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The effects of humidity on tin whisker growth by immersion tin plating and tin solder dipping surface finishes

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Abstract

The drive to replace lead (Pb) from electronics has led to the replacement of tin (Sn) alloys as the terminal plating for electronic devices. However, the deposition of Sn based alloys as the component surface finish tends to induce Sn whisker that causes unintended electric shorts when the conductive whiskers grow across to the adjacent conductor. Internal stress is considered as the driving force that causes the growth of Sn whiskers. In this study, stress type of elevated temperature/ humidity exposure at 55°C/ 85%RH with the storage for up to 24 months was conducted to define the acceleration factor in samples with deposition of immersion Sn plating and Sn solder dipping. The addition of Nickel (Ni) under-layer was also applied to examine the correlation to field conditions. The results showed that the whisker length increased in high humidity irrespective of the deposition methods. It was also shown that pure Sn solder dipping mitigated the whisker growth but does not completely prevent it when alloying Sn with 0.4%wtCu. Additionally, Ni under-layer was indicated to be more efficient in mitigating the growth of whisker by prolonging the incubation time for whisker formation.

Selection and Peer-review under responsibility of the Scientific Committee of MIMEC2015

Keywords: Immersion tin; solder dipping; tin whisker; humidity

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1. Introduction

The move to ban the use of Pb in the electronics industry has precipitated the selection of pure Sn and Sn-based Pb-free alloys as the component terminal plating especially for printed circuit board (PCB) surface finish when the Restriction of Hazardous Substances Directive (RoHS) took effect on 1 July 2006. Pure Sn is increasingly adopted to replace Pb among various Pb-free surface finishes due to the promising compatibility with existing Sn-Pb assembly processes and systems. Sn is non-toxic, low cost and able to exhibit excellent solderability [1]. Reliable solder joint is indicated by the metallurgical interaction between the component surface finish and the solder alloy. However, the reliability of using pure Sn and Sn based Pb-free alloys in high density PCB assembly is a major concern for many PCB manufacturers because of the spontaneous growth of Sn whiskers protruded out of the Sn layer surface leading to short circuits, system failures and severe loss to electronics devices. The currently accepted theory states that the factors of these Sn whiskers growths are including elevated temperature at relative humidity, residual stress, mechanical force, intermetallic compounds (IMC) formation and oxide layer [2]. Additionally, increasing temperature will accelerate diffusion rate of atoms with Sn plated surface finish. Nevertheless, elevated temperature without humidity conditions did not result in stimulating whisker growth which had been reported by Dittes et al. [3]. Further study on the humidity effects on Sn whisker formation suggested that high humidity conditions induce severe oxidation and corrosion [2]. High humidity was accelerated by the condensation process, and as a result increased the volume in the Sn layer and formed compressive stress on the surface finish. Thus, the present study was carried out to further investigate the effects of humidity and addition of Ni under-layer on Sn whiskers formation for Sn plated surface finishes.

Nomenclature

RH	relative humidity
PCB	printed circuit board
RoHS	Restriction of Hazardous Substances Directive
IMC	intermetallic compounds
JEDEC	Joint Electron Device Engineering Council
FESEM	field emission scanning electron microscope
EDX	energy dispersive x-ray analysis
FIB	focused ion beam

2. Experimental Methodology

The copper (Cu) based substrates were first subjected to a series of pre-treatment procedures followed by deposition of immersion Sn plating, pure Sn solder and Sn0.4Cu solder dipping. Electroless Ni under-layer was deposited as the mitigation method. JEDEC standard JESD22-A121A was applied as a guideline to investigate the Sn whiskers formation [4]. In this study, the accelerated whisker test was conducted by storing the samples deposited with and without Ni under-layer at high temperature with relative humidity of (55 °C/85 %RH) for up to 24 weeks (approximately 4000 hours) to promote atomic diffusion in a humidity chamber. Additionally, a set of Sn plated Cu substrates with the same deposition parameters were prepared and stored under ambient conditions (28°C±2 with uncontrolled humidity) as reference. Whiskers growth was examined at various time intervals using field emission scanning electron microscope (FESEM) and energy dispersive x-ray analysis (EDX). Due to the large number of whiskers, the average of five longest whiskers per sample was recorded. The length of a whisker is defined in accordance to JEDEC standard No. 22-A121A with a single measurement of the effective shorting distance [4]. Whisker length was measured as the straight line distance from the termination surface to the most distant point on the whisker where the radius of sphere containing the whisker with its centre located at the point of emergence. A focused ion beam (FIB) methodology was used to examine the microstructure of intermetallic compounds (IMC) by preparing cross-sections from selected samples to observe the IMC layer, grain structure of the Sn layer and grain structure at the base of the Sn whisker.

3. Results and Discussion

3.1. Effects of temperature/ humidity on Sn whiskers growth

The results of whisker length measurements taken from samples of immersion Sn coating with and without Ni under-layer are plotted in Fig. 1 (a) and Fig. 1 (b) respectively. For the immersion Sn coating without Ni under-layer, the maximum length of whiskers was higher which was measured at approximately 21 µm for the 2 µm thick (12 minutes plating time) after 24 weeks of exposure compared with just over 7.8 µm for the same condition when a Ni under-layer was used. It is also interesting to note that no whisker was observed within the first 8 weeks of exposure in the immersion Sn coating samples with deposition of Ni under-layer. This is further confirmed that using an under-layer of Ni has significantly affected the growth of Sn whiskers by increasing the incubation time for whiskers formation [5]. The length of whiskers increased with increasing storage time regardless of coating thickness. Sn whiskers are also shown to grow longer on the thickest immersion Sn coating at all storage durations.

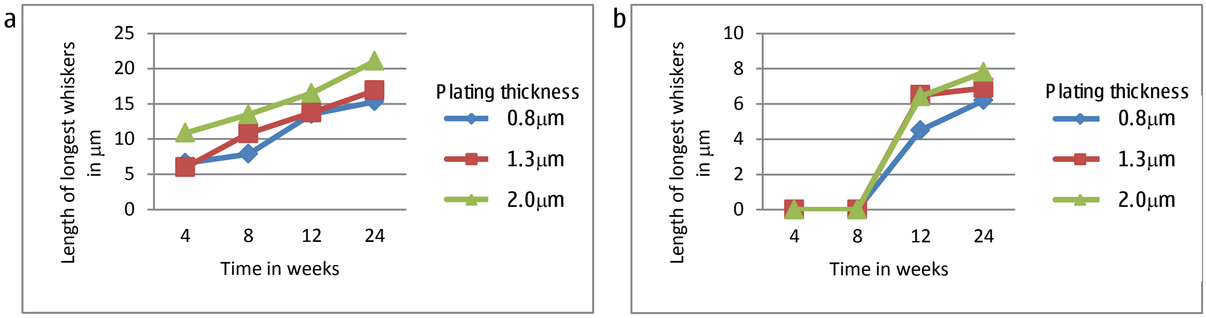


Fig. 1. (a) Whisker lengths for comparable thicknesses of immersion Sn plated on Cu based substrates without Ni under-layer; (b) with Ni under-layer in 55 °C/85 %RH

Whiskers were only observed to form after 8 weeks of exposure for substrates dipped in Sn0.4Cu solder with and without mitigation measures as shown in Fig. 2 (a) and Fig. 2 (b). The results show that the effect of Ni under-layer on whisker length may not be significant, however, the length of whiskers decreased from 9.2 µm to 6.6 µm after 24 weeks exposure. The data clearly show that dependent of Sn plating thickness for 0.8 µm, 1.3 µm and 2.0 µm thick lead to raise the formation of Sn whiskers when such substrates were subjected to elevated temperature and humid ambient. Besides, Ni underlying approach has significantly reduced the growth of Sn whiskers when the first whisker was observed after 12 weeks of exposure to elevated temperature humidity with the longest length of 5.5 µm. The maximum length of Sn whisker found in substrates with Ni under-layer is obviously shorter than those in substrates with no Ni under-layer. It is, of course, demonstrates the same finding to the data collected from substrates which were exposed to the ambient condition when performed an addition Ni under-layer as the mitigation approach. No whiskers have been observed on Cu substrates dipped in pure Sn solder, with or without Ni under-layer, for all exposure durations under the environmental conditions of high temperature/relative humidity. These results also confirm the effectiveness of solder dipping in whisker growth mitigation.

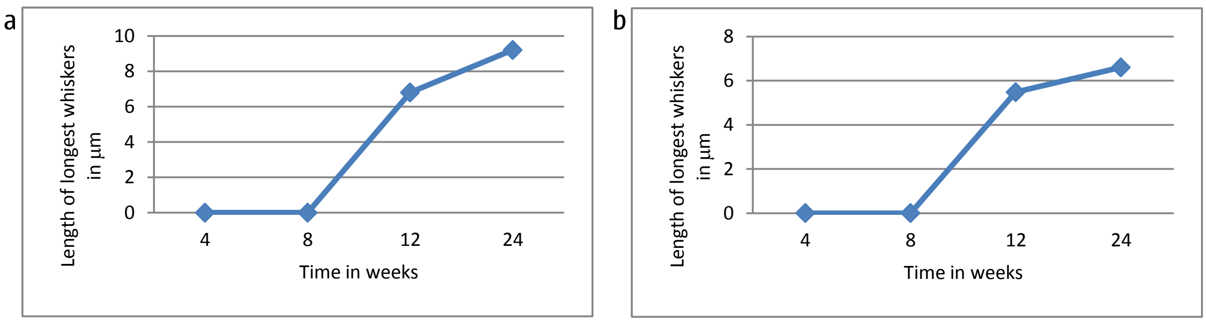


Fig. 2. (a) Whisker lengths for Sn0.4Cu solder dipped on Cu based substrates without Ni under-layer; (b) with Ni under-layer in 55 °C/85 %RH

As shown in Fig. 3 (a) and Fig. 3 (b); there were various whiskers with different morphologies grown on immersion Sn coating without Ni under-layer after exposure to 55 ^oC/85 %RH for different durations. The whiskers observed are all of the spiral-type with constant diameter of about 1 µm. As can be seen clearly, the whiskers also had striation marks on their surface similar to those observed under ambient conditions storage. Although the whisker length did not significantly increase during exposure to 55 ^oC/85 %RH, the addition of Cu to Sn solder appears to have caused a significant effect on whisker growth with increase in whisker diameter. This result is in agreement with [6] that growth of whiskers is caused by Cu_6Sn_5 IMC layer formation on eutectic Sn-Cu alloys and thus the addition of Cu to Sn solder promotes whisker growth in their length, shape and growth rate.

a b

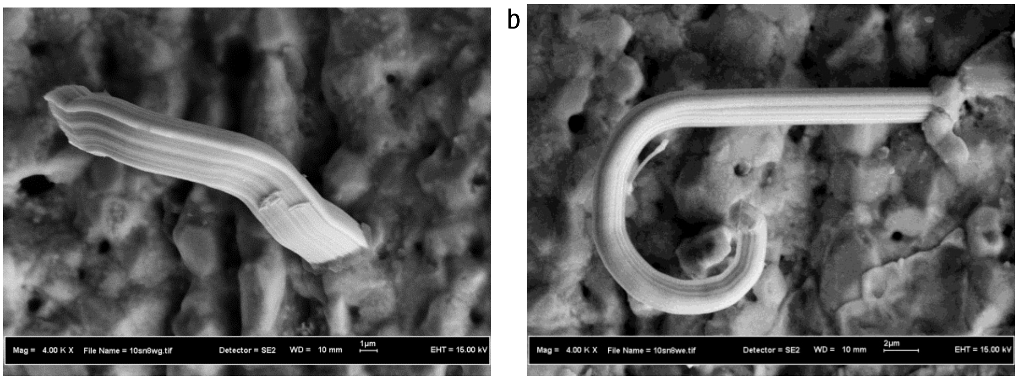


Fig. 3. Whiskers grown on immersion Sn without Ni under-layer after exposure to 55 ^oC/85 %RH; (a) for 8 weeks; (b) for12 weeks

3.2. Effects of intermetallic (IMC) formation on Sn whiskers growth

A comparison of the initial Cu_6Sn_5 IMC growth after 7 days of storage as shown in Fig. 4 (a) with the growth after 4 months storage in Fig. 4 (b) clearly shows that the IMCs grew larger with increased of storage time. It is seen that with increasing storage time the IMC grew into large particles along the grain boundaries in Fig. 5 (a) and (b). The IMC was confirmed as Cu_6Sn_5 as indicated by the EDX results. It is clear that the growth of interfacial Cu_6Sn_5 IMC can be a source of compressive stresses acting on the Sn grains. The fact that the substrates exposed to humidity conditions showed higher tendency to grow whiskers is due to the non-uniform IMC layer and precipitation of larger IMC precipitates at the grain boundaries. IMC layers that are uniform and stable act as protective layers of Sn whisker nucleation on the Sn plating [7]. For the immersion Sn plated substrates plated with Ni under-layer shows no IMC growth after 2 days of exposure to 55^oC/85%RH. This is attributed to the slow interfacial reaction between Ni and Sn compared with Cu-Sn reaction [8]. Interestingly, the results showed that with Ni under-layer, whisker nucleation was delayed compared with Sn coating without Ni under-layer.

a b

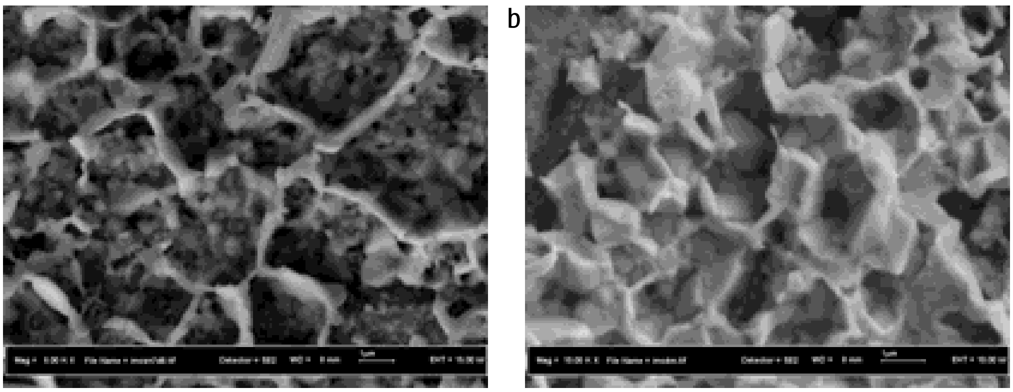
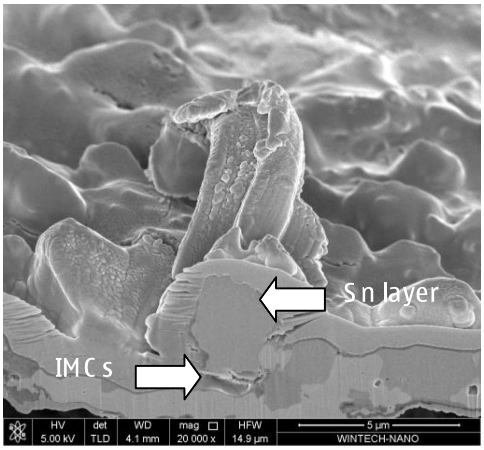


Fig. 4. Interfacial IMC between 1.3µm thick Sn and Cu; (a) after exposure to 55^oC/85%RH for 7 days; (b) for 4 months

a



b

EDX result for Sn layer

Element	Weight%	Atomic%
Cu L	13.64	22.78
Sn L	86.36	77.22
Totals	100.00	

EDX result for Cu_6Sn_5 IMC

Element	Weight%	Atomic%
Cu L	35.89	51.12
Sn L	64.11	48.88
Totals	100.00	

Fig. 5. (a) FIB Interfacial IMC between 1.3µm thick Sn and Cu without Ni under-layer showing IMC growth after 4 months of exposure to 55°C/85%RH; (b) EDX results for Sn layer and Cu_6Sn_5

4. Conclusions

On the basis of the analysis presented the following conclusions can be drawn:

1. Testing at elevated temperature and relative humidity of 55 °C/85 %RH accelerates the growth of Sn whiskers compared to ambient conditions.
2. Addition of Ni under-layer appears to extend the incubation time for whiskers to grow and assist in resisting excessive whisker growth during storage under high temperature/ humidity conditions.
3. The present results indicate that there is a correlation between the rate of IMC growth and whisker growth.

Acknowledgement

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