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EFFECT ON MICROSTRUCTURAL AND PHYSICAL PROPERTIES OF Sn-3.0Ag-0.5Cu LEAD-FREE SOLDER WITH THE ADDITION OF SiC PARTICLES

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Abstract

The Lead-free solder has been subject of concentrated research activity over the past era, but it is hard to meet the characterization and mechanical properties of Sn-Pb solder. Sn-Ag-Cu and Sn-Cu family of alloys were the most ideal and capable among all the Pb-free solder alloys proposed. Much publicity had been received by the eutectic Sn-3.0Ag-0.5Cu and Sn-0.7Cu solidifying their position as the most promising successor to Pb alloys solder. This study was to carry through the investigation of the effect of SiC particle on microstructure development and physical properties of Sn-3.0Ag-0.5Cu (SAC) based solder alloys. Powder metalurgy method (PM) was used to synthesize SAC-SiC composite solders, which involves some processes like mechanical blending, compaction and sintering. The outcome shows the additional of SiC particle has decreasing the β-Sn region and at the same time, the values of microhardness were increased.

Keywords*: powder metallurgy method, SiC, microstructure, microhardness, SAC lead-free solder*

Introduction

Lead-containing chemicals have been known as poisons for a long time [1]. However, its alloys have been used for several years without much aware it's harmful. Health concerns are relatively recent, and they came with the realization that very small amounts of lead have a profound effect on the human body [2]. The first thoughtful fear starts with the lead-containing dyes used in coat, and that industry has voluntarily switched to lead-free paint. Same goes to the other industries such as electronic industry, they now step forward about the lead-free solder for electronic packaging application [3]. In conjunction of that, research and development around the world produce variety of lead-free solder such as SnAg, SnAgCu, SnCu, and the other alloy systems to fulfil exactly the same requirement of traditional Sn-Pb and Pb-Sn Alloy [3, 4]. Furthermore, SnCu and SAC are among the promising candidate that near to meet the requirement of market demand. But the limitation of SnCu properties cause it no demand from industries although the price quite low compared to SAC. In this case, the size of β-Sn region was able to affect the physical properties of SnCu. In this study, SiC was selected as reinforcement of Sn-0.7Cu solder due to its good mechanical properties, light weight and can resistance high temperature. These properties may expand Sn-0.7Cu solder to reach more high performance for electronic packaging industries.

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Materials and Processing

Particle size below than 45µm of Sn-0.7Cu and SiC powder were used in this research for the base matrix materials. SiC powder as reinforcement has a particle size of below than 44 µm. The various composition of reinforcement, SiC are 0.25 wt%, 0.50 wt%, 0.75 wt% and 1.00 wt% were using to fabricated with Sn-0.7Cu matrix solder.

Powder metallurgy technique (PM) was used for the fabrication of Sn-0.7Cu-SiC composite solder. The matrix solder, Sn-0.7Cu were mixed with dissimilar composition of SiC in airtight container using a planetary mill rotated at a speed 200 RPM for one hour. After that, 12mm diameter mould was used for solder mixture compaction at a load of 4.5 tons (44.21 x 106 MPa) using a 15-ton manual hydraulic press [6 & 19]. Next, the samples were sintered using a microwave at 185oC in 2 minutes [7].

Solderability performance for the composite lead-free solder was investigated on Cu-substrate (PCB FR-4 type). Both bulk samples of the composite lead-free solder were cut into smaller pieces with approximately 1 gram. Next the pieces of bulk samples were positioned on Cu-substrate with a no-clean (NC) paste flux type AFM037A that was provided by ASAHI Flux Medium. Finally, the samples were heated to a maximum peak temperature of 250 ºC in desk lead-free reflow oven [8].

Microstructure Analysis and Hardness Test

All the samples were mounted for observation of microstructure under optical microscope. The mounted was used is hardener and epoxy that ration is 1:10. To observe the microstructure, the samples after mounted ware grinded and etched. The solution needs to be prepared for etching is the mixture of 2 % of HCl, 3% of HNO_3 and 93% of methanol. Each of the samples were etched for 5 second to reveal the microstructure.

The value of microhardness, is the typical method to characterize the mechanical properties of solid-state interfaces. This testing was refer based on ASTM B933-09 standard. The compacted 12-mm diameter samples were tested using the Vickers Microhardness Test Model FV-700e. The testing was measured on the flat surface sample with 1 Kgf indenting load and 10 second dwell time [9].

Result and Discussion

Microstructure

Fig. 1. shows the optical images of SiC as a reinforcement in Sn-0.7Cu based solder and pure Sn-0.7Cu solder. This study was carried out to compare between varieties percentage of SiC reinforcement in Sn-0.7Cu solder with pure Sn-0.7Cu solder. β-Sn region for composite solder were decreased by increasing the amount of SiC particles. From the findings, it was proved that the grain growth was able to be retarded and the finer β-Sn phase was increased by the addition of SiC particles. The grain refinement phenomenon in the composite solders can be explained by consideration of the thermodynamics and kinetics of grain growth. The interfacial energy between them was increased when a grain boundary encountered SiC particles in the grain growth process, thus causing the enhanced thermodynamic resistance of the grain growth. Moreover, the SiC particles also functioned as diffusive barrier to suppress metal atom diffusion on the surface of the grains. The finer microstructures was lead by this process of contribution to hindering the growth of the grains [10].

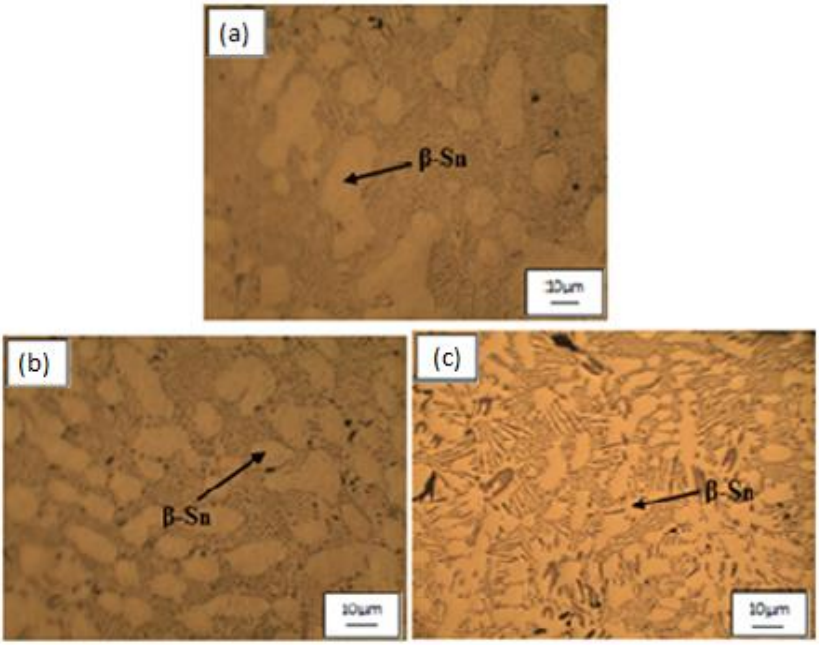

Fig. 1. Optical images of SiC as a reinforcement in; (a) pure SAC, (b) SAC-0.5SiC, and (c) SAC-1.0SiC

Reinforcement concentration between grains will tend to prevent and limit grain boundary sliding and retard the grain growth. Gain et al., [11, 20] the IMC particles size was reduced by the addition of ZrO_2 nano-particles into Sn-Ag-Cu. It also found that the absorption of ZrO_2 at the grain boundary and able to change relative relationship of the growth velocity between crystalline direction of the IMC particles.

The microstructure of SAC composite lead-free solders was observed by using SEM backscattered image. Fig. 2. (a) and (b) shows the grain boundary and β-Sn matrix on the surface of pure SAC and SAC-SiC. Fig. 2. (b) shows the observation area of SiC particles that were located between grain boundary for SnCu-SiC composite solders.

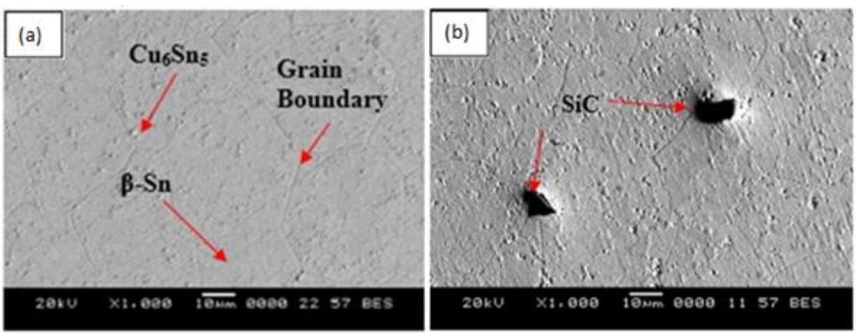

Fig. 2. SEM microstructures of; (a) pure SAC solder; (b) SAC-0.25SiC composite solder.

Figure 3 illustrates the location of SiC particles in SAC-SiC composite solder. The dark element is SiC particles. It also showed the SEM-EDX analysis result to support that the existence of SiC particles within solidified SnCu solder.

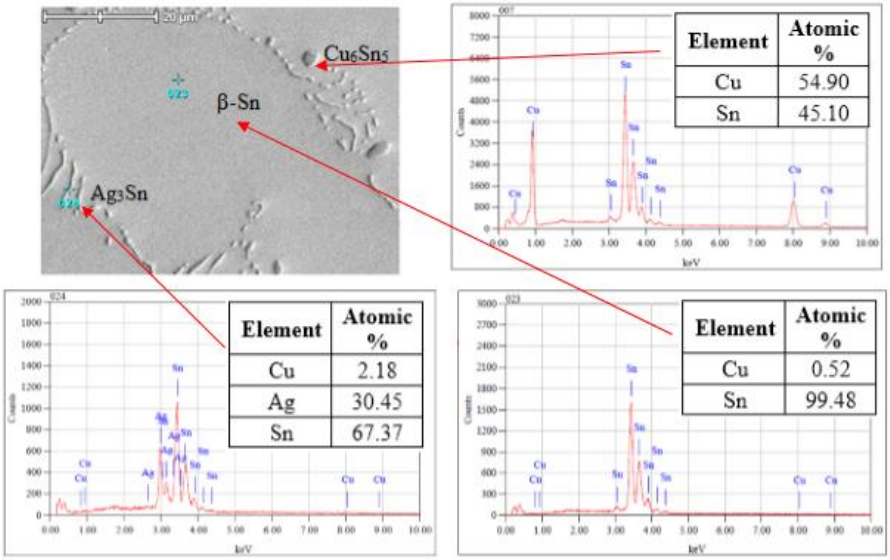

Fig. 3. Point analysis of SnCu-SiC

Hardness Test

Table 1 showed the comparison of hardness's data between the various compositions of SiC as a reinforcement for SAC lead-free solder. From the table, it found the difference of the hardness value is not significant. This little difference value occurs because the range of percentage difference of SiC is small. However, the increasing of the hardness properties by addition of SiC as a reinforcement was improve the hardness value compare the to the pure SAC lead-free solder. The properties of SiC, a ceramic type material with high strength and high hardness, is causing to enhance the properties of solder.

The additional of SiC particles influence the growth and size of β-Sn region in SAC-SiC composite lead-free solder. It believed the decreasing size of β-Sn region which has increased the microhardness value. Also, with fair distribution of SiC particles and good interfacial integrity between the solder matrix and SiC particles, variable quantity of SiC particles addition will greatly affect the hardness. Liang et al., [13] found that the large size of β-Sn could lower the microhardness value compared to eutectic Sn and Ag3Sn region. All this phenomenon happens because the reinforcement particles reduced the size of grains in solder matrix and these fine grains give and increase in the strength of the solder alloy according to the Hall-Patch relationship [14].

Table 1. The data of hardness test

Percentages of SiC (wt.%)	HV
0.00	14.1
0.25	16.4
0.50	17.0
0.75	17.4
1.00	18.6

SiC particles was functioned as the pinning grain boundaries the enhancement of microhardness value was attributed. The reinforcement that was placed in the solder matrix were able to change the solder alloy's deformation characteristics by retarding dislocation movement, as well as impeding grain boundary sliding in solder matrix, resulting the improvement of microhardness [15]. That mechanism were the obstacles to the movement of dislocations and increased dislocation densities. the hardness of composite lead-free solders displayed consistently higher value than both pure SAC lead-free solders due to homogeneous distribution of SiC particles and refinement of the IMC particles. According to the dispersion strengthening mechanism, the fine IMC particles and ceramic reinforcement can advance the mechanical properties of a solder [11]. This phenomenon was also founded by other researcher, Chuang et al., [16] the effect of Al_2O_3 addition on Sn3.5Ag0.5Cu to the grain size and the width of the grain boundary regions is substantially reduced for composite solders, which is crucial in influencing the strength of the solder.

Conclusion

This study has proven that lead-free solder properties can be enhanced by adding SiC particles as reinforcement. The microhardness value for Sn-0.7Cu-SiC composite lead-free solder was improved since the β-Sn region was reduced, which mean the soft area was decreased. After various characterization studies, the conclusions have been gathered as follow:

The microhardness value for composite lead-free solder was improved since the β-Sn region was reduced, which mean the soft area was decreased.

The addition of SiC particles in SAC lead-free solder were successfully improved microhardness surpass the value of pure SAC lead-free solder.

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