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EFFECT OF HIGH-TEMPERATURE AGING ON MICROSTRUCTURE PROPERTIES OF Sn96.5-Ag3-Cu0.5 (SAC305) LEAD-FREE SOLDER JOINTS

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ABSTRACT

The use of Sn96.5%Ag3%Cu0.5% (SAC305) as lead-free solder is increasing rapidly as an interconnection for electronic devices. Electronic devices face harsh environmental applications during the operation which can reach temperatures of 200 °C and expose soldiers. The microstructure properties of lead-free solders are highly dependent on the process and operating parameters such as salty water, moisture, and high temperature. In this study, the effects of aging (storing) the samples at high temperatures on SAC305 alloy were investigated as a function of microstructure characterization. Microstructure morphologies are evaluated regarding the growth of inter-metallic compounds IMCs (Ag3Sn and Cu6Sn5) and grain size. The scanning electron microscope (SEM) and optical microscope were used to analyze the microstructure of Sn grain morphology. Also, to investigate the elemental distribution, energy dispersive spectroscopy (EDS) was used. The results show distinct changes in the microstructure of SAC305 solder alloy due to the aging effect; the quantitative analysis of grain size and intermetallic particle support this result.

Keywords: solder joints, SAC305, Isothermal aging, Ag3Sn.

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1. INTRODUCTION

The solder microstructure is the main attraction factor for using the Sn-Ag-Cu solders (e.g. SAC305). The SAC305 alloy is used as an alternative for SnPb solder in microelectronic devices because of the great mechanical response (shear and shear fatigue resistance) in the electronic devices during the service (e.g.) [1-9]. The processing parameters of Sn-Ag-Cu solder joints are the most common factor influencing the microstructure. Varying processing parameters have an effect on the initial microstructure after reflow and on their mechanical properties. The solder composition, surface finish (under bump metallization, or UBM), solder size, and cooling rate are the variables that can affect the microstructure; all of these variables, or just one of them can affect the morphology of the solder alloy. The mechanical properties of the solder joint are correlated with the microstructure of the solder, which is particularly influenced by the orientations of the Sn grains, dendritic arm, and distribution of Ag3Sn and Cu6Sn5 precipitates. Figure-1 depicts the density and size of Ag3Sn particles and the same for Cu6Sn5 particles, which significantly impact the mechanical response and dependability of Sn-Ag-Cu solder joints. [1, 13].

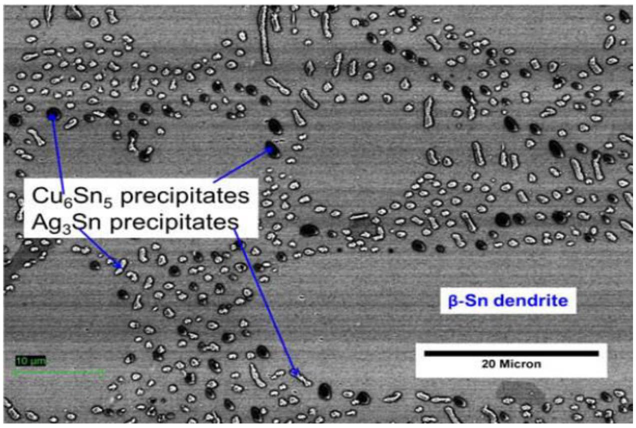

Figure-1. Backscattered scanning electron micrograph of (SAC305) showing the β-Sn dendrites and the theAg3Sn and Cu6Sn5 precipitates.

Pb-free solder joints experience microstructural changes while being used in an electronic device; these changes will be in the Sn matrix and under bump metrology (interfaces) due to temperature variations. Because of the effects of high temperature on the Ag3Sn and Cu6Sn5 particles in the Sn matrix, the intermetallic (IMC) layer at the interface will thicken. The growth (coarsening) of the Ag3Sn and Cu6Sn5 precipitates negatively impacts their pivotal work in stopping the crack propagation and dislocation motion. During the operation, the fatigue resistance of the solder joints will decrease, resulting in decreased mechanical properties and decreased fatigue performance. Isothermal aging of a solder joint at elevated temperature will accelerate the precipitates' growth process. For example, Genanuet al;

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showed that when the sample aged at a temperature of 125oCfor a certain time, the lifetime timeSAC305 upon accelerated thermal cycling (ATC)with a profile of -40oC to 125oC will go down (shown in Figure-2) [14]. Many researchers studied the effect of aging on solder joint samples. They report that the changes in the microstructure due to the changing in the processing factors that affects the mechanical properties (e.g., shear strength, shear fatigue, hardness, creep resistance, and tensile); in addition, Because of aging, the accelerated thermal cycling ATC lifetime of Sn-Ag-Cu solder joints will decrease. [15-24]. Meanwhile, adding a new element to the Sn will affect the microstructure, which several researchers will report; the microstructure of lead-free sold is influenced differently depending on the type of the added element. For instance, by adding the Bi element to the Sn, the Bi will be in a solid solution phase in Sn, which be more stable during aging. A study done by Genanu *et al*. investigates the effect of adding Bi to the Sn matrix. They report adding Bi to the SnAgCusolder alloys has a more stable microstructure during aging. The SnAgCu-Bi solder joints alloy shear fatigue test primarily demonstrated that solid solution strengthening improved the shear fatigue performance; even after aging, the SnAgCu-Bi samples still have a good shear fatigue lifetime. [16].

The current study first aims to carefully investigate the microstructures of SAC305 lead-free solder joints as reflowed with SEM micrographs and, secondly, Investigate how the evolution of microstructure is impacted by aging.

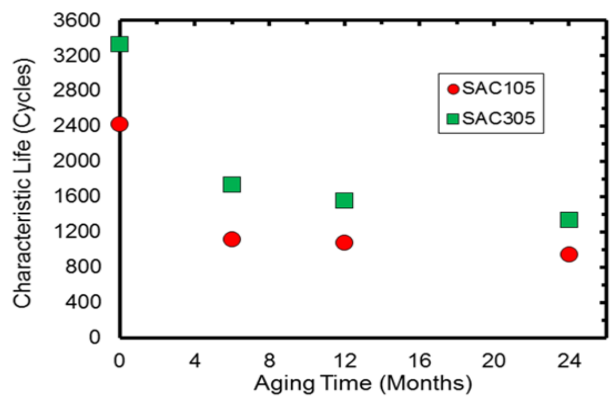

Figure-2. The effect of aging on characteristic life SAC105 and SAC305 solder joint samples. The aging temperature was 125oC for different periods [14].

2. EXPERIMENTAL WORK

The samples used in the current study were created by reflowing lead-free solder joints. The solder joint shave is assembled by reflowing a solder ball 500µ in diameter on a printed circuit board (PCB) on a Cu surface finish pad; the Cu pad's solder mask is 400 µ in diameter. The PCB board was coated with flux before placing the solder balls, placing the solder ball sd one using stencil printing. The PCB board's particular design was a minor component that made it possible to be placed precisely in the Differential Scanning Calorimeter (DSC). It is possible to cut the PCB boards so that the DSC only contains one solder joint (see Figure-3). The reflowing process was in a nitrogen atmosphere to avoid any oxidation. The reflow profile had a peak temperature (PT) of 240^{o}C and time above liquid us (TAL) of 70 seconds. This reflowing process is performed in DSC on all the solder joints; from the DSC, the solidification temperature is measured for every solder joint. The aging process is done in an oven with a stable temperature of 125 ^{C} for 1000 hours.

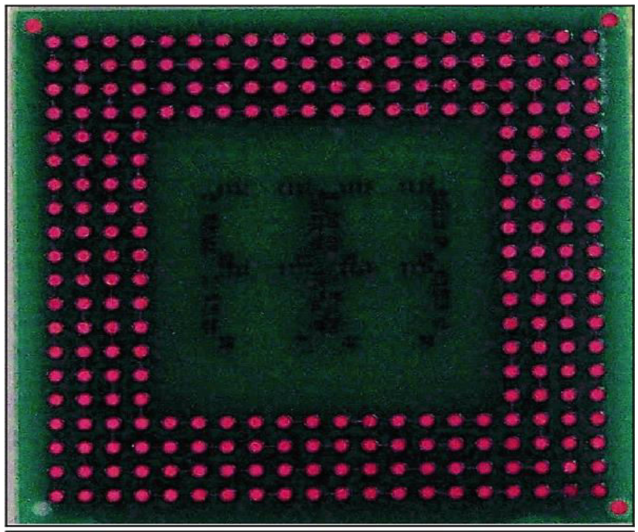

Figure-3. Shows the test vehicle of the board where solder joints will place on the area colored by red dots with only one solder sphere was placed.

Some samples were selected to examine the microstructure; the selected sample was mounted in epoxy, then the cross-section was done by grinding the sample with different sandpaper using diamond abrasive for each step, flowed by polishing with 0.02µm colloidal silica. To examine solder samples' morphology, optical microscopy was used with a bright field to check the growth rate of intermetallic compounds (IMC) after aging. While examining Sn grain morphology, the cross-polarized field is used; this checking and examination process is done for every solder alloy. Scanning electron microscope (SEM) type Zeiss was used, the SEM powered with an energy dispersive spectrometer (EDS) and for chemical analysis with backscattered mode for very careful imaging analysis in terms of microstructure analysis and investigation and for failure analysis. A computer software called Axiovision image analysis is used to analyse the percentage of the volume fraction Sn dendrite phase and for the dendritic phase to count the number of Ag3Sn precipitates to get the number of Ag3Sn per unit area (Figure-4 shows how to get the number density of the Ag3Sn particles) [14].

3. RESULTS AND DISCUSSIONS

A quantitative analysis examination of the near eutectic SnAgCu material in SnAgCu/Cu solder joints was conducted, as shown in Figure-4. Using the number of

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SEM images, a measurement of the near eutectic of SnAgCualloy for the area fraction was done, as shown in Figure-4. Figure-5 shows a normal SEM micrograph for SAC305 with low magnification at room temperature. The shape, size, and several Ag3Sn particles were examined using optical and scanning electron microscopy (SEM) for many soldiers' joint samples. SEM micrographs showed in Figures 5, 6, and 7. SEM micrographs revealed the distributions of Ag3Snparticles for as reflowed samples (at room temperature samples) and for the aged samples with different aging times at a temperature of 125oC (see Figures 5, 6, and 7). Furthermore, the SEM micrographs show the morphology of the theAg3Sn particles, showing that most of the theAg3Sn particles are fine particles.

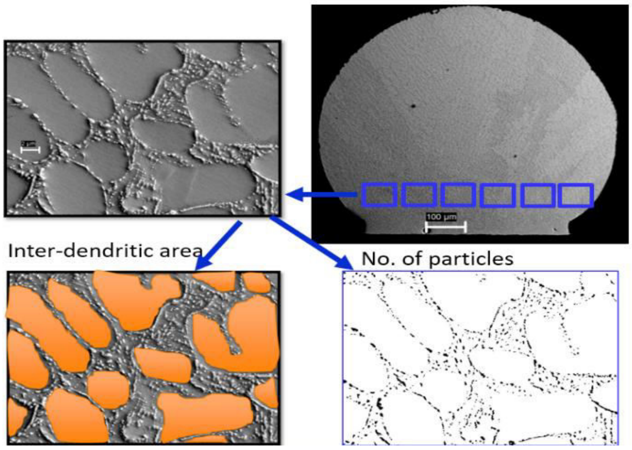

Figure-4. Back scatted scanning electron micrograph of SAC305 on Cu pad showing how to identify and calculate the number density of Ag3Sn particles (the number Ag3Sn particles per unit Area) and how to identify the Sn dendrite phase by using Axiovision software.

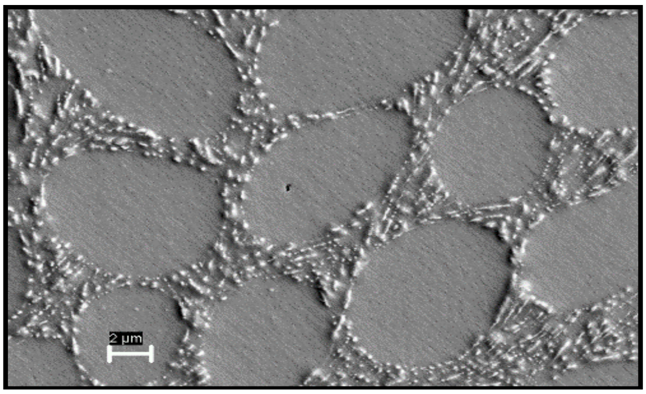

Figure-5. Low magnification of SEM micrograph of as reflowed SAC305 solder alloy.

The big influence of aging the solder alloy on the Ag3Sn precipitates is clearly shown in Figure-6, illustrating that the number of Ag3Sn particles reduced after aging. The Ag3Sn precipitates were coarsened and grew depending on the Ostwald ripening role. The growth mechanism occurs when the small precipitate dissolves into a bigger residue to form a bigger precipitate. This coarsening of Ag3Sn particles was clear in every cross-section solder alloy, which aged at 125^{o}C and for 1000 hours. After aging, the number density Ag3Sn precipitates reduced from 3.1µm-2to 0.2µm-2. The size of these Ag3Sn precipitates was very small and was nano in diameter.

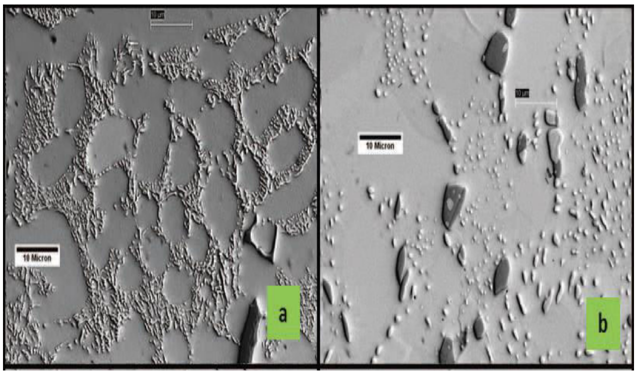

Figure-6. Scanning electron microscopy (SEM) images with low magnification ofSAC305 solder joints on Cu substrate (a) before aging (room temperature), (b) after aging at 125oC for 1000 hours.

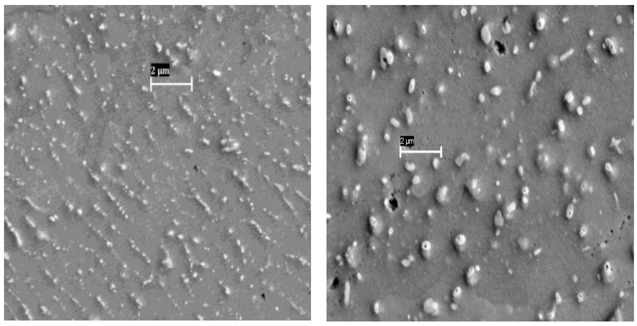

Figure-7. Scanning electron microscopy (SEM) images with high magnification of SAC305 solder joints on Cu substrate (a) before aging (as reflowed), (b) after aging at 125^{o}C for 1000 hours.

The intermetallic (IMC) layers at the interface, which is a layer of Cu6Sn5, figure8showscontinuous IMC layer for as reflowed samples (at room temperature), which is very important to connect the solder to the Cu pad; this IMC layer maintains the flexibility for the joint connection. Thus, with the thinner IMC, the better mechanical performance for the solder joint, and the joint will be more malleable and reduce the possibility of acing brittle failure. After aging, the IMC layer was still continuous, but the IMC thickness did increase. Also, the IMC layer morphology changed from a straight layer to a finger-like shape. The ductility property of the solder joint with a thick IMC layer will be reduced and increase the chance of brittle failures [20]. The average IMC layer thickness increased from 0.55 µm to 0.98 µm.

After the careful examination of the microstructure in terms of Ag3Snprecipitates, the IMC layer at the interface, and the Sn dendrites and for both at room temperature and after aging appears that all the samples show a similar size of Sn dendrite area and similar Ag3Sn precipitates morphology in term of the sizes of the particles and their densities. The results of the quantitative measurements of the microstructures agreed with the mechanical concepts. The aging time appears to have significant effects on the Sn dendrites, the spacing, and size of Ag3Sn particles, and the IMC layer, see Figures 8a and b.

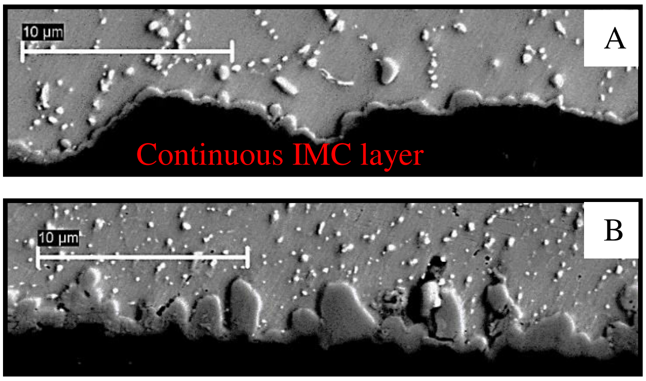

Figure-8. SEM micrographs of the IMC layer for SAC305 solder joints on Cu substrate (a) as reflowed (before aging), (b) aged sample for 1000 hours at 125oC.

4. CONCLUSIONS

This work investigated the microstructure of SAC 305 solder joints and was examined for two sets of samples: reflowed (room temperature samples) and after aging for 1000 hours at 125oC. The number of Ag3Sn particles is affected significantly after aging and varies by several orders of magnitude. The IMC layer was found to be a thin layer that gives the flexibility to assemble solder joint interconnects. However, after aging, the Cu6Sn5IMC layer thickness increased, and the IMC morphology changed to a finger-like shape but still but continuous layer. After aging, the number of Ag3Sn precipitates decreases linearly.

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