The Effects of Oxidation Layer, Temperature, and Stress on Tin Whisker Growth: A Short Review

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Abstract. In order to reduce the Tin (Sn) whisker growth phenomenon in solder alloys, the researcher all the world has studied the factor of this behaviour. However, this phenomenon still hunted the electronic devices and industries. The whiskers growth were able to cause the electrical short, which would lead to the catastrophic such as plane crush, the failure of heart pacemaker, and the lost satellite connection. This article focuses on the three factors that influence the whiskers growth in solder alloys which is stress, oxidation layer and temperature. This findings were allowed the researchers to develop various method on how to reduce the growth of the Sn whiskers.

1. Introduction

Tin (Sn) whiskers have become a problem in electronic packing field since the beginning of this technology has been widely applied in all sectors [1–4]. Normally they have diameter 1-20 µm and their length is 5-500 µm [5]. Besides tin, another metal that popular for this issues were Cd and Zn but the Sn draw the most of attention compare to the others. Sn whiskers generally were good conductors, which this advantage were lead to electrical failures and even catastrophic disaster [6]. The growth of tin whisker was effectively controlled by alloying tin with Pb, and SnPb soldering and coating are until now widely used [7]. Yet, this practice alloying with Pb were strictly phased out by The Restriction of the Use of Certain Hazardous Substances (RoHS) due to the toxicity of lead that generally know [6]. To eliminate or reduce the Sn whisker growth, the growth phenomena of this problem were needed to be understood. Since 1940s, many theories, including dislocations-based theories [2-7], recrystallization theory [8], compressive stress-based theory [9-10] and many other [11-12] have been suggested. The latest factors that were studied by researcher related with compressive mechanical stresses, oxidation layer and temperature change.

2. Oxidation layer effect the whisker growth

There were several researcher such as Schroeder et al. [20] and Nakdaira et al. [21] studied the growth of whisker can be induced in the conditions at high humidity and temperature by oxidation or corrosion of the tin finish. Another researcher, Oberndorff et al. [22] have tested in high humidity inducing severe oxidation and corrosion by matte tin plated leadframe package. From the observation, the whisker growth causes by tin oxide that have high molar volume. Su et al. [23] have done a study
The mention that the last sample have a higher whisker population per component and have a longer maximum whisker length due to development corrosion stress.

The observation by B. Horvath et al. [23] show the differences in trends of the whisker growth for tin-copper alloys. The whisker behaviour and corrosion resistance of the alloys was investigated by using polarisation measurements to reveal the relation between them. In figure 1, Scanning Electronic Microscope Backscattered Electron image mode was used to observe the condition of few corrosion spot for the sample that aging at 85°C/85% RH. It also can be observed at the corrosion spot, the whiskers were growth but the whisker’s surface is free from dark corrosion. Another researcher, Osenbach et al. [22] found the area of corrosion crosses the non-corroded area of the surface film was parallel with no apparent height difference which shown that the surface of the film was pinned during the process of corrosion. With this method, the oxidation-induced excess tin atoms has been retarded in the original volume of the tin layer and create local stress and excess strain energy [22]. The corrosion may perform to spread only on the area near the top free surface but it may also spread deep inside the film putting mechanical pressure on the neighbouring tin grains. Nakadaira et al. [21] conclude as the corrosion increase, the corroded layer was in connection with the whisker base, retarding the growth of the whisker.

3. Temperature and humidity
European Union and Japan were restricted to ban the use of lead in electronic industry because of the hazardous to human and environment. This restriction force the researchers to improve the properties of solder by adding rare earth (RE) elements in to the solders. The result show the positive improvement mostly in all mechanical properties but the problem comes when tin whisker also found to grow faster compare to the lead solder [28-32].
The effect of temperature and humidity on tin whisker growth has been investigated since the early years of electronic application [1,25]. According to the opinion of Arnold and Osenbach, the higher temperature and humidity speed up tin whisker growth, which able to cause more atom mobility and in-depth oxidation of tin at higher temperature and/or higher humidity. Meanwhile the low temperature and low relative humidity could redue whisker growth on tin coating, [25,26]. The oxidation of RE-Sn intermetallic compounds was caused the rapid growth of the tin whisker in lead-free solder [29,33,34]. At room temperature, thread-type of whiskers were found to growth, while at 150°C, hillock-type whiskers grew [29, 35]. Unfortunately, there are still limited study on the effects of temperature and humidity on tin whisker growth for RE-Sn alloys. Figure 2 shows the illustration for the mechanisms of tin whisker and hillock grown.

4. Stress effect on tin whisker growth
Generally, there are an amount of usually decided upon variables that effect whisker formation. Many researchers come to an understanding that compressive stress in tin is the essential factor that driving force behind whiskers growth [15]. A four-point bending technique was used by C-K. The growth trend of numerous whiskers was observed in specimen S1 by C-K. Lin.

Figure 2. Illustration by C-F. Li et al. (2013). The growth mechanisms of (a) tin whisker and (b) hillock grown form Sn5Nd. [36]

Figure 3. The trend of growth Specimen S1 for several tin whiskers [37].
The mechanical stress has been applied for 79 days and after that, observation of the growth of whiskers was reported in figure 3. From the graph, they report the growth of whiskers almost stopped except whisker 3 that keep growing until day 114. The similar observation also was reported by the Sakuyama S et al. [39]. From the figure 4 and 5, tin whiskers were keep growing on whether mechanical stresses were applied or not. Unfortunately, the continuously applied the compressive stress able to increase the whisker density but decrease their length. When the tensile stress were applied continuously, the density and length of whisker were reduced by comparing with the case no stress applied.

Figure 4. Interconnect between length and applied stress of whisker [37].

Figure 5. Interconnection between density and applied stress of whisker [37].

Tu et al. [38] explain that a compressive stress gradient was induced stress-free broken oxide spot for creep or the growth of a whisker to reduce the stress. The driving force was supplied a compressive stress gradient for the diffusion of tin from the stressed region to the root of a whisker by a diffusion type of creep mechanism [38].

5. Conclusion
The study of whisker phenomena is substantially improved knowledge about the factor effect the growth of tin whiskers. From this knowledge, it can allowed researcher to make demonstrable,
efficient progress in identifying the key variable related with tin whisker. There are several special characteristics to approach the whisker studies;

i. As the corrosion increase, the corroded layer is in contact with the whisker base, disturbing the growth of the whisker

ii. The higher temperature and humidity speed up tin whisker growth and the low temperature and low relative humidity could reduce whisker growth

iii. Continuously applied the mechanical tensile stress were able to retarding the growth of tin whisker formation.

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