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Application Notes

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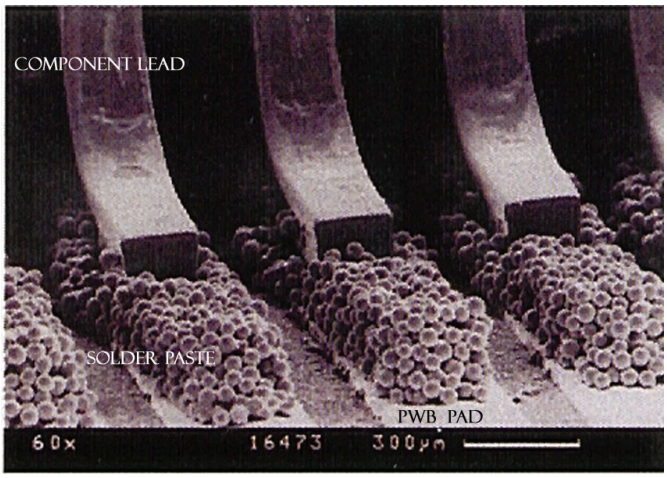
Lead Free Solder Alternatives

The introduction of legislation restricting the use of lead in consumer products, notably Japan and Europe has forced international manufacturers to reevaluate electronic assembly options. The recent IPC Works 99 conference was dedicated to the evaluation of alternatives for lead free soldering. Session topics included applications for printed wiring board finishes, solder paste for IR reflow (bars for wave solder), and component finishes. Separate discussions also covered related topics such as, reliability, cost and environmental issues. Analysis of the structure and composition of the solder joint reveals the contribution of each of the three surfaces is in the approximate weight ratio 75:20:5, for solder paste (or wave), PWB surface finish, and component lead finish respectively.

The finishes, paste, component and PWB, do not necessarily have the same composition and due to the divergent methods of their respective application, it is likely they will not be the identical. However, they must be compatible and provide adequate protection to the base material to be joined by the solder. Due to extensive industrial experience, good reliability record and low cost, a lead free solder system based on tin is the most desirable choice.

Criteria of Lead-free Solder Alternatives

- Nontoxic
- Available and affordable
- Narrow plastic range
- Acceptable wetting characteristics
- Easy manufacturability
- Acceptable processing temperature
- Form reliable joints



There exists, in the field of published literature, literally hundreds of possible alloy combinations vying as the preferred replacement for 63Sn/37Pb. The list of criteria for the candidate replacement is long and many contenders may fail based on a limitation in one or more of the selection criteria. Most of the metals proposed as alternatives for lead are less toxic than lead. Although there is, still debate regarding the relative benefits of the alternatives due to the interpretation of TCLP test results. Indium and silver although used in minor amounts will increase alloy costs and therefore are at an economic disadvantage. Alloys with otherwise attractive melting points will not become popular due to troublesome binary alloys (i.e. Sn/Bi) that may degrade assembly reliability. The absence of lead in the alternative alloys will reduce wettability and change the appearance of solder joints. The ability to manufacture lead free alternatives is judged approximately equal in ease for most applications. Although forming wire for hand soldering applications with tin/bismuth is difficult. The first consideration for lead free alternatives is usually based on melting point. Care must be exercised when selecting otherwise similar melting points and consideration given to the difference between the solidus and liquidus. Alloys possessing a wide differential or pasty zone are prone to cold joints. Finally, certain alloys such as the eutectic 42Sn/58Bi are prone to reliability problems known as fillet lifting.

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Lead Free Interconnect Alternatives

Component Finish	Solder Alloy	PWB Finish
Sn	99.3Sn, 0.7Cu	OSP (Entek 106)
Pd/Ni, Pd-Ni/Pd, Pd-Ni/Au	97.5Sn, 2.5Ag	Organo Silver
Ni/Au	Sn, 3.5Ag, 0.5Cu	Immersion Ni/Au or Ni/Pd
99.0Sn, 1.0Cu	Sn, 3.5Ag, 3Bi	HASL Sn, 0.7Cu Sn, 3.5Ag
Sn/Bi	Sn, 2Ag, 0.8Cu, 0.5Sb	Sn/Bi

PWB Surface Coating

Of the three components that contribute to successful soldering, the printed wiring board surface finish is the unit with the most successful alternatives. Lead free (HASL) hot air solder leveling, organo silver, organic solderability preservatives (OSP) and electrolytic or immersion coatings of Ni/Au, Pd/Ni, Pd, Ag, Sn, and Sn/Bi, all have varying degrees of successful manufacturing history. Considering that approximately 70 % of all PWB substrates are currently hot air solder leveled, continued evaluation of lead free solder HASL alternatives is certain. OSP's in conjunction with eutectic solder paste currently enjoy a majority of the remaining 30% share of the PWB surface finish market. OSP's are compatible with a variety of lead free solder pastes. But, OSP's are at a disadvantage when compared to the various metallic coatings. The future reduction in OSP proliferation is predicted based on the higher reflow and wave soldering temperatures demanded by the new lead free solder alternatives. When used with conventional eutectic solder pastes, OSP's have demonstrated sensitivity to elevated soldering temperatures, multiple temperature excursions or hand soldering rework cycles typically found in SMT assembly. It would appear that Sn/Ag or Sn/Cu HASL is likely to remain the preferred PWB surface finish. Of the remaining alternatives, the other metallic coatings will probably increase in popularity at the expense of OSP's.

Component Lead Finish

The absence of lead in the component coating reduces the wetting characteristics of the lead free solder. This phenomenon can be empirically determined by observing the wetting characteristics of lead free solders using any one of the industries accepted wetting tests. The appearance of solder joints and the comparisons of fillet coverage or lack there of demonstrated by Pd/Ni lead finishes also serve to distinguish solders with and without lead. Although bismuth is known to improve the wetting characteristics of lead free mixtures, it forms troublesome binary alloys with both tin and lead that will limit or preclude its usefulness. The anticipated higher melting temperatures of the lead free solders would improve the performance of Pd and Pd/Ni component coatings, but the limited solubility of Pd and the escalating cost make its wide spread use and adoption unlikely. In order to reduce melting points below 230 °C mixtures of two or more elements will be necessary. Of the possible tin based systems, Sn/Ag and Sn/Cu would be the most likely choices. Due to the significant differences in the electrode potentials of Sn and Ag the eutectic composition of Sn-3.5Ag would be difficult to electroplate, especially in dedicated high-speed equipment already in place for that task. Relatively low melting point (232 °C) low cost, familiar processing and good wetting characteristics keep pure tin on the list of component lead finishes. The pernicious formation of tin whiskers represents a serious reliability problem that is likely to eliminate pure tin from mass adoption as the finish of choice. Sn-0.7Cu (nominal 1.0 percent weight Cu) appears to be the most adaptable alternative for component lead finishes.

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Sn/Pb Solder Replacement

As the major portion of solder in a joint is supplied in bulk either as bar stock in the wave or screen printed paste, formulating a multi-element product with an appropriate melting point is relatively easier than the application for PWB surface or component lead finish. Although there are a number of alloy compositions with melting points below that of Sn63/Pb37, these alloys are prone to one or more problems. Alloys with significant amounts of indium tend to be relatively expensive. Alloys containing bismuth are subject to low cycle fatigue failure or fillet lifting. While alloys containing zinc are prone to corrosion. It may be argued that the above-mentioned disadvantages may not in and of themselves be fatal flaws for a potential candidate. But, in light of the number of potential candidates with equal or better performance characteristics literally any disadvantage from the list of design criteria may be sufficient to eliminate a candidate from further consideration.

Most conventional PWB laminates are sensitive to thermal degradation following one or more excursions above 260 °C. Component packages based on commonly used epoxy based compounds may sensitive to multiple assembly excursions above 245 °C. The commonly accepted rule of thumb applied to eutectic solder paste dictates an assembly temperature 40-50 degrees above the eutectic or 245 °C which ever is lower. Although lower assembly temperature is clearly desirable, the low temperature alternatives exhibit one or more undesirable characteristics. For these reasons, a closely grouped list of alternatives with melting points of approximately 220 °C appears to provide the best all around compromise.

Major Lead Free Solder Replacements

Alloy System	Composition	Melting Point
Sn/Ag	Sn,3.5Ag	221(e)
	Sn,2Ag	221-226
Sn/Cu	Sn,0.7Cu	227 (e)
Sn/Ag/Bi	Sn,3.5Ag,3Bi	206-213
	Sn,7.5Bi,2Ag	207-212
Sn/Ag/Cu	Sn,4Ag,0.5Cu	217*
	Sn,4.7Ag,1.7Cu	217*
Sn/Ag/Cu/Sb	Sn,2Ag,0.8Cu,0.5Sb	216-222
Sn/Zn/Bi	Sn,7Zn,5Bi	170-190

* Eutectic point not agreed

A number of international manufacturing companies have made successful consumer applications with Sn/Ag, Sn/Ag/Cu, and Sn/Cu pastes joining lead free components and PWB's. At this time assembly with all three alloys have been demonstrated successfully and further long-term evaluation will determine the alloy of choice.