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EFFECT OF THERMAL AGING ON THE IMC LAYER BETWEEN SnAgSb SOLDER AND Cu SUBSTRATE

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ABSTRACT

Intermetallic compounds (IMCs) play a great role in solder joint reliability. Intermetallic formation was studied between SnAgSb solder and Cu substrate of a power package device. The integrity of IMC region is vital to the performance and reliability of the semiconductor packages. The solder joint of the as received packages were subjected to the thermal aging test for 50, 100, 200 and 400 hours at 175^{o}C. The microstructure evolutions and phases determination of the interfacial region were observed using scanning electron microscope (SEM) equipped with X-ray energy dispersion spectrometry (EDS). Thickness of IMCs layer was digitally measured and it shows the thickness increased with the increasing of the aging time.

INTRODUCTION

In semiconductor packaging, the process of mounting a semiconductor die or chip to a substrate or package is known as die attach as shown in Figure 1. Connections to the die are usually made using wire bonding technology. A die can vary in a size from less than 0.5 mm x 0.5 mm to large than 50 mm x 50 mm, the choice of attachment material being dictated by the size, substrate material (e.g. ceramic, polymer, glass metal) device requirements and operating environment.

The properties and performance of solders are essential to the integrity of the solder joint. In this paper, the die attach materials employed was a solder material which contains Stannum (Sn) as its base material and Argentum (Ag) and Antimony (Sb) as an added elements. The selection of SnAgSb solder material fulfilled the requirements of die attach performance based on good mechanical strength, process temperature that will not effect the die function, good coefficient of thermal expansion (CTE) which allows absorption of stress from thermal expansion mismatch between the die and substrate, joint fatigue resistance such as mechanical and thermal, electrical and thermal conductivity [1]. Other lead free solder properties for consideration in manufacturing application are chemical inertness with low outgassing, reworkable and ability to automate process.

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During soldering process, the formation of interfacial intermetallic compounds is one of the mechanisms for establishing the connection between solder and substrate. The thickness and the morphology of the intermetallic compounds at the interface can impact the thermal fatigue life, isothermal shear fatigue life, tensile strength and fracture toughness. The thickness of the IMC layer depends on several of factors, such as temperature, time, volume of solder, property of the solder alloy and morphology of the deposit. The temperature variations enhance the growth of IMC and induce internal stress. These compounds are typically quite brittle and will adversely affect the integrity of the solder joint. Therefore, it is of importance to investigate and to be able to control the growth of IMC. Yu and Wang [2] showed Cu_6Sn_5 was the major IMC formed between lead free Sn-based solder and Cu substrate. Since the intermetallic layers are inevitable, it is best to keep it as thin as possible. The aim of this study, are investigate the growth of interfacial IMC layers of SnAgSb solder on Cu substrate undergoing thermal aging condition.

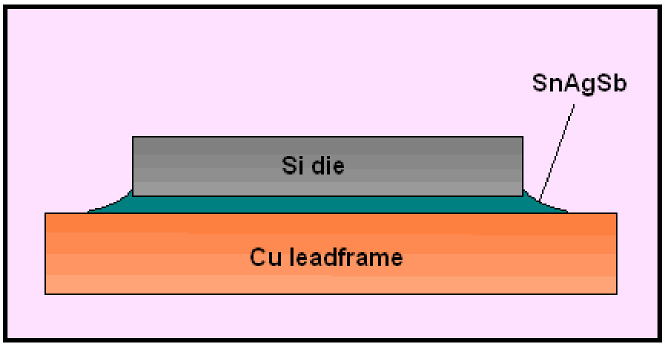

Figure 1: SnAgSb soft solder as die attach material for semiconductor package.

EXPERIMENTAL METHOD

Thermal Aging

The morphology of a material can be diversed when it was induced with amount heat for certain duration of time. A thermal aging experiment was prepared to observe the differences for solder material before and after thermal aging at higher temperature of 175°C in a furnace. The furnace temperature was controlled with an accuracy of ±2°C. Four durations of 50, 100, 200 and 400 hours of aging time were selected. The solder materials used was SnAgSb.

Cross sectioning

After each aging time, the samples were taken out from the furnace and mounted in epoxy resin and hardened for few hours. The samples were ground with 240 and 600 grades of abrasive sandpapers and were polished with 6 µm, 3 µm and 1 µm diamond suspensions. In order to reveal details of the interfacial structure, 0.025 µm colloidal silica suspensions was used for final polishing. The microstructure evolutions were observed using Hitachi S4800 Scanning Electron Microscopy

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(SEM) and the IMC phases determination were measured by Energy Dispersive X-ray Spectroscopy (EDS).

Digital measurement of IMC thickness
Considering the irregular shape of the IMC layers, their thicknesses were digitally measured using the software "Quartz PCI 7". The measurement of maximum thickness and minimum thickness of IMC was determined from SEM images and the average readings were calculated.

RESULTS AND DISCUSSION

Morphology of Interfacial structure
The SEM micrograph of copper-solder interface formed during package assembly process is shown in Figure 2. Thin layer of intermetallic compounds of Cu_6Sn_5 and Cu_3Sn can be identified at the Copper/SnAgSb interface.

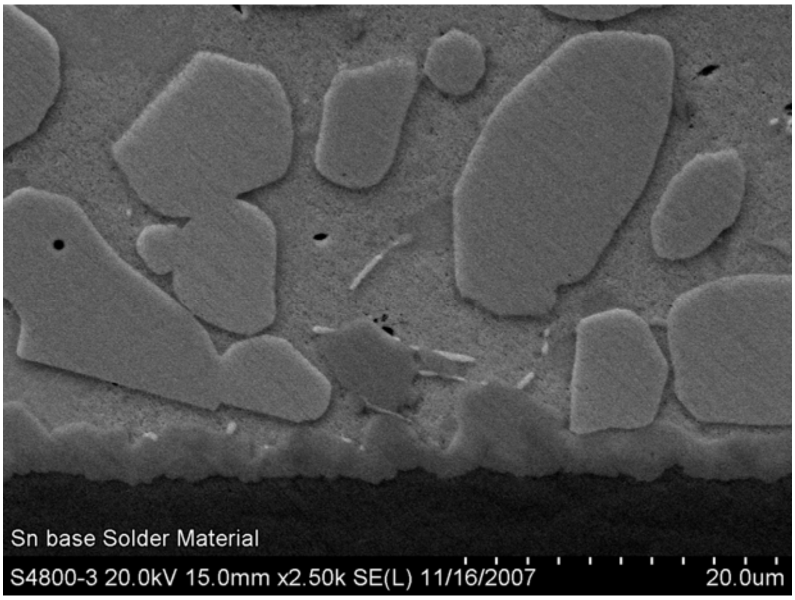

Figure 2: Metallurgical surface of SnAgSb solder/Copper prior to thermal aging.

Figure 3 (a) to 3 (d) show the morphology of Cu/SnAgSb solder after thermal aging at 175^{o}C for 50, 100, 200 and 400 hours. All the micrographs were captured at magnification of 2500x. The thermal aging modifies the microstructure at the copper/solder interface as the intermetallic layers increased in thickness with increasing aging time. It was observed that a Cu_6Sn_5 phase grows as an irregular interfacial morphology at the Cu/SnAgSb solder interface.

After exposed to the aging time of 50 hours, a very thin dark line of two distinct intermetallic layers was visible at the Cu/SnAgSb solder interface. The specimens that exposed for 100, 200, and 400 hours display two distinct intermetallic layers of

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Cu_6Sn_5 phase and Cu_3Sn phase. The spots taken for EDS analysis is shown in Figure 4.

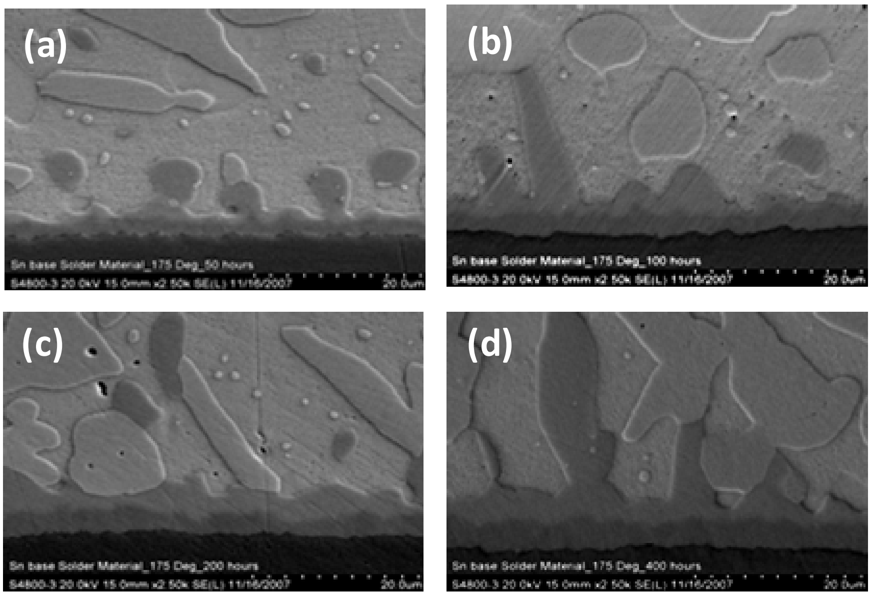

Figure 3: SEM micrographs of SnAgSb/Copper solder joints thermal aged at 175 ◦C for: (a) 50 hours, (b) 100 hours, (c) 200 hours and (d) 400 hours.

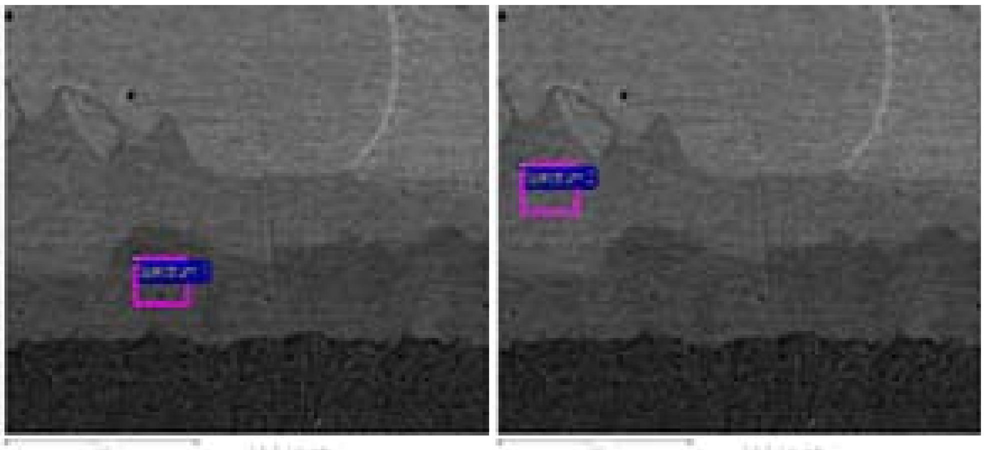

Figure 4: Spot areas of EDS analysis at two distinct IMC region.

The compositions of Cu_6Sn_5 phase and Cu_3Sn phase were confirmed by EDS analysis as shown in Figure 5 (a) and 5 (b) respectively. After forming the Cu_6Sn_5-phase layer structure between the solder and Cu substrate, a thin layer of the Cu_3Sn was formed at the interface between the Cu_6Sn_5 and Cu. The formation of IMC during this process must be controlled due to brittleness of Cu_3Sn phase [3]. The intermetallic layer must be kept as thin as possible to avoid failure of solder joint.

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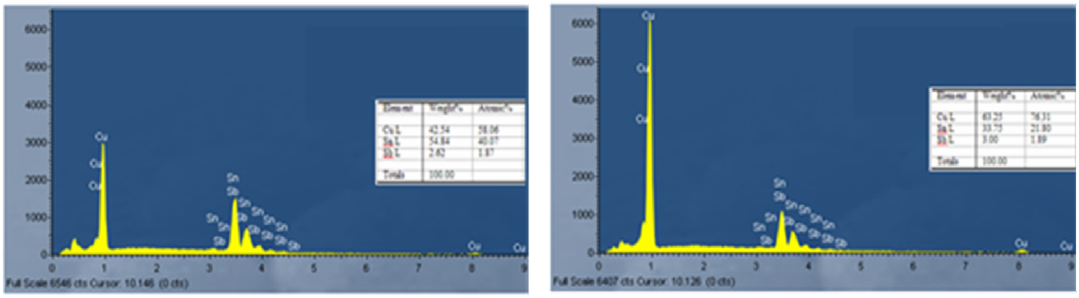

(a) (b)

Figure 5: (a) EDS analysis of Cu_3Sn phase in SnAgSb solder material aged at 175°C for 400 hours, (b) EDS analysis of Cu_6Sn_5 phase in SnAgSb solder material aged at 175°C for 400 hours.

The effect of thermal aging on the interfacial structure of SnAgCu solder joints on Cu [3] showed formation of Kirkendall voids exist at the Cu/Cu_3Sn interface as well as within the Cu_3Sn layer. The Kirkendall voids were observed for aging temperature of 100, 125 and 150°C for 200 hours. However in this study, no Kirkendall voids were observed at the interfacial structure of SnAgSb solder joints on Cu even at 175°C for 400hours. The EDS analysis indicated a great amount of Sb was dissolved at the IMC layer and this influence its morphology. Adding Sb could inhibit IMC formation and growth [4]. From this result, it shows SnAgSb solder is a better compared to SnAgCu solder composition in term of the interconnect materials.

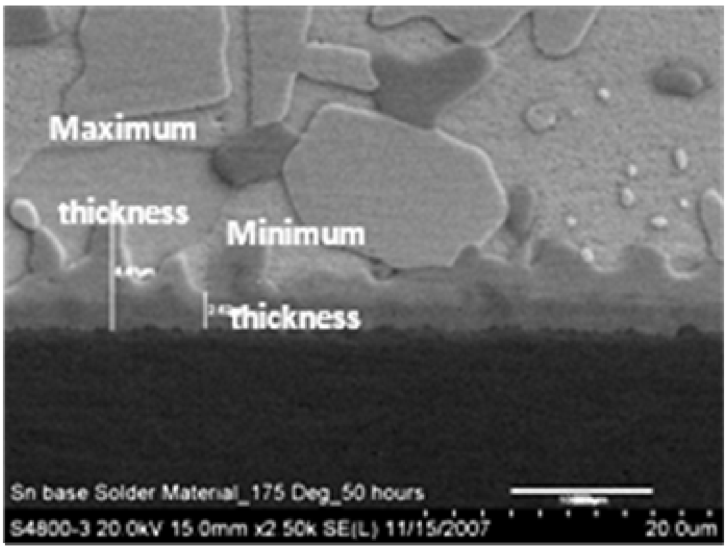

Figure 6: IMC layer thickness after thermal aging at 175°C for 50 hours.

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IMC thickness

Figure 6 represents the IMC layer after aging at 175°C for 50 hours aging and how the thicknesses were measured. The average thickness was taken from the maximum thickness and minimum thickness of total Cu_3Sn+Cu_6Sn_5 IMC layer. The average thickness of IMC layer between SnAgSb solder and Cu substrate for all specimens are plotted as a function of aging time in Figure 7.

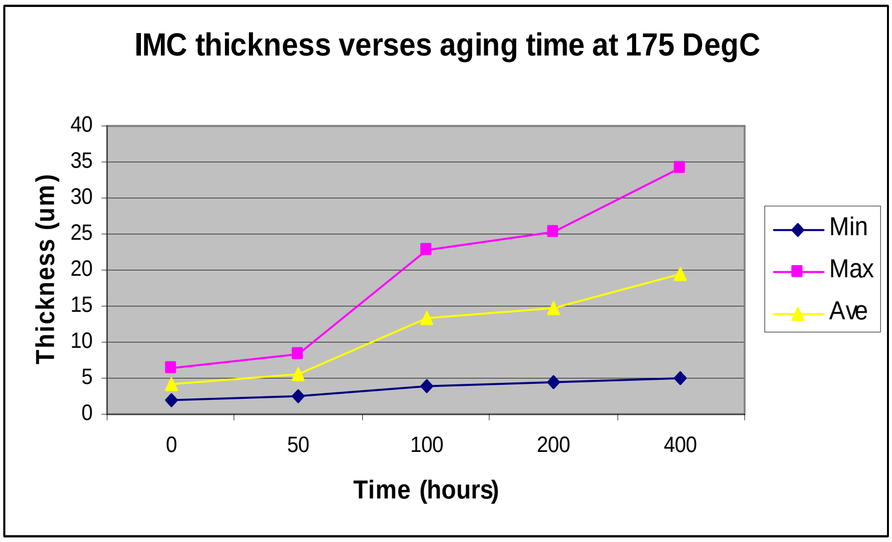

Figure 7: IMC thickness verses aging time at 175°C.

Figure 7 shows that IMC layer thickness increased gradually with aging time. The growth of IMC thickness was slow before reaching 50 hours but significantly increased between 50 to 100 hours. Subsequently, the IMC growth gradually increased until reaching 400 hours.

CONCLUSION

Based on thermal aging tests at 175°C for 50, 100, 200 and 400 hours of the SnAgSb/Cu joints, the following statements were drawn:

1) The SnAgSb solder bonds with Cu substrate through the formation of two distinct IMC layers consisting of Cu_6Sn_5 phase and Cu_3Sn phase.
2) Kirkendall voids have not been observed at the interfacial SnAgSb/Cu even at 175°C for 400 hours. Sb was found to be dissolved at the IMC layer and this influence its morphology.
3) After aging at 175°C, the IMC layer thickness was increased with the increasing of the imaging time.
4) SnAgSb solder is a good composition material for the lead free interconnects material.

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