

Part 2: Lead-free Implementation Alloys for Two Approaches

This is a four-part series. Part 1 outlined the two primary options in implementing lead-free electronics, while Part 2 provides the viable solder alloys for either of two approaches. Part 3 will illustrate successful lead-free implementations, and Part 4 summarizes critical production parameters.

Manufacturing vs. Alloy Design¹

Lead-free soft solder compositions for use in interconnections in electronic packaging and assembly must be made of Sn-based material. Effective alloying and doping elements to strengthen the Sn-matrix include Ag, Bi, Cu, In, Sb, Ga and Se. Metallurgical interactions and microstructure evolution in relation to temperature rising and changing are critical scientifically to developing new lead-free solders. Binary phase diagrams offer general information about the conditions and extent of metallurgical interactions.

Lead-free materials have been studied thoroughly over 14 years of research. Basic material properties, such as liquidus/solidus temperature, electrical/thermal conductivity, and intrinsic wetting ability on the commonly used substrates, mechanical properties and ambient shelf stability have been gauged. The conductivity and shelf stability are not as sensitive to the makeup of a specific alloy system as intrinsic wetting ability, mechanical performance and phase transition temperatures. Optimizing all necessary properties through in-depth application of materials science and metallurgical phenomena is key.

Lead-free solder alloys must possess characteristics compatible with practical manufacturing techniques, other constituents of the system and end-use environment. Understanding practical and process parameters in relation to the fundamental alloy properties is paramount to the success of lead-free implementation. Specific attention should be paid to the ability to accommodate a wide array of assemblies and applications. The focus also should be on the capacity to absorb fluctuations inherent with SMT manufacturing.

As outlined in Part 1, there are two parallel approaches to implement lead-free systems. The two approaches are distinguished by the process temperature, which in turn is dictated by alloy melting temperature.

Modification Approach

This approach corresponds to a relatively higher process (soldering) temperature (> 235°C for reflow and > 245°C for wave). Under these process conditions, eutectic and near-eutectic SnAgCu compositions are the top choices. In this case, the Sn-matrix primary is strengthened by the hard phases (intermetallics) through building long-range internal stress. These hard particles also can serve as effective blocks for fatigue crack propagation, and are expected to partition the Sn-matrix into finer grains. This, in turn, facilitates grain boundary gliding mechanisms, accounting for the extended fatigue lifetime under elevated temperatures.

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Although the mechanical properties correlate precisely with the percentage of Ag content and Cu content, respectively¹, overall performance of the compositions covering Ag in the range of 2.5 to 4.1 percent and Cu in 0.4 to 1.5 percent is considered satisfactory with respect to general manufacturing. They compare favorably with 63Sn37Pb, 96.5Sn3.5Ag and 99.7Sn0.3Cu under prevalent testing conditions.

Drop-in Approach

This approach works with the existing soldering process (i.e., < 235°C for reflow and < 245°C for wave). To fit in with the existing soldering process, it takes enhanced SnAgCu alloys (in addition to Sn3.0-4.0Ag1.0-3.0Bi1.0-8.0In compositions). The enhancement not only lowers the alloy's melting temperature but also enhances intrinsic wetting ability. Furthermore, the enhancement reduces the dross in the wavesoldering process. SnAgCu enhanced by In or Bi falls into this category. Their mechanical properties, particularly fatigue resistance, also are better than SnAgCu. The superior mechanical properties of enhanced SnAgCu compositions are well understood based on the sound material science fundamentals — the alloys are enhanced not only by the hard phases but also by the solution-strengthening mechanism (i.e., Labush's statistical theory). This dual strengthening mechanism works synergistically. It can hardly surpass the nearly miraculous effects of indium on both Ag and Cu as well as on Sn, making SnAgCuIn the star performer.

It is acutely important in manufacturing success to exercise best practices; that is, to identify the temperature tolerance level of the assembly system first, and from that to select the right approach and thus the proper lead-free alloy for SMT manufacturing. This is the right way to assure high production yield and service reliability.

Reference

1. Jennie S. Hwang, "Environment Friendly Electronics: Lead Free Technology," Electrochemical Publications, Great Britain, 900 pages (ISBN: 0 901 150 401)

Dr. Jennie Hwang, an SMT Advisory Board member, has been elected to the National Academy of Engineering, inducted to the WIT International Hall of Fame and named an R&D-Stars-to-Watch. During 22 years of SMT manufacturing, she has helped improve SMT production yield and solved various field failure problems and reliability issues. She has also shared her experiences and knowledge in authoring more than 200 publications, including the sole authorship of several textbooks, and in lecturing to more than 10,000 professionals worldwide. She holds two M.S. degrees in organic and physical chemistry and a Ph.D. in materials science and engineering. Contact her at (216) 839-1000 or e-mail: JSLHWANG@aol.com.

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