Understanding Lead-Free Alloys

By Karl Seelig

One result of the push to find lead-free solder alternatives is that there are now many options available to the board assembler. Much development, patterning and research has gone into finding viable solutions for those who want to eliminate lead from their process. However, each of these alloys is different in significant ways and background information is necessary.

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The Alternatives:

Many of the new products are rich in tin with a variety of other elements added to enhance different characteristics. The most basic solders are binary alloys that have been used for years in non-electronic applications. Tin-lead has been a suitable standard alloy for many years simply because it meets most of the requirements for electronics assembly. However, with the urgent need for controlled recycling and reduction of hazardous waste related to finished products, the greater use of lead-free solders has led to the discovery of some of their noteworthy characteristics. For example, high joint strength, better fatigue resistance, improved high temperature life and harder solder joints are among the features seen in some of the newer materials. Nevertheless, it is important to remember that these benefits are very much dependent on the specific alloy. Not all lead-frees are created equally and each should be thoroughly investigated before implementation into production.

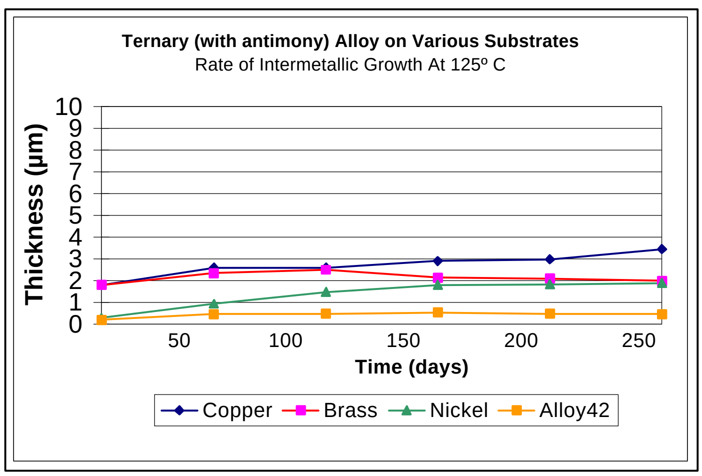
As a general rule, most lead-free solders melt at temperatures higher than those of tin-lead. The exceptions are alloys containing indium or bismuth, which tend to lower the melting point. The main "problem" with indium is its cost, with prices currently in the area of $150/lb. With approximately only 200 tons of indium produced globally each year, the supply is quite easily depleted and prone to drastic price fluctuation. Typically, choosing an indium-based lead-free alloy makes the most sense with temperature-sensitive components that do not require high joint strength and where the end product will not be subjected to harsh or high stress environments.

As for bismuth-based lead-free alloys, a lower melting temperature than that of tin-lead is offered together with a cost similar to that of tin (in the area of $3/lb.) Unfortunately, bismuth in soldering alloys tends to create embrittlement, and if a bismuth-based alloy picks up any lead, the melting temperature will drop again, causing joint embrittlement.

At first glance, the bismuth-bearing alloys appear to offer high tensile strength, but in peel strength tests they are prone to failure due to poor fatigue resistance. The same can be said for indium-based lead-free alternatives.

Tin/silver as a 96/4 alloy is fairly common and has a long history in the hybrid circuit industry. Unfortunately, with a spike temperature of 260°C, this alloy's melting point is too high for many surface mount applications.

Ternary tin/copper/silver alloys comprise a family of lead-free alternatives that show high promise. Sources of supply are sufficient and the alloys exhibit good wetting, fatigue resistance and good overall joint strength. One form * is doped with antimony and exhibits an advantage: It does not grow intermetallics with copper when soaked at 125°C (see chart). Antimony has been known to stop gray tin transformation at low temperatures and historically, the military required 0.2 to 0.5 percent antimony to enhance the thermal cycling properties of tin-lead alloys.



However, the issue of the toxicity of antimony arises. As with most metals, salts, oxides and organo-metallic compounds of antimony are typically the most toxic forms of the element.

They, however, do not form in standard soldering processes. Antimony has been approved for use in potable water systems as well as in food containers. In pewter tableware, which is commonly used in the preparation of food, antimony is often found at levels of 7 to 9 percent, and copper at levels of 1 to 3 percent. Further the antimony-doped alloy has been environmentally tested to confirm that it will not leach silver or copper into ground water. The accepted reason is that the two elements tied in the tin and antimony reduce their solubility.

Lead-free solders are available in paste, bar and cored-wire form, although the latter's manufacturability remains an issue for alloys that contain high levels of bismuth or indium, which tend to inhibit their drawing ability. Lead-free solders typically need higher soldering temperatures and successful implementation involves resolution of several critical issues.

- The physical (thermal and mechanical) needs of the joint.
- The temperature requirements of the components to be soldered. Most parts and board materials can take up to a 240°C spike, but some specialized exceptions remain.
- The field environment (temperature, acceleration and shear) of the end product.
- The phase-in period for a complete transition to a lead-free regime. (How long will tin-lead components and tin-coated PWB's be used during the transition period?)
- Repairs on in-field products. This may militate against using bismuth or indium-based lead-free alloys for assembly since lead significantly affects their melting points.

With a great number of ongoing and completed studies on lead-free soldering alloys available to the end-user, there is a wealth of information entering the public domain. Preliminary results suggest that the tin/silver/copper-based alternatives offer superior long-term reliability and joint strength for most applications and that antimony as an additive brings good high temperature soak characteristics.¤

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