components. EMPF investigations found that simple changes in the plating bath temperature and storage conditions could change the amount and length of whiskers produced. With that in mind, you may wonder how close suppliers are watching Sn plating on COTS parts from overseas, purchased sub-assemblies or reworked formerly leaded parts? The present mitigations strategies for Sn whiskers are: control of the finish to matte, reduction in organic contamination, minimization of mechanical compressive stress and continued use of lead in conflict with future industry practice. This is the first of a three part series on Sn whiskers that will address the implications of Sn whiskers on Navy electronics.

Figure 1 - micrograph of Tin Whisker

Since 1988 several weapons systems have failed due to Sn Whiskers, examples are the Phoenix Missile, F - 15 Radar, Patriot Missile and Avionics relays [1, 2, 3, 4, 5, 6]. If the military is depending upon these systems to perform without failure when deployed, then it should be concerned with the Sn whisker issue facing electronics manufacturers. Sn whiskers have been an issue off and on over the last 50 years. However, with the advent of Pb - free solders mandated by both Europe and Japan to address environmental issues whiskers seem to have returned. Figure 2, shows typical Sn whiskers growing on a plated surface [7]. Since these whiskers can develop aspect ratios >1000, i.e. Length/Diameter, their presence which can lead to shorting threatens the viability of an electronic device using high Sn materials. It has been reported that Sn whisker formation has lead to failure in heart pacemakers do to shorting to the package, grounding/shorting in avionics radar and relays, and the loss of satellites from process failure, terminal shorting and relay breakdown. Unfortunately, little is known about how whiskers form and why do they appear so metallurgically stable once developed.

Figure 2 - Whisker Growth - Courtsey of I. Hemeford and NASA Goddard

Metallurgically the nucleation and growth Sn whisker are a balance of mechanical stresses, alloy chemistry, crystallography and morphology. All of these inputs can be affected and affected by the plating and assembly processes used to assemble the electronic component. The present phenomenological model is based upon compressive stresses leading to the nucleation and growth of Sn whiskers [8, 9, 10]. Although in these same studies other elements, e.g. Cu, Zn, are found to effect whisker growth in addition to the nature of the surface finish, i.e. bright, matte or satin. Stress development can also be enhanced due to thermal treatment which aids in the formation of intermetallic compounds; a specific example is Cu6Sn5 which is often found associated with whisker formation.

At this time an analytical model to predict Sn whisker formation does not exist. Present models for dendrite and cell formation in solidification nor vapor phase whisker formation describe Sn whiskers adequately for predictive use [11]. The issue is that in the Sn whisker case the growth happens within a uniform temperature field. Unlike phase change growth which balance thermal gradients against material transport mechanisms the isothermal transport to produce Sn whiskers is more akin to the heat treating of Steel or the aging of Aluminum (Al). In isothermal nucleation and growth is produced by the elimination of a metastable phase formed by rapid cooling from an elevated temperature. For example Al aircraft alloys are solutionized by heating above 400C to dissolve and evenly distribute the alloying elements. The material is the rapidly quenched, e.g. in water, to lock the dissolved atoms in solution. Holding the Al alloy at or slightly above room temperature allows the formation of a fine distribution of particles of alloying elements which provide strengthening. In the Sn whisker case it has been show that the whiskers have a body centered tetragonal crystal structure, white - Sn, with a density of 7.23 g/cm3. However, Sn also has several other crystal structures with much lower densities, δ- Diamond Cubic at 5.23 g/cm3, SnII and α Sn at g/cm3 [12]. Therefore a proposed mechanism is that the difference in density, or atomic packing, drive the nucleation and growth of a Sn whisker from a low density phase to a high density one.

To develop an understanding to predict and control Sn whisker formation is an issue semiconductor and electronic assembly engineers to come to grips with. Process control in the factory and product reliability in the field require it. This is especially true in high reliability areas with long life cycle expectancies. It is unfortunate that the commercial market at large with the possible exception of telecommunications with probably not be of assistance as Sn whisker often manifests themselves well outside of the usual reliability window. The EMPF is presently developing manufacturing and reliability processes with Pb - free alloys and supporting that work by developing a thorough understanding of the underling metallurgical science involved. The final goal is to predict, process and protect against failure in high reliability applications.

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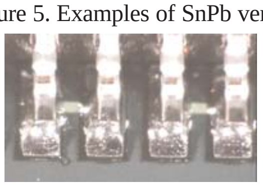
LEAD FREE (continued from page 2)

maintenance - will be required. New ovens on the market are capable of supporting Pb free soldering.

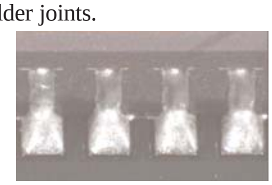
INSPECTION

Pb free solder joints have a different appearance to SnPb solder joints (Figure 5). The Target Inspection Criteria for solder joints, based on IPC-A-610, is that the solder joint will have a bright shiny appearance, a smooth surface finish, and good wetting coverage on the pad and lead.

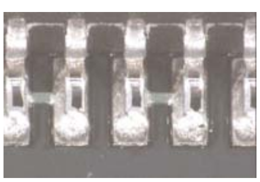
Figure 5. Examples of SnPb versus Pb solder joints.



Solder: SnPb
Board: HASL Finish
Component: NiPd Finish



Solder: SnPb
Board: OSP Finish
Component: SnPb Finish



Solder: SnAgCu
Board: HASL Finish
Component: NiPd Finish

Solder: SnAgCu
Board: OSP Finish
Component: SnCu Finish

Pb free solders have a dull grainy surface finish. As previously indicated, Pb free solders do not wet as well as SnPb. IPC A-610C, Paragraph 6.1, was included to take into account the results from using Pb free solders. It reaches across Class 1, Class 2, and Class 3 packaging requirements. It allows for solder alloys which produce:

- Dull matte surface - Gray color - Grainy appearance -
- Considered normal for the materials or processes involved

These changes take into account the differences when using Pb free solders. However, operators which are familiar with the output on SnPb soldering, would have to be recalibrated when inspecting Pb free solders.

FUTURE ACI LEAD FREE SOLDERING PROJECTS

The EMPF will continue to perform research and development in Pb soldering. A Pb solderability analysis will be performed to quantify what level of contamination or oxidation prevents Pb solders from being soldered. Pb contamination will be investigated to determine what level of Pb contamination reduces Pb free solder joint reliability. Due to the high Sn content of Pb free solders and finishes, Sn whiskers is becoming a major concern. ACI hopes to correlate Sn whisker growth to the environment, and board and component finishes.

ACI's EMPF offers a two-day Pb free soldering course. This course uses various Pb free solders within ACI's Demonstration Factory. Participants are encouraged to bring samples of their hardware for soldering. If there are any questions, please feel free to contact the Electronics Manufacturing Learning Center Registrar at (610) 362-1320.

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Cut here and save!

TECH TIPS...
LEAD FREE REWORK

Electronics manufacturers are taking the initiative to take Pb out of electronics manufacturing. Because of this change, it is inevitable that commercial or military hardware built with tin lead (SnPb) solders will have to undergo a rework or repair operation in order to be sustained. While there is plenty of data with respect to performing rework and repair operations with SnPb, there has been minimum documentation on rework and repair operations with Pb free solders. Rework and repair operations are critical to maintaining operation availability in the field, as part of a program's sustainment. The military must be aware of the challenges faced when rework ing or repairing its electronic hardware in a Pb free environment.

To following tips demonstrate how Pb free rework and repair has been successfully accomplished at the EMPF. The EMPF-009 board (Figure 1) was the test vehicle for this demonstration. Concentrating on the PBGA-169 package and the 80 pin QFP, the following tips are provided to account for using Pb free solders instead of SnPb solders.

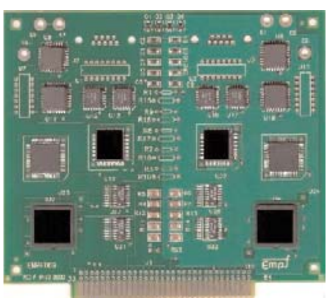
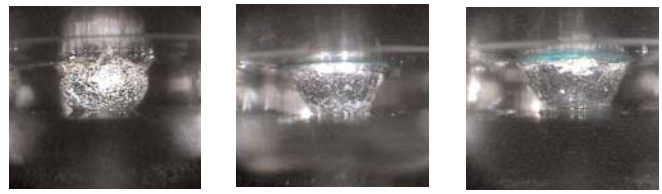


Figure 1. EMPF-009 Board

Removing the PBGA-169 package was done using a standard rework and repair process. The rework station was programmed to a top side peak temperature of 240^{o}C to 260^{o}C, which allowed the component to be exposed to a peak of 210^{o}C. Upon the component's removal, the board's pads were cleaned, and had the Pb free solder, Tin (Sn), Silver (Ag), Copper (Cu), applied. SnAgCu has a melting temperature of 221^{o}C, as opposed to the SnPb 183 ^{o}C melting temperature. This required the rework station to be programmed to a top side peak temperature of 300^{o}C. This high temperature was needed to support the SnAgCu higher melting temperature. The EMPF-009 board had a ground plane under portions of the PBGA, which increases the hardware's thermal mass, forcing the use of higher processing temperatures.

The resulting solder joints on the PBGA without the ground plane were acceptable. The Pb free solder joints had a dull grainy appearance, when compared to their SnPb counterparts. However, the PBGA package, soldered on the ground plane, produced unacceptable solder joints (Figure 2, Figure 3). Also, due to the higher temperatures used, the PBGA package warped.

Figure 2. EMPF-009 Rework & Repair Solder Joints



Lead Free rework & repair BGA without ground plane | Lead Free rework & repair BGA over ground plane | Lead Free rework & repair BGA over ground plane

Figure 3. EMPF-009 Rework & Repair Solder Joints X-Ray

Lead Free rework & repair BGA without ground plane | Lead Free rework & repair BGA without ground plane | Lead Free rework & repair BGA over ground plane

TECH TIP #1: The top side and bottom side of the board must be raised to an adequate temperature to produce an acceptable solder joint without damaging the component or board. Too much of a thermal gradient between the top side and bottom side can warp the component and/or the board.

TECH TIP #2: Both the boards and components must be baked, prior to having the rework operations performed. This will reduce the probability of component and board delamination due to the higher temperatures associated with Pb free solders.

TECH TIP #3: The area to be soldered must have all solder removed from the pads, to avoid Pb contamination to the Pb free solder joint.

TECH TIP #4: Because the solder tip will be set at a higher temperature, the tip is more susceptible to oxidation and contamination. Therefore, the tip must be covered with fresh solder and cleaned more often than with SnPb solders.

ACI's EMPF offers a course on Pb free soldering, that provides detailed instructions on performing rework and repair operations. For more information, contact the Helpline at 610-362-1320.

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National Center of Excellence for Electronics Manufacuring
2004 Course Schedule

Skills

SMT Manufacturing
February 23-27
May 24-28
August 23-27

BGA Manufacturing, Inspection & Rework
January 26-27
April 12-13
July 19-20
November 30 - December 1

Chip Scale Manufacturing
January 21-23
June 21-23
November 15-17

Continuing Professional Advancement in Electronics Manufacturing

Lead Free Manufacturing NEW
January 15-16
March 8-9
June 17-18
November 1-2

Design for Manufacturability NEW
February 19-20
May 3-4
August 30-31
December 6-7

Failure Analysis and Reliability Testing
March 15-17
November 29-December 1

Characteristic Properties of Materials
March 29-31
October 25-27

Electronics Manufacturing

Boot Camp A - Week 1
February 2-6
May 10-14
July 26-30
October 4-8

Boot Camp B - Week 2
February 9-13
May 17-21
August 2-6
October 11-15

Certifications

IPC J-STD-001 Instructor Certification
January 5-9
March 1-5
April 19-23
June 7-11
August 9-13
September 13-17
October 18-22

J-STD-001 Instructor Recertification
January 26-27
March 22-23
May 3-4
August 30-31
December 6-7

IPC-A-610 Instructor Certification
January 12-16
March 8-12
April 26-30
June 14-18
August 16-20
September 20-24
October 25-29

IPC-A-610 Instructor Recertification
January 29-30
March 25-26
May 6-7
September 2-3
December 9-10

IPC Challenge
January 28
March 24
May 5
September 1
December 8

IPC-7711/7721 Rework, Repair and Modification of Printed Boards and Electronic Assemblies (Operator)
March 15-26
July 12-23

WHMA-A-620 Wire Harness Manufacturing (Operator) NEW
January 21-23
June 21-23
November 15-17

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NAVY MANTECH manufacturing technology program

Manufacturer's Corner
PHOENIX X-RAY

The EMPF utilizes x-ray systems to inspect every PCB assembly, whether it is a military or a commercial product. In doing this, the EMPF insures the quality and reliability of the solder joints of CSP, Flip Chip, BGA and Micro BGA packages.

By design, x-ray systems provide the capability to look inside opaque/solid substances. Many of today's microfocus x-ray system manufacturers offer either open-tube or sealed-tube technologies. A sealed-tube x-ray source generally is a glass tube analogous to a light bulb where the contents of the tube are in a vacuum. An open-tube source, which generally consists of an all-metal construction, creates a vacuum by performing a two-stage pumping process every time the system is switched on. The vacuum is maintained throughout the system via a secondary pumping system. Although open tubes may use either directional or transmission target optics, for the purposes of this writing, any reference to an open tube is indicative of a transmission target.

To determine which type of system fits your needs, several fundamentals must be considered: detail detectability, tube voltage, geometric/total magnification, application requirements, cost of ownership, the image chain, software and system investment.

Detail Detectability, also known as feature recognition, can be estimated as approximately half of the x-ray source focal-spot size. In general, most sealed tubes will have larger focal spots than open tubes.The focal-spot size of microfocus x-ray is a fundamental parameter. One technique used for quantification is lateral resolution, which is the smallest feature that can be differentiated by the system in a top-down view. The smaller the focal-spot size, the sharper the image at high geometric magnification.

Tube-voltage Requirements depend on the application. Penetration of the sample or photon attenuation is based on three factors: material thickness, density, and mass. The higher the voltage, the greater the penetration capabilities of an x-ray source.

Voltages for sealed tubes generally range from 80 kV to 150 kV; open-tube systems vary from 100 kV to 225 kV. Both technologies usually have variable voltage ranges starting around 10 kV with increases in increments as low as 1 kV up to the maximum tube voltage.

Tube current controls the quantity of x-ray photons that the tube generates (flux). The end effect of a higher current is a higher contrast due to less noise. Since the focal-spot size is directly proportional to the power (voltage × current), the tube current typically is smaller at a higher tube voltage to maintain image sharpness. Low-density applications typically require higher current and lower voltage.

Geometric and Total Magnification
Beware of randomly spoken magnification values. The distinction between geometric vs. total magnification capabilities is essential. Geometric magnification is the true or actual magnification without enhancing capabilities, including optical and digital zoom, pixel, and software. Total magnification is the geometric magnification plus magnification enhancement tools such as zooming. Total magnification takes into account the optical characteristics of the detector and size of the display monitor.

The larger the geometric magnification, the smaller the observed feature can be defined as:
Mgeo = FID/FOD
where: FID = focus-to-intensifier distance
FOD = focus-to-object distance

Open tubes have a minimal focus-to-object distance and are best suited for applications demanding high magnification. Sealed tubes have a larger minimum FOD resulting in lower achievable geometric magnifications.

Application Requirements
A quality sealed-tube system is of great value for many applications. These systems, many capable of 70× geometric magnification, can inspect various components. For example, sealed-tube systems with penetration requirements up to 150 kV and a tube output power up to 10 W yielding current up to 250 µ are not only popular but are also excellent tools for BGA inspection (see Table 1).

Open-tube systems provide a more complete package, yielding a higher level of BGA analysis capabilities. For example, in addition to the higher level of BGA analysis, open-tube systems permit analysis of flip-chip bumps, package inspection, and a wider range of failure analysis in general. These systems accommodate applications requiring higher geometric magnifications, voltage, and tube current.

Factor	Sealed Tube	Open Tube
Detail Detectability (µm)	5	1
Geometric Magnification	-70	-1,600
Maximum Tube Voltage (kV)	80 -to-150	100-to-225
Maximum Tube Power (W)	5-to-10	10-to-30
Main Costs of Ownership	Replacement Tubes	Preventative Maintenance

Table 1

continued on page 10

PHOENIX X-RAY (Continued from page 9)

Open-tube systems are more powerful than sealed tubes and can be even easier to use with a properly designed control system. With a sealed tube, you have the ability to see the hair on a cricket's leg. With an open-tube system, you can see if the hair on the cricket's leg has split ends.

Cost of Ownership and System Price

The up-front costs of open-tube systems generally are higher due to the added support systems such as the vacuum pumps and a more complex x-ray control. However, both technologies have their associated costs.

All major components of open tubes may be exchanged, resulting in a virtually unlimited tube life. Open-tube systems require a scheduled maintenance program and have consumables such as filaments, targets, and seals. Sealed-tube systems require minimal maintenance with the tube itself as the only consumable. Typically, sealed-tube systems have a life span of three to five years depending on usage and design.

The Image Chain

The detector is the next important piece of the x-ray system. Like the x-ray tube, detectors come in different flavors and are broken down into two categories: analog or digital.

The most popular and economical analog image acquisition method is the x-ray image-intensifier device coupled with a high-resolution CCD camera. The image intensifier is an analog device contained in a large evacuated glass envelope. It comprises a scintillation screen and a photo cathode by which the x-rays are converted back to electrons, then accelerated to produce a smaller, brighter image on a second, phosphorescent screen similar in operation to a CRT.

The output from the image intensifier enters a chain consisting of lenses, a CCD camera, the image processing system, and the final output onto a monitor. Many manufacturers use general-purpose cameras that, although relatively inexpensive, do not offer the best contrast.

A small handful of manufacturers uses cameras that are sensitive to the spectrum of light emitted by the intensifier. These optimized cameras usually are identifiable by their pancake or disk-like design.

Image-intensifier packages are offered with 9", 6", and 4" input areas. Image intensifiers also are available with combination modes such as dual-field (6"/4" or 4"/2") and tri-field units (9"/6"/4").

The magnification factor and image resolution will vary with intensifier selection. The x-ray-to-light conversion efficiency increases with the diameter of the input field. A smaller intensifier will provide higher magnification but requires more flux.

The digital or flat-panel detectors come in various configurations, such as a solid-state amorphous silicon sensor operating as a two-dimensional photodiode array. X-rays are converted to light using a vertical structured scintillator. The flat-panel detector consists of a photo-diode matrix and a scintillator screen for x-ray conversion.

The amorphous silicon-based digital detectors provide up to 16-b, 64k gray-scale images as compared to 8-b, 256 shades of gray provided by the camera of an image-intensifier system. The digital detector, with its higher cost, is useful for capturing small changes in material density and examining low absorbing materials such as nonconductive epoxy. Some cameras can be upgraded from 8-b, 256 gray scales to 10 b or 12 b, providing some improvement.

Software

Programming capabilities and a user-friendly graphical user interface (GUI) are key. Having the tools is great, but being able to use them is essential. Image processing and filtering functions that provide comprehensive capabilities for custom and standard applications plus a user-friendly GUI are necessary.

System Investment

Ultimately, the system you select must be appropriate for your current as well as future applications. It also must accommodate the changes in production to smaller, denser materials to reflect today's technology trend. The maximum value for the dollar is not the least expensive system out there, but the best system for the money.

Contact X-ray vendors that can provide you with a solution within your budgetary constraints. Since image quality is essential, submit samples of your product to each of the qualified vendors for imaging.

After determining which systems provide the best quality, go step by step through the features, further narrowing down the list. Then, request a hands-on demonstration of each potential supplier's recommended configurations. Driving a system yourself will tell how well a system is going to fit your application and facility needs.

Jeff Stong is the Equipment Advisory Board Coordinator for ACI. Comments or questions about this article can be sent to jstong@aciusa.org

Ask the EMPF Helpline!

Calls to the Helpline asking for help with soldering are on the increase. In the past few months, callers having problems soldering components with Palladium (Pd) over Nickel (Ni), Pure Tin (Sn) over Ni, Gold (Au) over Ni and Silver (Ag)/Platinum (Pf) over ceramic have hit the Helpline. The increasing numbers of components with leads and terminations employing Pb free finishes may be the reason. Here is an example of one such call.

Caller:
"We are having trouble soldering to an Electroless Nickel, Immersion Gold (ENIG) board. Can you tell us what is wrong?"

Helpline: "There are a number tests that can point to something wrong with the process, the material selection, or the solderability. Assuming your material selection and process controls are adequate, we can assume there is a problem with the board, do you need to know more?"

Caller: "Yes, our supplier maintains the boards are good and we need an independent evaluation."

SOLUTION - Solderability testing provides interested parties with an indication of how good the surface finish is working. These tests can be as simple as a dip and look or may involve use of sophisticated equipment that attempts to quantify the performance of the solderable surface. These tests provide a necessary starting point for assessing the performance of Pb free component finishes.

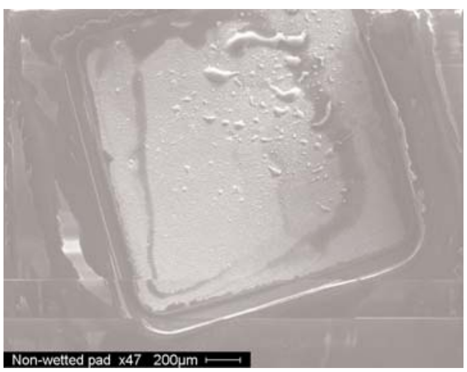

Figure 1 - SEM image of dewetting on ENIG surface finish.

Figure 1 shows the image of the board finish in question after solderability testing. The board finish had failed to protect the nickel barrier over the copper.

In the days of SnPb soldering, suppliers of materials for the electronics industry could design fluxing compounds optimized for one or two metal interfaces and generally satisfy the needs of the market. Soldering, most often, involves melting the surface finish and joining it to the lead or land pattern. This is no longer the case. The advent of Pb free materials and the diversity of PWB, leadless terminations and component lead finishes present real problems. Variation in the performance of the finishes may bring your manufacturing process to a stop.

While we are seeing an increase in the number of soldering related problems, the process end remains essentially unchanged by the introduction of Pb free surface finishes. We have soldered to copper (Cu), nickel (Ni) and the same Pb free frame alloys for many years. The intermetallic compounds will still be Sn based, generally SnCu, or SnNi depending on the basis or barrier metal. But, the material providing the protective finish, and the performance of those finishes, is different. The interactions of the Pb free alloy, flux, surface finish and solderable basis metal are quite different. Furthermore, the variety of interactions increases. Fluxing chemistries and process parameters must be optimized to respond to all the finishes employed in the design.

In the short term, manufacturers must learn to use Pb free components with SnPb solders. We have observed that good results are possible but process windows are a little smaller. It is also possible that your current flux will not produce the desirable results.

Most of the Pb free finishes are applied over a Ni barrier. Ni is plated onto the lead to prevent the underlying metal from diffusing through the surface finish, where it would be subject to oxidation (NiO, NiOOH). Ni, then, is the surface to which we solder. If the surface finish fails to provide protection, the Ni barrier itself becomes unsolderable.

While test methods have been established, absolute acceptance criteria have not. Thus far, we have been able to identify causes for soldering problems through careful analysis. We are working to correlate existing acceptance criteria with data tests using the new Pb free alloys. This should help users set up performance-based requirements.

Soldering to Ni requires slightly higher temperatures and longer dwell times. However, caution is advised. Some leadless terminations may leach off components when subjected to high temperatures and extended dwell.

Inspectors are going to see solder connections that look bad. Contact angles are going to be higher than desired. Lines of demarcation at the finish to solder interface may be clearly visible and yet, acceptable. You should still be seeing low contact angles and evidence of wetting. When in doubt, test again (components and boards should have been tested before you put them into stock). Remember, these finishes are not as rugged as Hot Air Solder Leveled (HASL).

For more information on Pb lead soldering contact the Helpline at 610-362-1320.

Guy Ramsay is a Senior Laboratory Technician/Instructor for ACI. Comments or questions about this article can be sent to gramsey@aciusa.org

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Skills

2003 CLASSES

BGA Manufacturing, Inspection & Rework
December 1-2

2004 CLASSES

SMT Manufacturing
February 23-27

BGA Manufacturing, Inspection & Rework
January 26-27

Chip Scale Manufacturing
January 21-23

Certifications

2003 CLASSES

IPC-J-STD-001 Instructor Recertification
December 8-9

IPC-A-610 Instructor Recertification
December 11-12

IPC Challenge
December 10

2004 CLASSES

IPC J-STD-001 Instructor Certification
January 5-9
March 1-5

J-STD-001 Instructor Recertification
January 26-27
March 22-23

IPC-A-610 Instructor Certification
January 12-16
March 8-12

IPC-A-610 Instructor Recertification
January 29-30
March 25-26

IPC-7711/7721 Rework, Repair and Modification of Printed Boards and Electronic Assemblies (Operator)
March 15-26

IPC Challenge
January 28
March 24

WHMA-A-620 Wire Harness Manufacturing (Operator)
January 21-23

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March 29-31

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

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