Study of whisker growth from SAC0307-SiC composite solder alloy

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Abstract: *In the current study, tin (Sn) whisker growth was observed on the surface of the SAC0307-SiC composite solder joint. A commercial SAC0307 solder alloys were reinforced with SiC nanophases to produce composite solder joints. SiC nanoparticles and nanowires were mixed with SAC0307 solder paste in a weight fraction of 0.5 wt% using the ball milling method. The solder paste was deposited by stencil printing on the test PCBs, and 0805 chip resistors were soldered by IR reflow method. The solder joints facilitated the growth of the Sn whisker through accelerated lifetime tests (85 ℃ / 85RH% THB, 4000h). The samples were observed by scanning electron microscopy (SEM) every 1000 hours of the test. On the SAC0307-SiC composite solder joints, Sn whiskers and large corrosion spots were observed after 1000 hours of the THB test. In the case of SAC0307 reference samples, only minor corrosion signs were found after 1000 hours of the THB test. The main finding was that the addition of SiC nanophases promoted Sn whisker growth and decreased the corrosion resistance of the composite solder joints*

1. INTRODUCTION

Modern electronic devices are indispensable in our daily lives, including industry, transportation, communication, and healthcare. As the demand for multifunctionality and miniaturization of electronic products increases, technologies such as miniaturization, thinning, high density, and high efficiency of electronic product mounting technology is being developed. In addition, with the growing interest in global environmental alert zones, efforts to regulate the use of environmental substances to suppress the generation of harmful substances in the production process are expanding worldwide. The global trend of eco-friendly products is driven by the European Union (EU) Directive on the Restriction of the Use of Hazardous Substances in Electrical and Electronic Products (RoHS), which has been in effect since July 2006 for six major hazardous substances (Pb, Hg, Cd, Cr6+, PBB, PBDE), and the Waste Electrical and Electronic Equipment (WEEE) Directive, which stipulates reuse or recycling, has been in effect since August 2005.

Therefore, eco-friendly product development is becoming increasingly important in the development of electronic products. There is a growing interest in lead-free solder, which does not use lead (Pb) in conventional Sn-Pb-based solder. In response to this demand, SAC series solder pastes such as SAC305 (96.5Sn3Ag05Cu) and SAC405 (95.5Sn4Ag0.5Cu), which use silver (Ag) and copper (Cu) instead of lead, have been used in the context of environmental regulations for electrical and electronic products [1]. The main problem with silver-containing solder alloys is that the price of silver continues to rise and large, brittle, plate-like Ag_3Sn intermetallic compounds (IMCs) form in the solder bulk during solidification, which can cause shrinkage defects and sensitivity to mechanical and thermal loading.[2] Therefore, solder of the SAC105 (98.5Sn1Ag0.5Cu), SAC0307 (99Sn0.7Cu) series with low silver content have been studied recently [3]. On the other hand, lower Ag content can lead to higher Sn content in the soldering alloy, which can increase the likelihood of reliability issues such as Sn whiskers [4, 5].

Sn whiskers are a natural increase in surface defects that typically appear on solder joints with pure tin or high tin content. Whiskers can be as long as 1 millimeter but whiskers are typically 20 to 100 micrometers. In microelectronics, Sn whiskers can form shorts between component leads, posing a significant reliability risk. The whisker growth is always induced by mechanical stress on Sn grains located close to the surface.[6] The mechanical stresses can be residual stresses from the processing of the tin object (soldering, surface plating, etc.), thermodynamic stresses (thermal expansion), stresses due to volume changes (intermetallic or intermetallic formation), or simply direct mechanical stresses creating whiskers. Among the naturally occurring reasons is the deformation of the grain due to corrosion of the tin. As the tin corrodes in contact with oxygen, the grain increases in volume and exerts pressure on the surrounding tin, creating whiskers.

A new research direction in microelectronics to inhibit the growth of whiskers in solder joints is the addition of ceramic nanoparticles (NPs) as reinforcements [7]. Ceramic nanoparticles are added to solder joints to form "composite" solder joints. Various ceramics have already been studied to inhibit whisker growth, including TiO_2, ZrO_2, Al_2O_3, Fe_2O_3, Si_3Ni_4, SiC, and La_2O_3. Ceramic nanoparticles significantly improve and disperse the particles of dissolved intermetallic (IMC) in the joints, thereby improving the mechanical quality [8]. For Sn-Ag-Cu based solders, the addition of ceramic NPs has been reported to result in a thinner intermetallic layer thickness [9]. The addition of ceramic NPs has the effect of inhibiting Sn whisker growth in composite solder joints, as it makes the grain size of the solder joint smaller and reduces the corrosivity of tin.[10]

Among the various nanoparticles, silicon carbide is a type of ceramic that is currently widely used in the semiconductor field. In order to enhance the physical properties of solder joints, silicon carbide has been studied to be mixed into solder paste to make composite solder joints [11]. Previous studies have shown SiC nanophases are effective in enhancing the electrical properties of solder joints [12]. However, it is assumed that whisker growth, which is associated with mechanical stress rather than electrical properties, can affect other forms.

This study was conducted for the reliability effect over time of conventional SiC composite solder joints. The comparison of nanoparticles and fibers in composite solder joints has not been widely studied. The two microstructures may have different effects on solder joints. We aim to investigate the difference between nanoparticles and fibers on corrosion resistance and whisker growth in SiC composite solder joints.

2. MATERIALS AND METHODS

For the whisker growth experiment, we used SAC0307 solder paste. Since SAC0307 solder paste has a tin content of over 99%, it is thought to be suitable for viewing tin-induced whisker formation. In addition, SiC nano-particles and nano-fibers were included at 0.5 wt% each to create composite solder joints. The nano-particles were less than 100 nm in size, and the nano-fibers had diameter (D) <2.5 μm and length/diameter ratio (L/D) ≥ 20.

Table 1. Investigated solder alloys.

Sample name	**Composition**
REF	SACX0307
SiC NP	SACX0307-SiC nano-particles (0.5 wt%)
SiC NF	SACX0307-SiC nano-fiber (0.5 wt%)

The solder paste was deposited by stencil printing on the test PCBs and 0805 chip resistors were soldered by IR reflow method. The IR batch oven with a linear thermal profile (pre-heating 150 ~ 180℃, reflowing 210 ~ 254 ℃, cooling down 254 ~ 170 ℃). The solder joints facilitated the growth of the Sn whisker through accelerated lifetime tests (85℃ / 85 RH% THB, 4000 hour). Samples were observed by scanning electron microscopy (SEM) every 1000 hours of the THB test.

3. RESULTS AND DISCUSSION

The solder joints of the sample were observed by SEM every 1000 hours. In the corroded areas, the crystal structure changes and appears as a darker band in the SEM image. This is due to the backscattering of electrons by the oxide, which is observed in the SEM. The changes in these samples can be seen in Fig 1, 2, and 3.

In Fig 1, the REF sample is presented in every 1000 hours of the THB test. On the REF sample, the corrosion started after 1000h (Fig 1b). However, despite the onset of corrosion, no whisker growth was observed until 2000 hours. In the case of REF sample, whiskers began to be observed after 3000 hours, which is Fig 1-c.

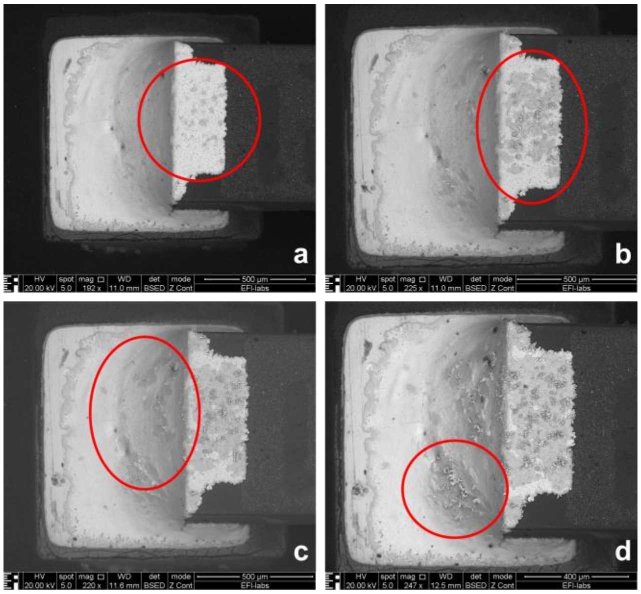

Fig. 1 SEM micrograph about the surface of the reference SAC0307 solder joints: a) REF 1000 h, b) REF 2000 h, c) REF 3000 h, and d) REF 4000 h.

However, the situation is different for the silicon carbide composite solder joints shown in Fig 2 and 3. The SiC composite solder joints start to show whisker growth after about 1000 hours, indicating faster corrosion than the original REF sample. In addition, in the micrograph after 3000 hours, the whisker can be seen covering most of the solder joint in Fig 2-c and fig 3-c.

In Figures 2 and 3 corrosion is also observed on the lower meniscus (pad area) of the solder joints. In Fig 1, the REF sample, there is almost no corrosion in the pad area, but in Fig 2, the SiC nanoparticle composite solder joint, it can be observed after 3000 hours. In the case of Fig 3, a nanofiber composite solder joint, the first observation was made after 1000 hours. In particular, in the case of Fig 3, the corrosion of the pad part has progressed rapidly and strongly, and even cracks caused by corrosion can be observed in the pad part after 3000 hours which is Fig 3-c. The comparison is even greater in the pictures after 4000 hours, where for the nano-fiber composite solder joint, most of the pad is also completely corroded, and whisker growth can be seen. This shows that the SiC acted to accelerate the corrosion of the solder joint by weakening the mechanical properties of the solder joint.

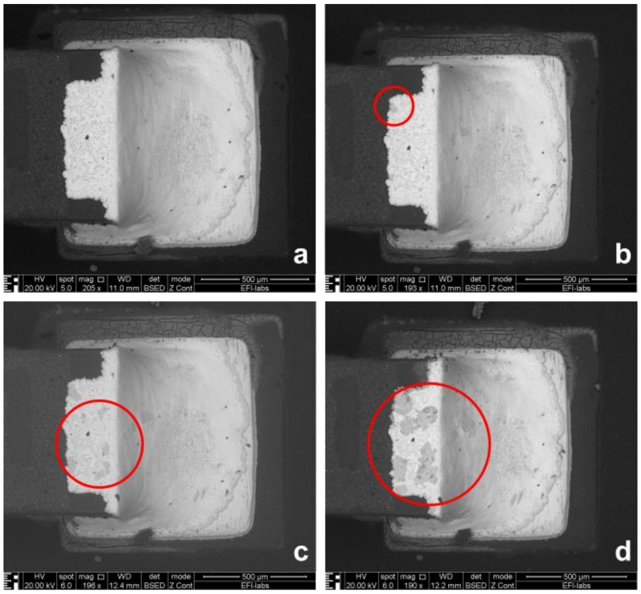

Fig. 2 SEM micrograph about the surface of the SiC nano-pareticles composite solder joints: a) SiC NP 1000 h, b) SiC NP 2000 h, c) SiC NP 3000 h, and d) SiC NP 4000 h.

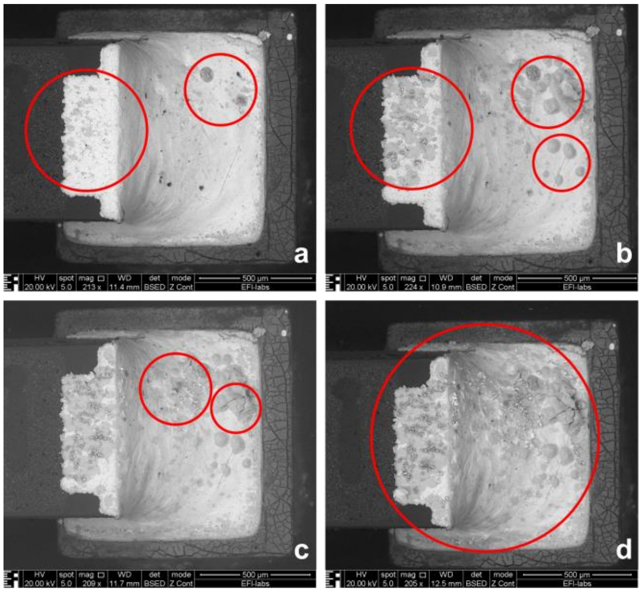

Fig. 3 SEM micrograph about the surface of SiC nano-fiber composite solder joints: a) SiC NF 1000 h, b) SiC NF 2000 h, c) SiC NF 3000 h and d) SiC NF 4000 h

The accelerated corrosion can also be seen in the growth of whiskers. Figure 4 shows a high magnification SEM image of the surface of the solder joint after 4000 hours to show the extent of whisker growth for each sample. In the figure, we can see that the whiskers have grown around the corroded area for the REF sample. This shows that the whisker grows as the tin corroded and the oxidized tin pushes out other surrounding tin grains. However, if you look at the photos of the composite solder joints in Figure 4, you can see that the whisker appears on the entire solder joint. This shows that the entire solder joint has been corroded, and the whiskers have grown regardless of their location. The number of whiskers occurreds also noticeably different: in Fig 4-a, there are enough whiskers to count, whereas in Fig 4-b,c, and d, there are so many whiskers growing and intertwined that it is impossible to accurately measure the number of whiskers.

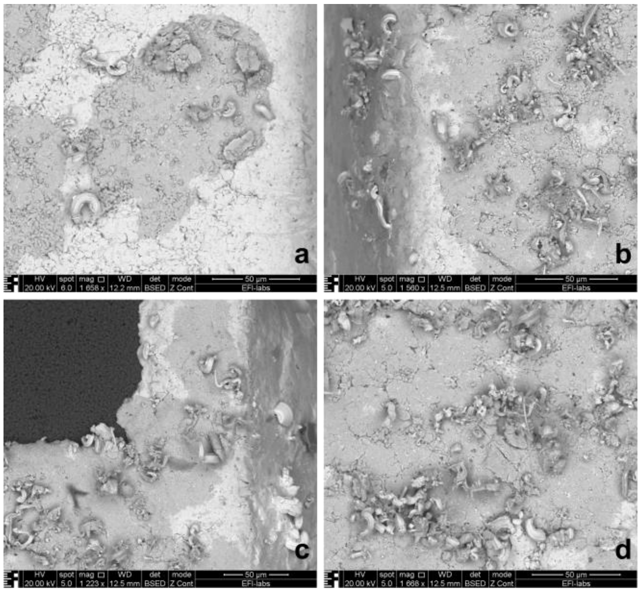

Fig. 4 SEM micrograph about the surface of the reference SAC0307 solder joints: a) REF 1000 h, b) REF 2000 h, c) REF 3000 h and d) REF 4000 h

The difference between nano-particles and -fibers of silicon carbide is also clear. Both materials worsened the corrosivity of the solder joints, but the corrosivity was enhanced in the case of the nano-fibers compared to the nano-particles. This is due to the structural features of the two materials. The penetration of oxygen into the material is affected by the diffusion function and the interaction energy between the grains [13]. SiC has a diamond crystal structure, but tin has a body-centered tetragonal structure. This appears to be due to a crystal mismatch between the silicon carbide and tin crystals, which facilitate diffusion.

When looking at the structural view, the fiber shows more severe corrosion. This could be caused by the differences in the diffusion behaviour of the different nano-phases. According to the diffusion theory , diffusion supposed to spread the same distance when the conditions such as temperature and humidity. In the case of nano-fibers, since it is composed of straight lines, it can be seen that even if the same distance of diffusion is achieved, it is possible to diffuse deeper. In other words, the diffusion from the straight structure of the grain of the solder joint made by nano-fibersoccurredd faster than the diffusion from other common grain shapes or grains made by nano-particles. In particular, the nano-particles used in the experiment are smaller than the average tin grain with a size of 100 nm or less. However, the length of the SiC fiber is more than twice as large as the average tin grain size [14]. Therefore, it can be confirmed that the corrosion in the SiC nano-fiber composite solder joint is more severe than the corrosion in the SiC nano-particle.

4. CONCLUSIONS

A study for Sn whisker growth of SAC0307 low Ag content solder alloy reinforced by 0.5 wt% of SiC nano-particle and nano-fiber was performed. The main conclusions are the following:

- On the SAC0307 solder joints whisker growth was observed during the THB test after 3000 hours.
- The SiC composite solder joints showed accelerated corrosion effect and whisker growth. Whisker growth was observed during the THB test after 1000 hours.
- Different crystalline structures of SiC resulted in different corrosion rates of the composite solder joints. This is due to the oxide can be diffused straightly followed by the SiC nano-fiber at the grain boundary of the Sn-matrix.

Experiments results have shown that SiC degrades the reliability of composite solder joints. Due to reliability risks, the use of composite solder with SiC nanostructures is not recommended.

5. ACKNOWLEDGEMENT

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