CHAPTER 23

BISMUTH ADDITION IN SN-AG-CU LEAD-FREE SOLDER

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ABSTRACT
Sn-Ag-Cu solder is a form of solder to replace Sn-Pb solder in electronic device soldering. Sn-Ag-Cu however, consists of various weaknesses when compared to traditional Sn-Pb solder in terms of mechanical properties and reliability. Alloying with elements such as bismuth, can be one of the methods to improve the solder properties. Therefore, a short review is carried out to understand the improved performance with bismuth doping in the solder melting temperature and reliability testing.
Keywords: Sn-Ag-Cu; bismuth; alloying; reliability; mechanical cycling.

INTRODUCTION

The advancement in technology has brought about an increase in demand for new alternatives to enhance the performance, functionality, and reliability of electronic devices. The soldering industry, along with the mandatory banning of tin-lead (Sn-Pb) solder, has urged the introduction of lead-free solder, including ternary tin-silver-copper (Sn-Ag-Cu) systems, which have since been one of the renowned solder types used in second-level interconnects of printed circuit board (PCB) assembly, thanks to their considerably low melting point and good wetting properties, making them one of the solder types with high compatibility with both traditional and modern board technologies. However, to produce Sn-Ag-Cu solders with ideal performance, different alternatives have been taken by scholars, including mechanical alloying of Sn-Ag-Cu solders. Alloying elements such as bismuth (Bi) serve as crucial factors in enhancing solder performance due to their capability of improving the solder's mechanical properties and reliability. Bi was found to be exceptional in enhancing the mechanical properties of lead-free solder due to its high solid solubility in the Sn matrix, where Bi tends to embed itself in Sn dendrites, thus hindering the movement of voids and preventing dislocation motion when exposed to mechanical or thermal stress. Since Bi only reacts with Sn to form the intermetallic compound (IMC) layer, the Bi atom helps to slow down the diffusion rate of the

Cu atom, thus assisting in controlling the growth of the IMC layer, which improves performance in aging and reliability testing.

BISMUTH AS AN ALTERNATIVE IN Sn-Ag-Cu SOLDERS

Melting temperature

Melting temperature is extremely crucial in clarifying the applicability of a solder in an assembly process for either first-level or second-level interconnects, as it impacts the set reflow temperature for a PCB during reflowing. Therefore, with the consideration that manufacturers are still highly dependent on traditional board technologies with glass transition temperatures having high adaptability to the melting temperature of Sn-Pb solder at 183 °C, the creation of a Sn-Ag-Cu solder system with a temperature as close as possible to the respective temperature turns out to be an essential task pursued by researchers. Enhancement alloys such as Bi thus emerge as ideal dopants due to their ability to lower the eutectic temperature of Sn-Ag-Cu solder, which decreases inversely with increasing Bi composition until it reaches its saturation point at 3%. Above 3%, the brittleness of Bi dominates the overall mechanical property of alloyed solder and deteriorates its yield strength, fatigue life, and characteristic reliability [1]. Its brittle nature thus refrains scholars from utilizing 58Bi-Sn solder despite its low temperature of 138°C. Figure 1 shows the microstructure of Sn-Ag-Cu alloyed with 3% Bi.

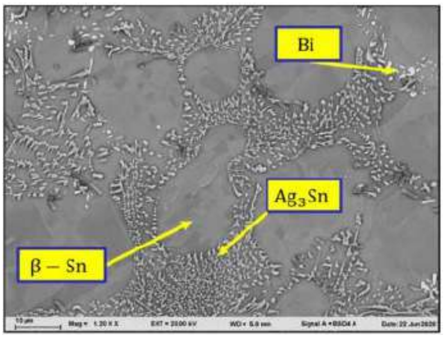

Figure 1. Microstructure of 92.5Sn-4.0Ag-0.5Cu-3.0Bi-0.02Ni [2].

Reliability of Sn-Ag-Cu-Bi in mechanical cycling

Assembled PCBs may be exposed to various forms of loading during actual service, either thermal or mechanical. Similar to thermal cycling, JEDEC standards define mechanical cycling as a form of load cycling under flexural instead of thermal stress to identify the product lifetime of a soldered PCB before product delivery to ensure robust mechanical and electrical connections between components and soldered boards. Mechanical cycling, however, does not restrict itself to only flexural bending but can be done through the introduction of force at different axes, either on a board or a reflowed solder bulk. For instance, with the aid of a universal six-axis load cell testing machine, cyclic stress in the form of tension, compression, and torsion can be exerted on a reflowed solder bulk specimen when placed within an aging chamber at 200°C [3]. Despite Bi's excellent performance in resisting the aging effect of Sn-Ag-Cu solders, in mechanical cycling, intergranular cracks can be observed along the grain boundaries, as shown in Figure 2 for either the case of pure or doped SAC305, but with a larger creep in pure solder, indicating the ability of Bi in enhancing mechanical cycling reliability [3]. The SEM image in Figure 2 further proves that instead of slip line steps that formed prior to intergranular cracking as observed in the case of SAC-Bi solder, transgranular cracks were observed beyond the grain boundaries of Sn dendrite in the case of pure SAC305 with continuous mechanical loading. At the level of PCB, however, a solder sphere can be mechanically cycled with the upper surface of a solder ball constantly exposed to shear stress in a micromechanical tester [4]. Mechanical cycling is also explored as an alternative approach to thermal cycling due to its shorter cycling period, which optimizes the duration for product delivery [5]. Nevertheless, the full performance of SAC-Bi in cyclic flexural testing is yet to be known.

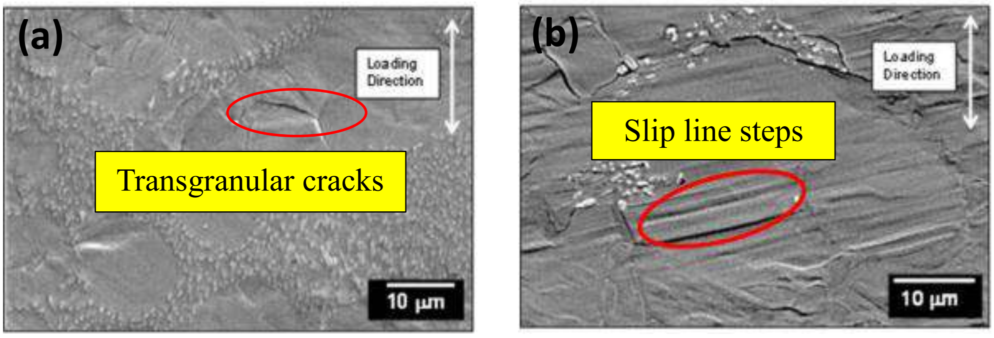

Figure 2. Microstructure of cracked samples for (a) pure SAC305 and (b) 3.0% bismuth doped SAC305 solders [3].

CONCLUSION

In conclusion, bismuth (Bi) greatly enhances the performance of a Sn-Ag-Cu solder by improving its mechanical properties and performance. It is well known that Bi has a high resistance to aging effects, and it also performed better in reliability testing. Thus, it is a good option as a dopant to be further explored in this specific application.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support and opportunity given by the Faculty of Engineering, Universiti Putra Malaysia. Micron Memory Malaysia Sdn. Bhd. through Research Grant (6300426-10801) and Universiti Putra Malaysia (UPM) for providing the necessary resources and support.

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