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Processing treatment of a lead-free Sn–Ag–Cu–Bi solder by rapid laser-beam reflowing and the creep property of its soldered connection

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Abstract

In this study, the processing performance of a lead-free Sn–Ag–Cu–Bi solder after rapid laser-beam reflowing was investigated, and the creep behaviors of the soldered joints were evaluated under different homologue temperatures from 0.68 to 0.82, with a systematical comparison to that of a Sn60Pb40 solder. The results show that after rapid laser-beam reflowing treatment the strength of the solder connections has been increased obviously and this is mainly due to grain refining effect and the Cu alloying effect; the lead-free Sn–Ag–Cu–Bi solder joints show a superior creep resistance in terms of a much lower creep rate and the elongated creep fracture lifetime over the traditional Sn–Pb solder.

Keywords: Reflowing process; Laser-beam treatment; Lead-free solder; Thermal creep

1. Introduction

Recently, in microelectronic and optoelectronic industry, it has been widely accepted that the traditional tin–lead (eutectic or close to eutectic composition) solders should be substituted by lead-free solders. One of the reasons for this trend is that both the scientific community and the general public have recognized the harmful influence of lead on environment and health, i.e., lead causes severe health damage. Thus, the materials containing lead are under constant regulatory and consumer pressure to reduce or eliminate toxic lead in most products. Another reason for lead-free trend is that, along with the increased functionality and miniaturisation of modern electronic, optoelectronic and photonic components at more stringent operational temperatures and stresses, the widely used traditional tin–lead solders would no longer satisfy the high performance standard required, such as excellent creep resistance and high size stability of the packaging systems. Consequently, these have pushed forward many recent research and development activities on lead-free solders. Thus far, over 100 solder patents have been granted, despite not all of these solders are commercially available for use in industry [1–5].

In search of appropriate lead-free solders for electronic packaging applications, the melting temperature of solders is a big concern, as it is the fundamental performance characteristics of a solder. For these applications, the melting temperature of the solder determines the maximum allowable temperature a product can be exposed to in service and the maximum processing temperature that devices and substrates can withstand during soldering. There is a commonly asked question, that is, which of these lead-free solders would be the most appropriate for the replacement of traditional tin–lead solders, but it is not easy to give simple answers since there is no absolute drop in replacement for Sn–Pb solders with identical melting-point, wetting performance, mechanical properties, and cost [1,3].

Currently, there are several promising candidate lead-free solders for consideration of different applications, including Sn–Ag, Sn–Cu, Sn–Ag–Bi, Sn–Zn and Sn–Ag–Cu systems. And among these candidates, the near-ternary eutectic Sn–Ag–Cu system solders, with the melting-point around 217–219 °C [6], seem to be more promising as the substitute for Sn–Pb based solders. However, the melting-point of Sn–Ag–Cu system solder is over 30 °C higher than that of Sn–Pb eutectic solders (i.e., 183 °C). This has led to an increased soldering temperature and slightly deteriorated the processing performance of the solder compared with Sn–Pb eutectic solders. Thus, it is expected to improve the processing performance of Sn–Ag–Cu system solders by lowering melting temperature and decreasing surface tension of the solder when melting. Some studies had shown that the addition of element bismuth (Bi) to tin based solders can reduce melting temperature [7], decrease sur-

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face tension and thus improve processing performance [8] of the solder. However, the addition of bismuth may also result in brittleness of the solder and deteriorate mechanical property of the soldered joints. In this study, the reflowing performance and thermal creep behavior of a lead-free Sn–Ag–Cu–Bi solder, where the element Bi with an amount of 2.0–3.0% (wt) was added to Sn–3.5Ag–0.7Cu solder to form a Sn–Ag–Cu–Bi system solder, were characterized at different temperatures, with a systematical comparison to a traditional Sn60Pb40 solder.

2. Materials and experiments

The Sn–Ag–Cu–Bi solder was fabricated by rapid solidification (i.e., melt spinning) method. The melting temperature of this solder is measured with a DSC being 214–223 °C, which is 3 °C lower than that of Sn–3.5Ag–0.7Cu with a single melting temperature of 217 °C. A Sn60Pb40 solder foil (melting temperature: 183–190 °C) was used for comparative study. Rapid laser-beam reflowing of two solders was conducted by a 50 W Nd: YAG laser with an appropriate energy density by focusing the laser-beam to a diameter of about 2 mm. Fig. 1 illustrates the configuration of laser-beam reflowing and then leads soldering on a PCB. After reflowing soldering, the samples were loaded in shear mode till fracture by an Instron 5567, then the shear strength of the reflowed samples can be obtained. It should be indicated that after reflowing soldering, it is difficult to measure exactly the total soldering connection area of pitches in the designed package (see Fig. 1), and thus to evaluate the strength in terms of stress. Therefore, in this study, the shear fracture load is used to evaluate the difference of the joining strength between two solder joints (lead-free Sn–Ag–Cu–Bi and Sn40Pb60 solders), other than stress. This is acceptable for a comparative study.

For creep test, dog-bone shaped soldering joint specimens were prepared by a hot-plate using a liquid activated-rosin flux. The geometry of the soldered joint specimens is shown in Fig. 2, which is close to the size of real soldering connections in packaging for surface mounting components. The creep tests were performed using a DMA (Q800, TA-Instruments) at different temperatures from 35 to 125 °C.

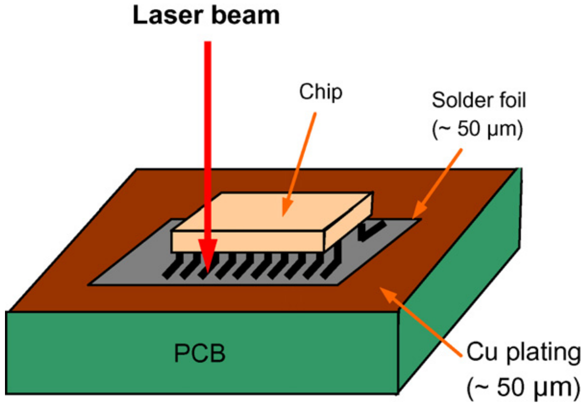

Fig. 1. Laser-beam reflowing and leads soldering on the PCB (without use of flux).

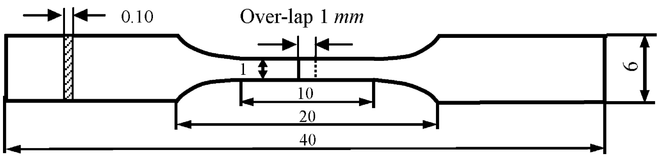

Fig. 2. Dogbone-shaped lap-shear soldered joint for creep test.

3. Results and discussion

3.1. Influence of rapid laser-beam reflowing on the strength of soldered connections

The results of shear strength of the soldered samples with rapid laser-beam reflowing and leads soldering (non-reflowed) are shown in Fig. 3. It is clear that for either Sn–Ag–Cu–Bi solder or Sn60Pb40 solder, the soldered connections after rapid laser-beam reflowing have higher strength. In particular, there is a more obvious increase in strength for Sn–Ag–Cu–Bi solder, from 14.5 N to 20.4 N, which corresponds to an increase by 40%, in comparison with Sn60Pb40 solder from 14.8 N to 18.7 N corresponding to an increase of 25%. This increase in strength after reflowing is mainly due to the grain refining effect which is caused by the rapid solidification of the solder followed the rapid laser-beam reflowing. It has been measured that the cooling rate of the solder after laser-beam reflowing was as high as 10^5 °C/s. Under this cooling rate, the rapid solidification of the solder occurs and primary crystallites re-solidify into smaller grains whose size is as small as 1–2 μm, compared with ~5 μm for non-reflowed solders. In addition, another contribution to the increase of strength after reflowing is the strong diffusion of copper to soldered joints, i.e., the Cu alloying effect in the solders. It had been shown that, as a result of rapid laser-beam reflowing, the Cu concentration within the joint volume increases; for example, Cu concentration was ~12% in the soldered connections of PbSn60 without reflowing, while increased to 27% after laser-beam reflowing [9], and this has led to a strong alloying effect in solder joints.

3.2. Creep behaviors of soldered joints at different elevated temperatures

Creep tests were conducted at different homologue temperatures for soldered connection joints of the two solders, that is, 0.68, 0.72 and to 0.76 (i.e., 35, 55 and 75 °C, respectively) for Sn60Pb40 solder, 0.71, 0.77 and 0.82 (i.e., 75, 100 and 125 °C)

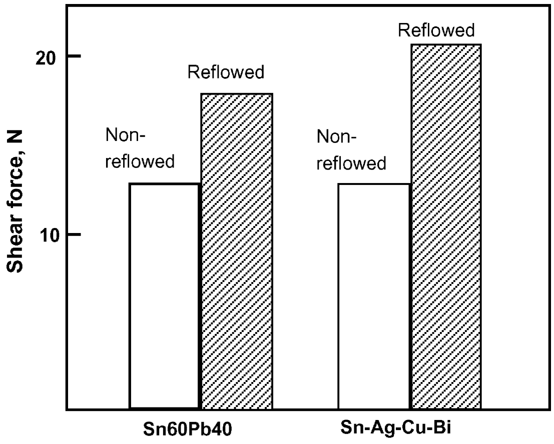

Fig. 3. Strength of the soldered connections with and without laser-beam reflowing.