Removal of Lead Shakes Up the Manufacturing Chain

provided by Premier Farnell plc.

Conformity Editor's Note

The date for complying with the European RoHS Directive (2002/95/EC), which restricts the use of a half-dozen hazardous substances in electronic equipment, is July 1, 2006. That date is now less than a year away, and is rapidly approaching. The RoHS Directive restricts the use of six materials:

- *Lead*
- *Cadmium*
- *Mercury*
- *Hexavalent Chromium*
- *PBBs (polybrominated biphenyl flame retardants)*
- *PDBEs (polybrominated diphenyl ether flame retardants)*

To meet these requirements many components are being reformulated. However, one of the largest impacts may be on the whole printed circuit manufacturing industry, which will have to move to a lead-free process. The effects of this are far-reaching. Changing printed circuit boards to PCBs involves picking a different solder alloy, which has a number of side-effects. For example, the melting point of all lead-free solders is significantly higher than the familiar 63-37 tin/lead alloy. This stresses the printed circuit board material and the components. Other issues come into play as well—such as the ability of the new solder/flux combinations to flow and wet components, their long term resistance to corrosion, and the issues involved in reworking lead-free electronics.

The electronic industry is hard at work on these problems, but lead-free electronics manufacturing looks to be a work in process. Your editor has to wonder whether the transition to lead-free technology will be seamless, especially for equipment where extra-high reliability is required. It is one thing to change the way a short-life, stay at home piece of equipment like a table radio is manufactured, but it may be quite another matter when the durability of long-life, high reliability is involved. Two areas that come to mind in this regard are the military's increasing use of COTS (commercial-off-the-shelf) equipment, and NEBS-compliant (Network Equipment Building System) products designed for telecom company central office and network use. Although RoHS exempts telecom network equipment from these requirements, it seems likely that when the rest of the electronics industry adopts RoHS, the telecom industry will be affected because manufacturing houses won't maintain separate processes.

Here are several examples where the performance of lead-free boards may need to be further investigated to see if it matches the levels we have become accustomed to with technology based on trusty old tin/lead solder:

- *Vibration: Lead is a mushy material which damps vibration. How will lead-free bonded circuit boards stand up to shock and vibration? Will heavier components need extra solder bonding to avoid cracking?*
- *Long term corrosion behavior: Different alloys behave differently. Will the long term behavior of lead-free PCBs be as good? How about "whisker" growth, a current problem with some high-tin solders? Will fine-pitch circuitry remain reliable over time?*
- *Circuit board materials and components: Circuit board materials, such as FR4 have been developed over a long period of time. Their composition will be driven to change by two factors. First, all lead-free solders have significantly higher melting points, meaning that manufacturing temperatures will be higher than before. Materials will have to be changed so their mechanical properties (such as warping or contact retention) do not deteriorate. Second, there are non-lead RoHS issues with brominated flame retardants. Some (PBBs and PBDEs) are going to be forbidden, but others may soon follow. Material manufacturers will probably find ways to make the new compositions meet standardized flame ratings, but there may be subtle variations in flammability which will affect previously designed products manufactured under new processes.*

The following pages highlighting some of these issues are extracted from an excellent document compiled by Premier Farnell (the "Premier Farnell RoHS Legislation and Technical Manual") and available at the Newark Electronics web site link: http://www.newark.com/services/rohs/documents/PKG153.pdf.

Lead Free Soldering

Glossary of terms

What are Tin-Whiskers?
Tin-whiskers are single crystal, electrically conductive, hair-like structures that grow from lead-free, pure tin surfaces.

What are Dendrites?
Dendrites are fern-like or snowflake-like patterns growing along a surface (x-y plane) rather than outward from it, like Tin-whiskers. The growth mechanism for dendrites is well understood and requires some type of moisture capable of dissolving the metal (e.g., tin) into a solution of metal ions that are then redistributed by electro-migration in the presence of an electromagnetic field.

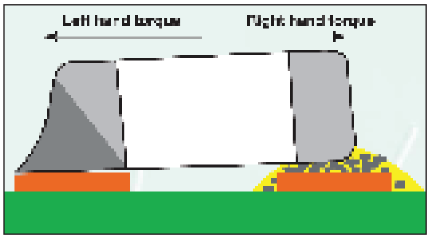
What is SIR?
Surface Insulation Resistance
Metal migration between isolated conductors on a completed assembly may produce electrical shorts. These occur when the space between the conductors is bridged by dendrites formed by re-deposited metal ions

What is a "popcorn" reaction?
When heat is rapidly applied to moulded components moisture can gather. Above 100°C it expands, turns to gas and tries to escape and when it can't it tends to break or “pop” the moulded compound like a “popcorn effect”

What is Wetting?
The ability of a liquid to flow across a surface as opposed to sticking to itself. Wetting occurs when the attractive surface energy of the pad, or lead, is greater than the surface energy of the solder drawing a molecularly thin layer of solder across itself. Heating solder adds to the surface energy in the solder, so the cooler the solder the better the wetting.

What is Tomb-stoning?
Defined as the raising of one end, or standing up, of a leadless component from the solder paste.

This phenomenon is the result of an imbalance of the wetting forces during reflow soldering.



Initial stages of tomb-stoning due to the force of imbalance caused by temperature differences

What is Kneading?
The process of mixing solder powder to solder flux to form solder paste.

What is Drossing?
The formation of oxides and other contaminants upon molten solder.

Replacements for Standard Solder

All lead-free alloys are different. (M.pt. = melting point)

Despite extensive research, there is no “drop-in” replacement for standard tin/lead solder.

Alloy composition	M.pt. °C	Comments
Eutectic tin/lead solder	183	Included for comparison. Good wetting and low melting temperature
Sn0.7Cu	227	Used for wave soldering applications (known as 99C), high melting temperature and wetting inferior to SnAg
Sn3.5Ag	221	Used as high temperature solder, wetting inferior to SnAgCu
Sn3.5Ag0.7Cu (and variations on this)	217	Most widely used lead-free alloy. Various percentages of silver and copper are used. Melting temperature 34°C higher than tin/lead and inferior wetting
SnAgBi alloys (some with Cu)	Ca. 210 -215	Better wetting properties than SnAgCu but must not be used with lead. Mainly used as solder pastes but has been used for wave soldering, mainly in Japan. Wire not available
Sn9Zn	198	Needs special flux and is susceptible to corrosion
Sn8Zn3Bi	Ca. 191	Used by several Japanese manufacturers where heat sensitive components are used. Difficult to use
58Bi42Sn	138	Low melting point, hard, brittle alloy

Reliability issues with lead-free solders:

The main differences between lead-free and tin/lead alloys that need to be understood to avoid reliability issues are:

Higher melting temperature

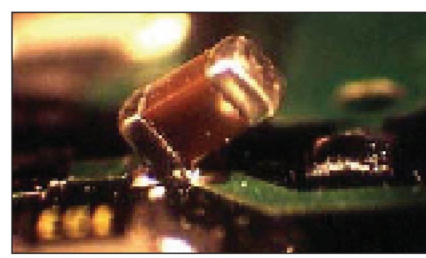
Lead-free alloy soldering temperature is higher (30°C - 40°C), which can lead to a variety of defects such as:

- Thermal fatigue of solder joints - not well understood, research is on-going
- Tin-whiskers from electroplated tin termination coatings - not fully understood, research is on-going
- Delamination of multi-layer PCBs
- Damage to plated through holes - especially with narrow holes in thicker laminate
- PCB warping - can damage components, cause open circuits, misalignment
- IC packages are more susceptible to “pop-corn” failure. The IPC/JEDEC-020B Moisture Sensitivity Level for components with lead-free soldering can be 1 or 2 levels lower.
- Damage to heat sensitive components Check upper temperature limit in manufacturers datasheet

Wetting

of most lead-free solders is inferior to tin/lead.

- Tin coatings behave differently to tin/lead, even with tin/lead solder
- Correct choice of flux important.
- It is more important with lead-free that component terminations and solderable surfaces are clean and oxide-free
- Use the correct temperature profile. If the temperature rises too slowly due to poor temperature control or insufficient power, surfaces will oxidise making solder wetting more difficult. Beware of too rapid temperature rise as this can damage some components and PCBs due to thermal shock.
- The surface tension of lead-free solders is higher than tin/lead solders. This limits solder spread as well as increasing the risk of “tomb-stoning”.



Example of tomb-stoning

Tomb-stoning can be prevented by alignment of the component perpendicular to the direction of the conveyer, using a paste with a wider pasty range, ensuring all surfaces have good solderability

Components: Typical maximum temperatures

Aluminium electrolytic capacitor - max. temp. depends on size:	240°C -250°C
Tantalum capacitor - various types:	220°C -260°C
MLCC ramp rate more important:	240°C -260°C
Film capacitor:	230°C -300°C
Surface mount relay:	226°C -245°C
Crystal oscillator:	235°C -245°C
Connector - depends on type of plastic used:	220°C -245°C
LED - may function but light output affected:	240°C -280°C
Ball Grid Array & Chip Scale Packaged devices:	220°C -240°C
Other ICs:	245°C -260°C

Equipment and processes

Hand soldering

- This is relatively straightforward and trials with samples of wire are easy to carry out.
- Greatest difficulty is with large thermal mass components.
- Many lead-free SnCu, SnAgCu, SnAg wire products available.
- Alloys with bismuth not generally available as it is brittle and difficult to make into wire (can be made as "specials" but more expensive).
- Need slightly higher soldering iron tip temperature.
- More aggressive solders and fluxes will shorten tip life - 10°C rise could halve tip life.
- Longer pre-heat needed and wetting will take longer unless very high temperature is used (this will reduce productivity).
- Older style soldering irons have poor temperature control - can result in overheating (large temperature cycle).
- New soldering iron equipment has much better temperature control
- "Lead-Free" iron tips being developed.
- Frequently too-high a temperature is used with SnPb for fast wetting - operators in these cases may be able to use the same temperature with lead-free wire.
- To find optimum tip temperature:- start at 350°C, reduce temperature until poor results occur then increase by 10°C (or increase until good results are obtained).

Wave soldering

- Lead-free solders can damage steel parts - contact machine supplier for advice.
- Higher temperature required.
- Need to choose suitable flux.
- Some components may be damaged if they pass through the wave.
- Drossing rate higher - consider using nitrogen over wave.
- Check bath composition initially, especially if some tin/lead terminated components used.

Surface mount

- Forced air convection heating needed for better temperature control.
- Minimise peak temperature with good temperature control and many heat zones. Ovens may need to be longer with throughput lower to achieve good results.
- A controlled cooling rate is advisable as some component coatings can crack if cooled too slowly. Too rapid cooling can damage certain brittle components such as MLCCs.
- Nitrogen helps but is not essential.
- Choose optimum paste by comparative testing with realistic test PCBs. Test each paste over an eight-hour shift. This can be carried with 12 PCBs:
- Print 4 (no kneading), then place components, measure tack on 2 of these.
- 1 PCB wait 1 hour then reflow.
- 1 PCB wait 3 hours then reflow.
- Wait 6 hours, then place components, measure tack, then reflow.
- Repeat with 4 more after 1 hour.
- Repeat tests.
- Repeat with 4 more after 1 hour.
- Repeat tests.

PCB coatings

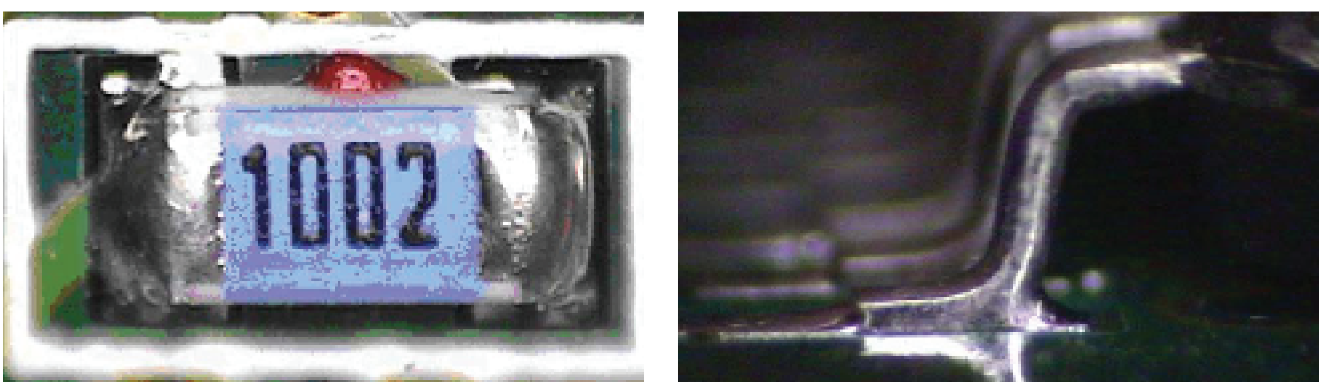
- traditional tin/lead hot air level (HASL) coatings cannot be used.

Inspection

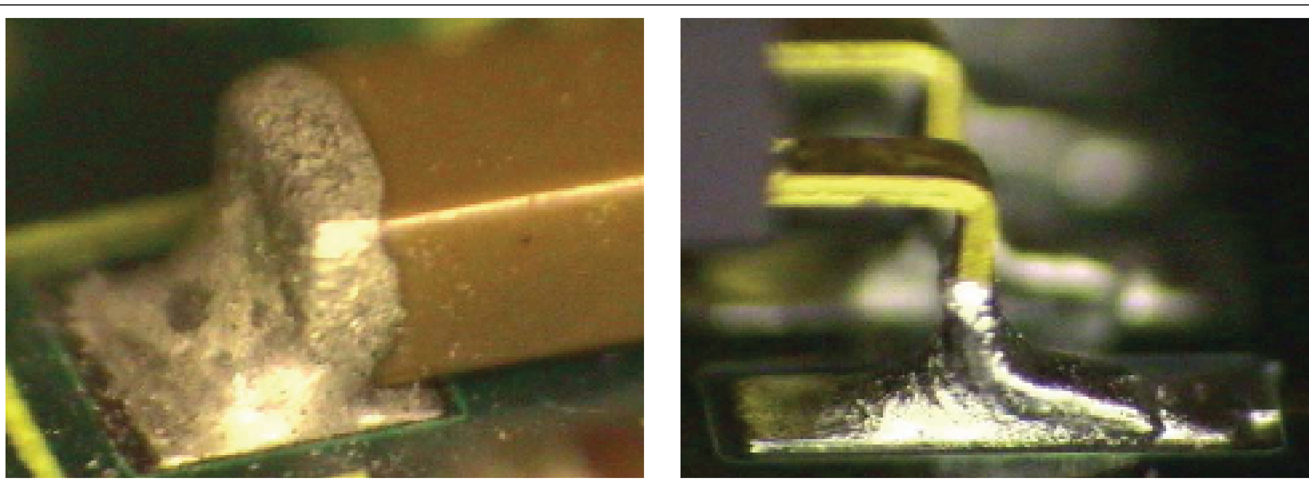
Lead-free solder joints appear different to tin/lead and therefore training may be required so that operators can recognise good and poor solder joints. The criteria in IPC - 610C, although originally written for tin/lead, should also apply to lead-free solder

Alternatives include:

PCB Coating	Limitations
Lead-free HASL	Need new equipment, pre-bake boards
Nickel/gold (ENIG)	Gives good protection and solderability for up to 1 year but most expensive option
Organic solderability	Low cost option, protection for up to 6 preservative months, very easily damaged
Immersion silver	Good compromise but tarnishes (sulphides)
Immersion tin	Good compromise but deteriorates in warm or humid conditions



Examples of tin lead solder joints



Examples of Tin/Silver/Copper solder joints

Rework and Repair

Spare parts for the repair of equipment put onto the market before 1st July 2006 are not within the scope of the RoHS Directive. Therefore these spares may legally contain the six restricted substances. By inference therefore, spare parts used for the repair of equipment put onto the market after this date, must not contain restricted substances.

The same types of rework tools that are used for tin/lead can be used for lead-free solders. It is advisable however to avoid mixing alloys so wherever possible, repair using the same solder as was originally used. Some combinations can give very poor reliability, in particular lead and bismuth.

The temperature will need to be high so there is a greater risk of damage to heat sensitive components and the PCB, including high aspect ration plated through holes.

More aggressive fluxes may be required. These can cause SIR, corrosion and dendrites problems.

Trouble shooting guide

No.	Defect	Cause	Solution
1	Poor wetting	i. Unsuitable flux ii. Surfaces oxidised or contaminated iii. Poor temperature control	i. Use different flux ii. Ensure surfaces are clean and oxide free - do not use parts beyond their use-by dates Rotate stocks of components and PCBs iii. Use equipment with better temperature control
2	No wetting	Part not hot enough Insufficient heating power for part to reach solder melting temperature in a short enough time.	Use equipment with good temperature control and sufficient power
3	PCB delamination	Moisture within laminate and incorrect temperature profile	Increase pre-heat time/temp. to dry PCB before reflow
4	PCB warping	High reflow temperature	Reduce reflow temperature Use high Tg laminate Re-design to eliminate stresses during reflow
5	Pop-corning of ICs	Moisture within package	Check moisture sensitivity level of component for lead-free processes. May need to store in dry environment or bake before use.
6	Cracked PTH	Stresses on copper due to high TCE of laminate. Drilling defects increase risk	Re-design with thinner laminate, larger diameter PTH, increase copper thickness, use low z-axis TCE laminate. Replace drill bits more frequently
7	Damaged components	Exceeded maximum temperature	Use alternative components if available Re-design to avoid heat sensitive components Use lower reflow temperature (may need new equipment)
8	Shorts on PCB (bridging)	Lead-free solders have higher surface tension than lead solder	Use hot-air knife after reflow Increase time above solder melting temperature Use different flux
9	Excessive number of solder balls	Incorrect solder reflow profile, incorrect flux	Modify profile, use more active flux
10	Voids in solder joints	Trapped gas from coatings or flux	Increase time of pre-heat and time above solder melting temperature.
11	Solder bonds fracture easily after reflow	Thick and brittle intermetallic layer formed	Decrease maximum temperature and time above solder melting temperature. Use nickel barrier layer under solderable coating
12	Short circuits occur in field	i. Tin whiskers form after period in service ii. Dendrites	i. Specify coatings with low susceptibility to tin whiskers ii. Use less active flux or clean to remove flux residues.
13	Open circuits occur in field due to thermal fatigue	i. High strain on solder joints ii. Poor solder wetting	i. Redesign to minimise joint strain. ii. Improve wetting - see 1.