Preliminary Study of Electrical Current Stressing on Tin Whisker Formation

Noor Zaimah Mohd Mokhtar1,*, Mohd Arif Anuar Mohd Salleh2, Aimi Noorliyana Hashim3

Center of Excellence Geopolymer and Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.

E-mail: arifanuar@unimap.edu.my

Abstract. The growth of Sn whiskers on Cu substrate Pb-free solder is considered as one of the emerging problems in electric and electronic devices as well as in aerospace interconnects. Electrical current stressing have been identified as a major driving force for Sn whisker formation. In this paper, we investigate the mechanism of Sn whisker growth through the effect of electromigration of Sn on copper substrate. Test samples were prepared by dipping method before proceed with current testing, and the characterization of whisker growths were evaluated using the Scanning Electron Microscopy (SEM) on the deposits near the anode and cathode areas. Results demonstrate that the accumulation took place at the anode side forming whiskers and depletion occured at the cathode side leading to the formation of void with the effect of current stressing associated with different exposure of time.

1.  Introduction
Tin whiskers are tiny electrically conductive filaments, which continuously formed on pure tin or tin-alloy finished surfaces. Numerous failures due to shorting from whiskers have been reported such as medical devices applications, military and aerospace [1][2][5][6]. Tin whiskers are usually obtained by various methods such as electroplating, soldering or hot dip. They can grow up to several millimeters in length with a diameter of a few hundred micrometers which caused a lot of damage, costs and reduced the lifespan of many electronics components. Sn-Pb solders and plating were used extensively for a long time to mitigate and reduce the growth of whiskers. However, due to the restriction of hazardous substances for environmental concerns, the materials containing lead (Pb) has been banned in electric and electronic interconnects [2][7][8].

Generally, compressive stress has been accepted as a primary driving force for tin whisker growth [3]. The mechanism of how the whiskers form is still limited. Nevertheless, there is some literature on other driving force for the whiskers to growth. In previos studies, the whiskers formed on the thickness below than <10μm with the environmental condition by electroplating [3][9]. The straight whiskers also formed on the Sn-Cu solder as illustrated in Figure 1.In this paper, we investigate the current stressing effect to the whiskers growth The effects of current stressing on pure tin was investigated at the increasing exposure time.
2. Experimental

2.1. Material Preparation
First, a 200g granular shape of pure tin was prepared using melting method at a temperature of 350°C in a solder pot. A flat square-shaped copper shim with dimensions of 15 mm x 15 mm size and 1 mm thickness was used as a substrate. The substrates were cleaned using acid cleaning liquid that contain of 5g (35%) of hydrochloric acid with 95g of deionized water (1.75%) to remove surface oxides and contaminations.

2.2. Dipping Procedure
The dipping process was carried out using a hot soldering machine. Hot dipping process has been chosen compared to the electroplating technique since it can save cost and reduce time consuming [3][4]. The preparation of the solder also will be easier compared with the electroplating technique. Each coupon was hang using a crocodile clip at the dipping machine as shown in the Figure 2 below. It is equipped with a direct current (DC) motor with 12V power supply and 531 rpm speed. The coupon was first covered with flux before dipped in the solder pot containing molten bath for 3 seconds and blown at a pressure of 300 Mpa to get an even thickness. The thickness for each samples were 20μm each. We prepared three coupon for each solder coating. Then, the samples were cleaned with acetone for 3 min using ultrasonic cleaner.

Figure 1. SEM of straight shaped whiskers of Sn-Cu solders.

Figure 2. Illustration of dipping test.
2.3. Electrical Current stressing
In order to accelerate whiskers, electrical current test was conducted at different time period and current stressing as listed in Table 1.

| Parameter          | Condition        |
|--------------------|------------------|
| Solder             | Tin              |
| Substrate          | Copper           |
| Dipping time       | 1s Plating       |
| thickness          | 20 μm Current    |
| stressing          | 0.0215A          |
| Current stressing  | 0h, 24hrs, 72hrs and 120hrs |

A 5V DC power supply was used at 0.0215A to conduct the electromigration test. Both sides of the coupon are connected with crocodile clips at the anode and cathode area. The schematic diagram of the interconnection of coupon for the electromigration test is shown in Figure 3.

![Figure 3. Schematic drawing of EMI test.](image)

During the inspection, the area of 0.09mm² has been screening for minimum 9 areas of coupon with secondary electron microscope (SEM). The maximum length and the whisker density has been recorded and shown in Table 2.

2.4. Whiskers Measuring
During the inspection, the area of 0.09mm² has been screened for minimum 9 areas of coupon with secondary electron microscope (SEM). The maximum length and the whisker density has been recorded and shown in Table 2.

| Time (hrs) | Whiskers number [µm] | Whiskers length [µm] | IMCs thickness [µm] |
|------------|-----------------------|-----------------------|---------------------|
| 24         | 4                     | 2                     | 2                   |
| 72         | 22                    | 8                     | 3                   |
| 120        | 48                    | 13                    | 5                   |
3. Results and Discussions

3.1. Effects of current stressing on the anode and cathode surface after 0.0215A electrical testing.

Figure 4 presents a secondary electron image that shows the surface morphology of tin on copper substrate. By comparing figure 4 a,b and c, it can be seen that whiskers has been formed when it goes to anode side. Moreover, densities of whiskers getting lower from anode to cathode area and there are voids being observed on the cathode area. The morphologies of samples at x2000 magnification shows whiskers in straight and kinked shape grew up to 10micrometer and diameter is about 2micrometer of current exposure. From the cross section in figure 5, it has been shown that, the layer of intermetallic compound (IMCs) is slightly thicker compare with the cathode side [8]. The thicker of IMCs layer shows that the formation of whiskers on anode has effects to the IMCs layer. Although the thicker layer of IMCs on anode, the IMCs layer on the cathode side seems no different after 5 days test.

![Figure 4](image)

**Figure 4.** SEM images of 120hrs of current stressing shows the growth of whiskers on different area; a) anode b) between anode and cathode c) cathode.

3.2. Effects of current stressing within increasing time

Figure 5 shows the whiskers formation of pure tin on copper substrate under controlled environment. It can be seen that the whiskers have grew longer when the time of current applied increased. It can be shown also that the densities of whiskers were higher over exposure of time.

![Figure 5](image)

**Figure 5.** SEM images of current stressing under different exposure of time.

Whisker growth by electrical current stressing comes from the bombardment of electrons moving in the electric field from the cathode to the anode, pushing Sn atoms towards the anode. This phenomena
creates voids on cathode and as a result, compressive stress happens within tin coating, which is relieved by whiskers formation through the layer near the anode region [9][10]. The schematic diagram in Figure 6 shows the whisker formation under the effects of electrical current stressing.

**Figure 6.** Schematic diagram of tin whiskers growth.

4. Conclusions

The formation of whiskers on electrical current stressing shows the least formation of whiskers on cathode while more whiskers formed on anode region. The whisker densities show higher under controlled environment over exposure of time.

5. Acknowledgment

This work was financially supported by the CREST R&D (P14C1-17/001) grant of University Malaysia Perlis and Nihon Superior Co. Ltd.

References

[1] K. N. M.A.A. Mohd Salleh *et al* 2017 *Sci. Rep.*, vol. 7, 2017.
[2] E. Chason *et al* 2013 *vol. 88*, no. 2, pp. 103–131, 2013.
[3] N. M. Mokhtar *et al* 2018, vol. 280, pp. 175–180.
[4] A. N. Hashim *et al* 2018, vol. 280, pp. 151–156.
[5] K. N. M. A. Mohd Salleh, *et al* 2013 *Appl. Mech. Mater.*, vol. 421, pp. 260–266.
[6] K. N. M. A. Mohd Salleh *et al* 2015 *vol. 82*, pp.136–147, 2015.
[7] K. N. M.A.A. Mohd Salleh *et al* 2017 *Sci. Rep.*, vol. 7, 2017.
[8] L. Reinbold *et al* 2009 *J. Mater. Res.*, vol.24, no. 12, pp. 3583–3589, 2009.
[9] C. Su, H. A. O. Chen *et al* 2014 vol. 43, no. 9, pp.3290–3295.
[10] K. N. Tu *et al* 2005 *Mater. Sci.Eng. A*, vol. 409, no. 1–2, pp. 131–139.