Materials Science and Engineering A 420 (2006) 55–62

MATERIALS SCIENCE & ENGINEERING A

www.elsevier.com/locate/msea

Mechanical and microstructural properties of SnAgCu solder joints

Janne J. Sundelin [a,*], Sami T. Nurmi [b], Toivo K. Lepistö [a], Eero O. Ristolainen [b]

[a] *Institute of Materials Science, Tampere University of Technology, P.O. Box 589, FIN-33101 Tampere, Finland*
[b] *Institute of Electronics, Tampere University of Technology, P.O. Box 692, FIN-33101 Tampere, Finland*

Received 1 March 2005; received in revised form 1 January 2006; accepted 1 January 2006

Abstract

Mechanical and microstructural properties of SnAgCu solder joints with hypoeutectic, eutectic and hypereutectic compositions were studied. Eutectic SnPb joints were used as the reference. Reflowed lap shear specimens made of FR-4 glass epoxy printed circuit boards with OSP and NiAu surface finishes were used in the tests. Mechanical properties and microstructural features of the joints were examined in the as-reflowed condition and after isothermal aging at 85 °C for 1000 h. Both the composition and PCB surface finish had a notable effect on the mechanical behaviour of the SnAgCu solder joints. The shear strength value of SnAgCu solder joints was mainly dependent on the size and distribution of Ag_3Sn dispersions. The coarseness of the dispersions depends strongly on the amount of Ag in the solder alloy, the cooling rate after the reflow and the aging history of the solder joints.

Keywords: Lead-free; Solder; SnAgCu; Shear strength; Aging

1. Introduction

Environmental and health concerns of lead have increased the pressure towards the lead-free soldering in electronics industry. Most of the commercial electronic products, which are put into market in EU, will be urged to qualify the lead-free regulations defined by RoHS directive, which will come into effect as soon as 1 July 2006. Therefore, a large scale transition from SnPb to lead-free solder alloys is on hand globally. SnAgCu has quite commonly been considered as the most viable replacement for SnPb. However, detailed studies of the effect of PCB surface finish and SnAgCu composition on the microstructure and mechanical properties of SnAgCu solder joints have been quite limited.

Organic solderability preservative (OSP) surface finish is used on Cu pads mainly to prevent oxidation of Cu. Experimental studies have shown that OSP does not affect the metallurgy of the solder joints. The use of NiAu surface finish is generally argued by the fact that Ni barrier prevents the diffusion of Cu atoms into the solder and thus excessive growth of intermetallic compounds [1]. The role of a thin Au layer used on Ni is to improve wetting properties, and to protect the pads from corrosion. The strength properties of SnAgCu solder joints on OSP and NiAu have been studied by a few research groups [2–4]. Their results are, however, contradictory with each other.

Several SnAgCu compositions for replacement of traditional SnPb solder alloys have been proposed by different consortia; in Japan 96.5Sn3.0Ag0.5Cu, in US 95.5Sn3.9Ag0.6Cu, and in EU 95.5Sn3.8Ag0.7Cu. The mechanical and microstructural properties of solder alloys in this composition scale have been studied in some extent. Kim et al. [5] found that both the cooling rate and the composition will affect the size of Ag_3Sn dispersions in SnAgCu solder alloys, and this in turn was suggested to affect the mechanical properties of the alloys. Shiau et al. [6] proposed that Cu content in SnAgCu solder significantly affects the formation of intermetallic layers. Reliability of SnAgCu solder joints with different compositions in BGA packages have also been studied [7,8].

Detailed studies on the effect of PCB surface finish on the shear strength of solder joints and their microstructural features are scarce. In the present work these features are studied.

2. Experimental

Mechanical properties of SnAgCu solder joints were measured by using special single-overlap shear specimens. The PCB specimens were made of glass epoxy FR-4 with a glass tran-

* Corresponding author. Tel.: +358 3 3115 2985; fax: +358 3 3115 2330.
E-mail address: janne.sundelin@tut.fi (J.J. Sundelin).

0921-5093/$ – see front matter
doi:10.1016/j.msea.2006.01.065

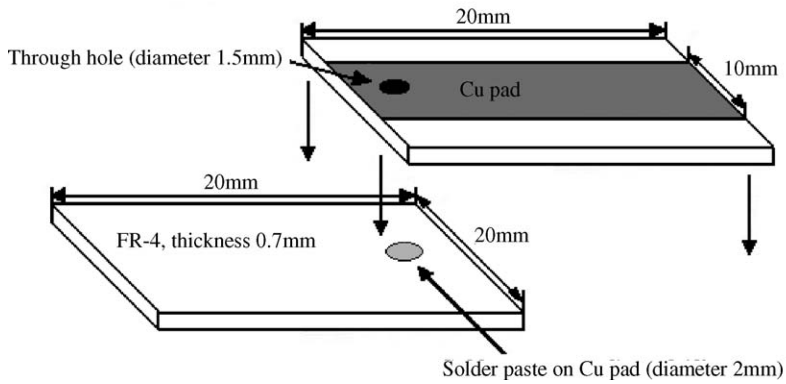

Fig. 1. Schematic presentation of the single-overlap specimens used in the shear tests.

sition temperature T_g of 180 °C. The PCB material consisted of four layers. Copper pads in the specimen, thickness 50 μm, were plated either with organic solderability preservative (OSP) or immersion gold over electroless nickel (NiAu). The design of the specimens used is shown in Fig. 1. The lower part of the specimen had a pad with a diameter of 2 mm and a via with a diameter of 1 mm and a depth of 0.2 mm. The purpose of the via was to prevent pad detachment from the PCB during shear testing. The solder paste was hand-printed on this pad using a stencil 200 μm in thickness. The upper part of the specimen had a large 10 mm × 20mm copper area with a through-hole of 1.5 mm in diameter. The upper part of the specimen was carefully laid on the lower part so that the through-hole was located on the printed paste. The role of hole was to allow the formed voids to drift away from the critical area of the joint and thereby to not affect crack propagation during the shear test.

The test matrix of mechanical tests included three different SnAgCu pastes with compositions, in weight percents, 96.5Sn3.0Ag0.5Cu, 95.5Sn3.8Ag0.7Cu, and 95.5Sn4.0Ag0.5-Cu. These compositions are hypoeutectic, eutectic, and hyper-eutectic, respectively. The solidus temperature of the SnAgCu solder in this composition range is 217 °C, and the liquidus temperature in the range of 217–224 °C. An Sn63Pb37 solder paste was used as a reference.

The soldering of the specimens was conducted in an industrial reflow oven with seven heating zones and one cooling zone. The reflow profile was a typical lead-free profile for SnAgCu with a peak temperature of 243 °C and a 40 s time above melting temperature (217 °C). The reflow profile is presented in Fig. 2. The tin–lead profile consisted of a peak temperature of 222 °C and a time above melting temperature (183 °C) of 37 s.

Some of the specimens were subjected to isothermal aging after the reflow process. Aging was performed in a conventional heat chamber at fixed temperature of 85 °C for 1000 h. The strength of the solder joints was measured in an universal Instron 4411 test machine in the as-reflowed condition and after thermal aging. Five tests were performed for each solder/surface finish combination in both the as-reflowed and aged conditions. The specimens were loaded and strained to failure at room temperature using a displacement rate of 2 mm/min.

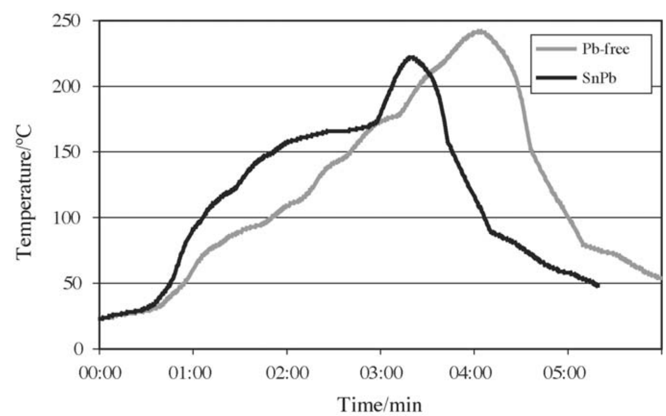

Fig. 2. The reflow profiles for SnAgCu and SnPb solder joints.

Cross-sectional samples were made after the shear tests from each solder/surface finish combination for microstructural characterization. The microstructure of the solder joint was analyzed with a scanning electron microscope (SEM) Philips XL30 and the compositional data was obtained with energy dispersive spectrometer (EDS) Edax DX4. Also, the paths of the fracture were studied with samples taken from the joints fractured in the pull test.

3. Results

3.1. Shear test results

The composition of SnAgCu solder affected the shear strength of solder joints, as can be seen in Fig. 3. In the joints on OSP, the joints with eutectic composition had the highest strength value after the reflow. The hypoeutectic SnAgCu joints had the second highest strength value, and the hypereutectic joints the lowest strength value of the SnAgCu joints. In the SnPb joints the strength values were lower than those in all SnAgCu compositions. In the joints on NiAu, the differences between different compositions of SnAgCu were clearly smaller than in the joints on OSP. The measured shear strength values are at the same level, when the limit of error is taken into account, and comparable to those of the SnPb joints.