Effect of addition of alumina nano whisker on microstructure and mechanical properties of a lead-free tin based solder

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Abstract

In present study the microstructure and mechanical properties of Sn-57Bi-1Ag based composite solder joints reinforced by different amounts of Al_2O_3 whisker were investigated. By addition of different amounts of Al_2O_3, solder microstructure, interfacial microstructure, shear strength and fracture surfaces of the joints were investigated. Microstructural examinations were done using scanning electron microscope (SEM). An Energy Dispersive Spectrometer (EDS) was employed for elemental analysis. The shear strength of the soldered samples was measured using a shear testing method. All fracture surfaces were observed by field emission scanning electron microscope (FSEM) to reveal the fracture mechanism and morphologies. The results show that addition of Al_2O_3 whisker in a proper amount reduces the grain size of the microstructure and improves the strength of the joints. Addition of 0.25 wt% ceramic reinforcement to the composite increased shear strength up to 24% (from 49/3MPa to 61/1MPa). In addition, when the amount of Al_2O_3 whisker increased to 0.25 wt%, a layer of intermetallic compounds (IMCs) formed between the bulk solder and the Cu substrate. It was also revealed that scallop-shaped Cu_6Sn_5 IMC morphology became slightly flattened, which caused the fracture path to shift from the IMC/solder interface to inside the solder matrix.

OBJECTIVES

Eutectic composition of Sn-58Bi because of its lower melting point (138°C) compare to Sn-37Pb (183°C) and also lower price and producing acceptable joints has been extensively substituted with lead containing solders in electronic industries [1]. However, this alloy, due to the presence of a Bi rich phase is hard and brittle [2]. Besides, low ductility of this alloy makes it weak against thermal and mechanical shocks. Also, metallurgical reactions between the solder and the copper substrate during soldering process results in formation of intermetallic compounds such as Cu_6Sn_5 at the solder/substrate interface that weakens the joint strength [3]. Among reinforcing materials, whiskers have received attentions during recent years [4, 5]. The aim of the recent investigation was to study the effect of addition of alumina nano whisker on microstructure and mechanical properties of a Sn-57Bi-1Ag solder. Addition of 1wt% Ag improves toughness of the solder [4] .

MATERIALS & METHODS

Sn, Ag, and Bi powders with purity of 99.9% (Merck, Germany) with average particle size of about 40, 63, and 40 µm respectively were used to prepare the solder alloy. These powders in stoichiometry amounts were mechanically milled under Ar atmosphere for 30 minutes at 200 rpm to produce 42Sn-57Bi-1Ag alloy. After alloying, alumina nano whisker (Sigam-Aldrich) with average length and diameter of 2.5 and 0.3 µm respectively was added to the solder in different amounts mainly 0.25, 0.5, and 1 wt% to make a composite solder. To perform joining experiments, a copper sheet with purity of 99.9% was cut into samples having dimensions of 10x10x5 mm^3. Then adequate amount of the solder alloy mainly 0.13 gr was mixed with almost 0.01 gr flux and placed between clean surfaces of the copper substrates. The sample was then placed inside a graphite jig to prevent movement of the sample during soldering process. The assembly was then placed inside a resistance furnace under Ar atmosphere and heated up to 180 °C and held for 5 minutes. After soldering, samples were cooled to room temperature, mounted and sectioned perpendicular to the joint area.

For microstructural examinations and chemical composition analysis a scanning electron microscope (SEM, VEGA/TESCAN) equipped with an energy dispersive x-ray spectrometer system was used. In order to evaluate the strength of the joints, a shear testing method was employed using a universal testing machine (SANTAM STM15).

RESULTS

Figure 1 shows scanning electron microscopy images of the solder layer. In All images the light and dark zones belong to Bi and Sn rich phases respectively From these figures it can be concluded that by addition of 0.25% alumina whisker the joint microstructure becomes finer. As can be seen, the grain size of the eutectic structure of $\beta - Sn$ and the Bi rich phase have reached to their lowest value which would result in improvement of mechanical properties of such joints. This is due to the fact that presence of alumina nano whisker in the molten solder act as nucleation sites for a non-homogeneous nucleation. Therefore, addition of small amount of whisker results in finer microstructure. However, addition of higher amounts of whisker into the solder does not prevent the grains of the Bi rich phase to grow. This is because of the fact that alumina whiskers become agglomerated resulting in lower influence in grain refining.[5]. presence of intermetallic compound of Cu_6Sn_5 is evident. The morphology of this layer in the sample having 0.25% whisker in its composition is smoother compare to other samples, which helps in improvement of joint strength. Figure 2 shows the shear strength of the joints vs the alumina whiskers content. From the figure, it can be seen that the strength of the joints increase from almost 49 MPa for the joints with 0% whisker to about 61 MPa for the samples having 0.25% whisker in their solder composition. Further increase in the whisker content resulted in lower joint strength. As mentioned previously, by increasing the percentage of the whisker the joints microstructure become coarser and interfacial layer of intermetallic become thicker. These are the main sources of reduction in the joint strength.

The SEM images in Figures 3 and 4 represent the fractured surfaces of the samples soldered using whisker free alloy and samples containing 0.25 and 1% whisker in their solder composition. From the figures, it was revealed that all the surfaces represent brittle fracture which is due to inherent brittleness of the constituent phases within the solder layer. The fracture path for the sample with no whisker is along the interface close to the intermetallic compounds (Figure 3a). For the sample with 0.25% whisker the surface is smoother and fracture has occurred along the interface but has changed direction into the matrix of the solder. This sample had the highest joint strength. However, for the sample having 1% whisker, the fracture surface is very rough which indicated a very brittle manner (Figure 4). This sample had the lowest strength value compare to the samples having 0.25 and 0.5% whisker in their solder composition.

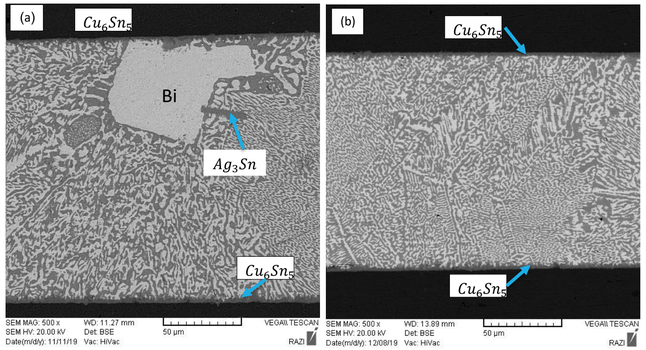

Figure 1. SEM images of the solder layer, a) without whisker b) with 0.25% whisker c) 0.5 and d) with 1wt% whisker.

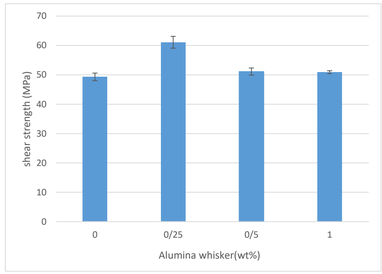

Figure 2. Shear strength vs the amount of alumina whisker in the solder alloy.

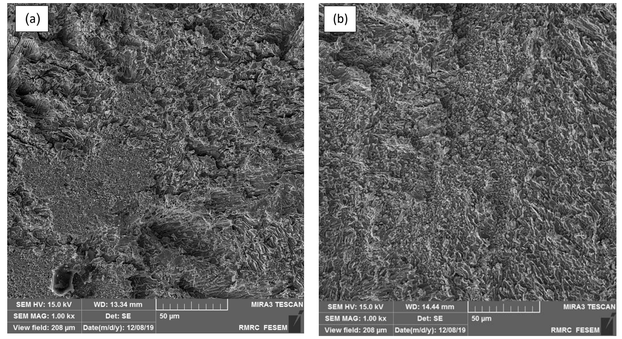

Figure 3. Fractured surfaces of the samples a) without whisker and b) with 0.25% whisker.

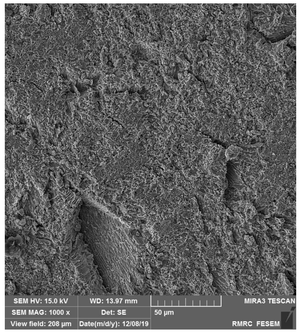

Figure 4. Fractured surfaces of the sample containing 1% whisker.

CONCLUSIONS

From the results of this study it can be concluded that mechanical alloying can be employed to prepare a bismuth-tin solder. Addition of alumina whisker modifies the microstructure of the solder layer. It also affects the shear strength of the joints. The highest strength value obtained was about 61 MPa and belongs to the samples having 0.25 wt% alumina whiskers in their solder composition.

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