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# The Elimination of Whiskers from Electroplated Tin

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After the implementation of RoHS and the discontinued use of lead bearing products and the introduction of lead free (LF) solders, tin and its alloys have come to the forefront as the first choice of replacement to tin-lead.

On the solder side the transition has moved forward and solutions have been implemented, like the SAC family of LF solders for paste reflow and tin-copper for HASL (hot air solder leveling). The industry is constantly making progress adapting its materials and processes to the higher reflow temperature profile for these LF solders. Today there is a much better understanding of the types of solder joints that are formed; their reliability and the type of intermetallic compound (IMC) formed.

On the surface finish side, replacing tin-lead has posed greater challenges. Component leads and connector finishes were being converted to tin as an obvious alternative. This works well as a soldering surface, however any part of the lead or the connection surface that is not soldered to, has shown a potential to form tin whiskers over the life of the part. Internal stresses in the deposit due to IMC formation or external stresses on the deposit are known to initiate whisker formation.

In this paper two approaches are implemented to dissipate the stress that is formed, the first is to modify the substrate surface to control the growth in thickness and direction of propagation of the IMC and the second is to modify the large columnar tin deposit crystal structure to mimic the fine equiaxed structure of tin-lead solder. The former is achieved thru controlled micro roughening of the substrate and the latter by the use of additives to the plating bath.

Data will be presented to show the effect of each of the two approaches on the dissipation of the stress, resulting from IMC formation. As the stress is dissipated the primary cause of whisker formation is eliminated.

**Introduction**

Electroplated pure tin and tin based alloys, are being used as alternatives to tin-lead in the majority of electronic components. These alternatives are known to produce tin whiskers which may give rise to short circuits on these components.

In the case of tin finish on copper and copper based alloys, the major cause of tin whisker formation is compressive stress. The stress is mainly caused by irregular growth of copper-tin intermetallic compound (IMC) at ambient conditions [1].

It is known that tin whiskers are readily formed on electroplated tin deposits on copper and are not observed on electroplated tin-lead deposits. The tin deposit and tin-lead deposit are different in the crystal structure. Crystal Structure has a direct impact on tin whiskers formation [2] [3].

A tin deposit with modified crystal structure (similar to tin-lead deposits) is capable of preventing whisker formation by dissipating and delocalizing the stress that cause whiskers.

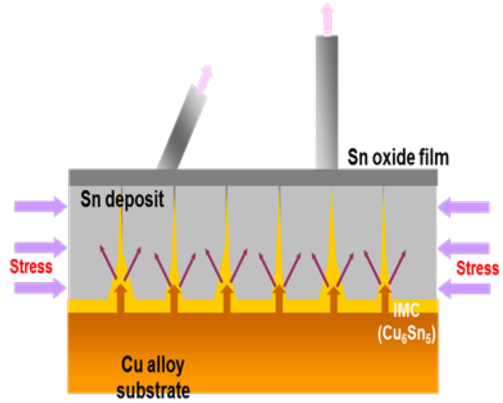
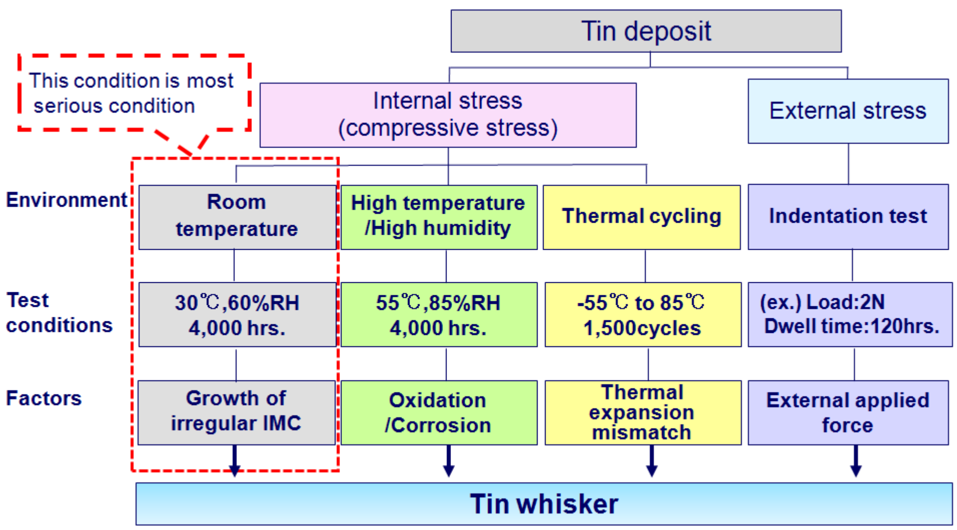



*Figure 1. Shows a schematic of tin whisker formation*




As shown in Figure 1, stress, channeled along the boundaries of the large grained columnar tin deposit, is responsible for the emergence of tin whiskers. Stress may be internal or external (refer to figure 2). The primary source of internal stress is attributed to the non uniform increase in the thickness of the IMC layer over time at ambient conditions (30°C, 60%RH for 4000 hours). Another condition that produces internal stress is exposure to high temperature and high humidity (55℃,85%RH 4,000 hours) for extended periods of time which gives rise to oxidation and/or corrosion. Internal stress could also be induced by thermal cycling (-55℃ to 85℃ 1,500cycles) due to mismatched CTE (coefficient of thermal expansion). The latter two forms are commonly used to induce internal stress in controlled experiments. External stress is also known to initiate whisker growth. An example is the stress induced by press fit connectors.

The approach taken in this study is to control the thickness of the IMC, as well as modifying the crystal structure of the tin deposit from large grained columnar to a small grain equiaxed structure. The former is achieved by increasing the area of the copper substrate, through chemical micro-roughening means. The grain structure is altered by the use of specific chemical additives to the plating bath. All testing was done under ambient conditions as listed above.

**Experiments and Results**

**A. Copper Surface Modification**

A study was conducted on the morphology of the copper substrate prior to plating. A series of substrates varying in roughness were evaluated for whisker formation after electroplated tin deposition. The roughness was controlled by chemical etching procedures. Average roughness "Ra", varied between 0.13 to 0.47 microns. As shown in figure 4, 0.47um Ra has a much larger surface area as compared to 0.13um Ra. The propensity to whisker was evaluated as follows:

Test Vehicle

The test vehicle - CDA19400 (Cu-2.3Fe-0.03P-0.12Zn) leadframe; refer to figure 3.

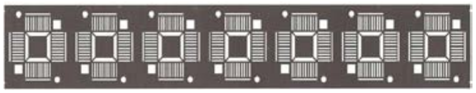


***Figure 3. Test Vehicle***

Tin plating

The plating bath was MSA based matte tin. The plating was run at a current density of 10A/dm2. Plating time was varied to produce a 3 um and a 10 um thick deposit. The former was for short term whisker evaluation and the latter which is typical of lead frame plating was used for long term evaluations.

Methodology

The test vehicles were subjected to chemical micro-roughening to produce a set of specific Ra values (Figure 4) The figure shows the SEM micrographs of the different degrees of micro-roughening as measured in Ra um.

The samples were then run thru a standard plating process as outlined in Figure 5. The samples were then stored under controlled ambient conditions (30$^{o}$C/60%RH) for extended periods of time (1000 hours). The samples were examined for whisker formation at various time intervals.

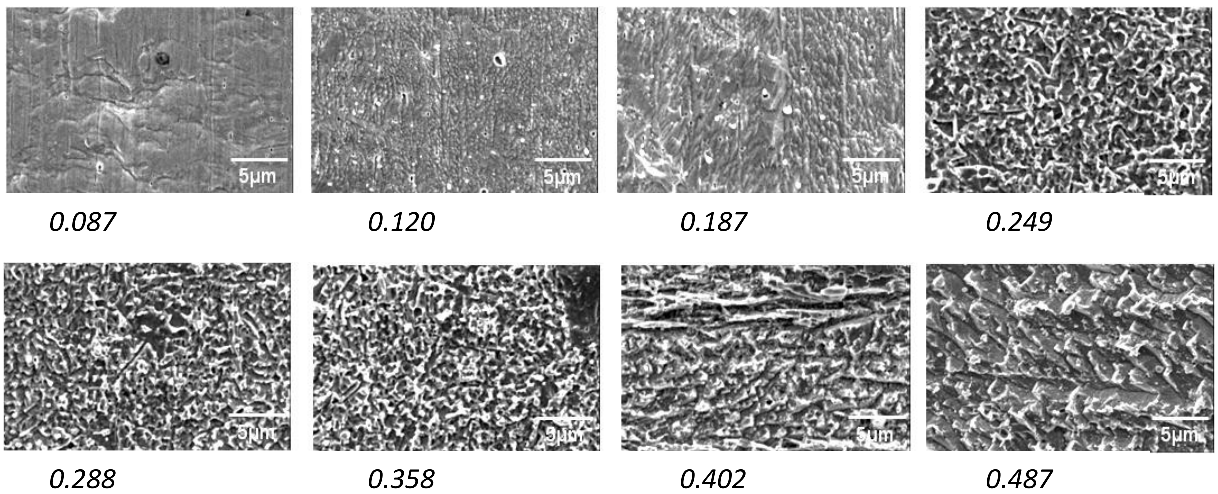



***Figure 4. SEM micrographs of different Ra values***

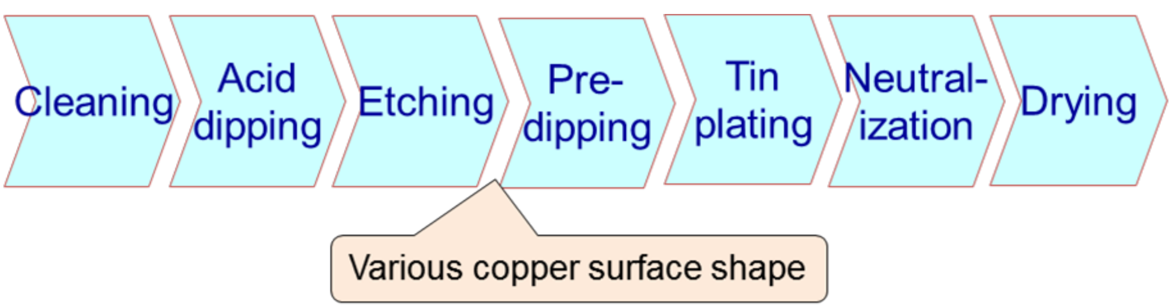



***Figure 5. Showing the process used for this study (typical plating sequence)***

Definition of a "Whisker"

A whisker is a protrusion >10um in length and that has an aspect ratio (length/diameter) >2.

Measurement of whisker length

The measurement according to JEITA ET-7410 is the straight line distance from the point of emergence of the whisker to the most distant point on the whisker.

Results and Discussion

Whiskers were examined, measured and tabulated after 1000 hours of storage under controlled ambient conditions (30$^o$C/60%RH). The data gathered from whisker examination on the various morphologies of roughening are graphed in Figure 6 and 7. Figure 6 looks at maximum whisker length as a function of roughness. Figure 7 looks at the whisker density per mm$^2$ as a function of roughness.

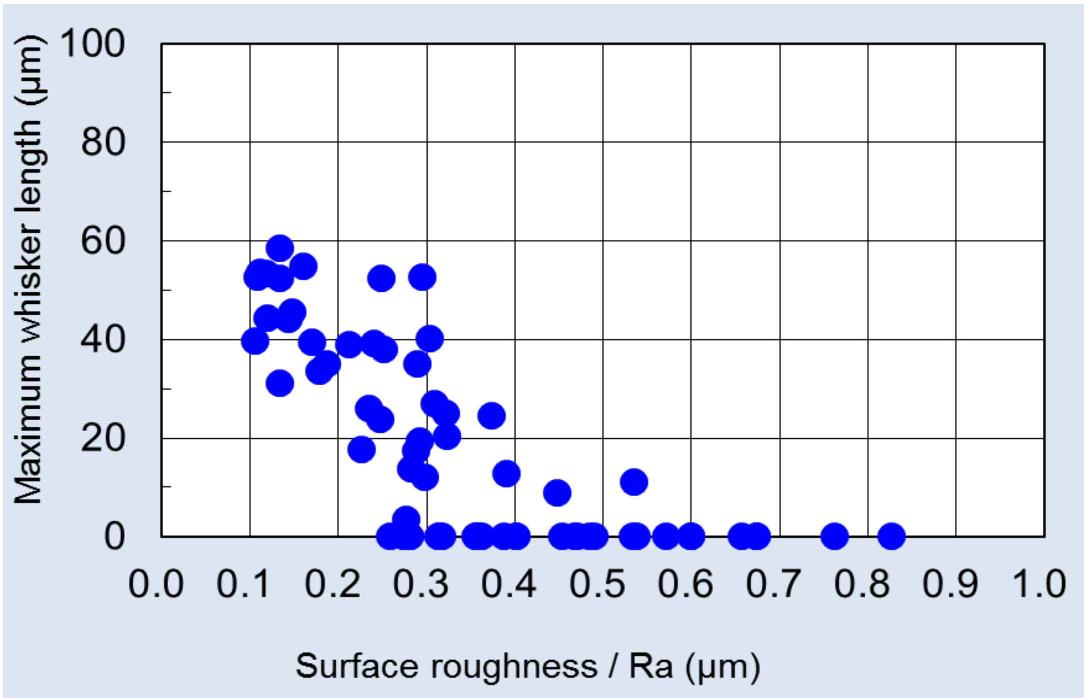



***Figure 6. Maximum Whisker Length vs Surface Roughness (1000 Hrs at 30$^o$C/60%RH)***

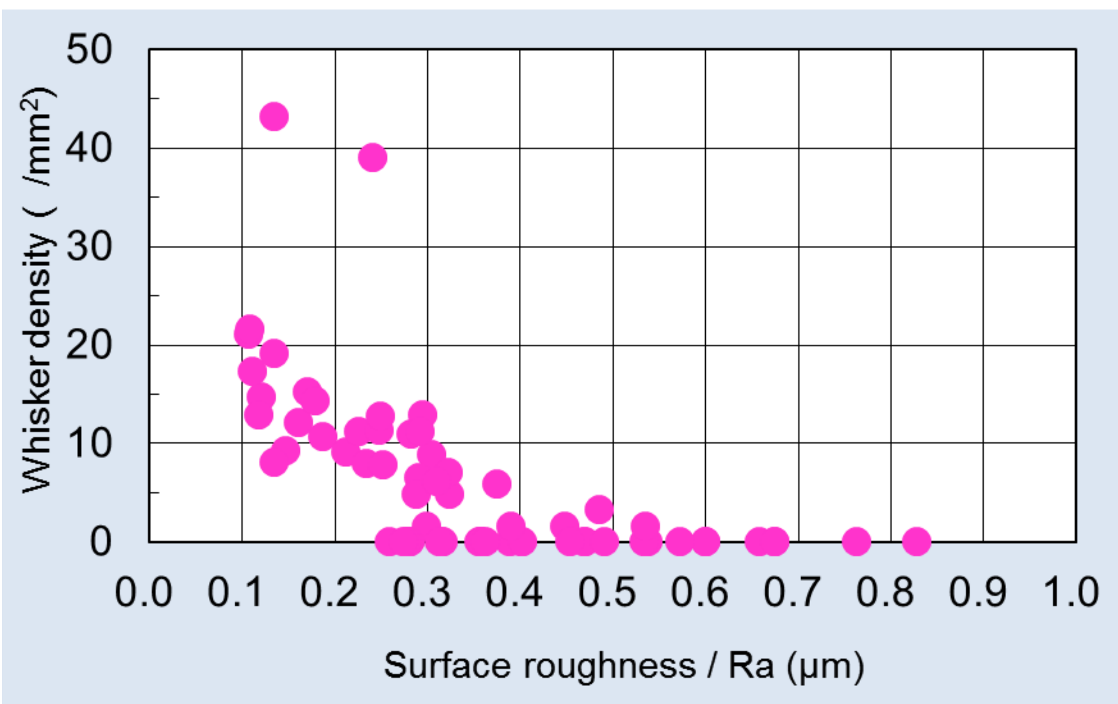
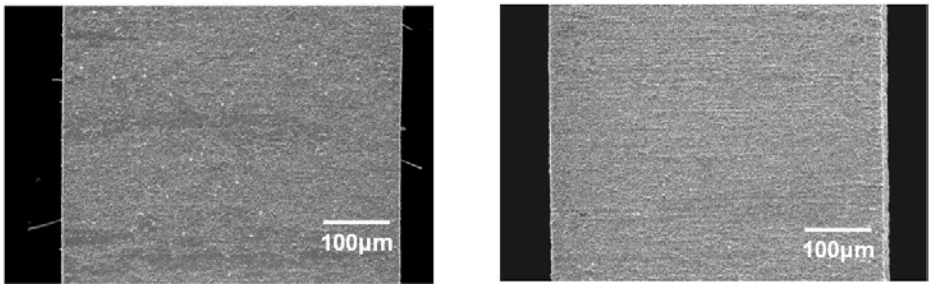



***Figure 7. Whisker Density vs Surface Roughness (1000 Hrs at 30$^o$C/60%RH)***

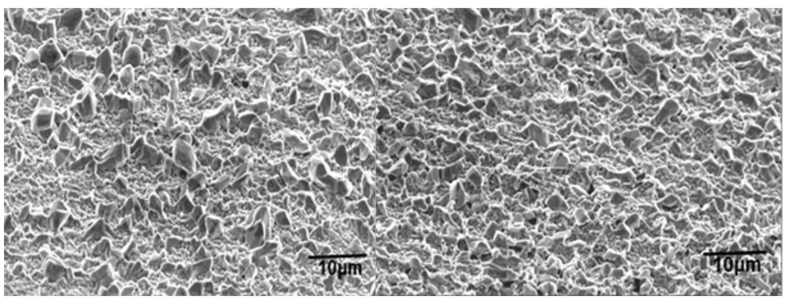
The data clearly indicates that there is clear correlation between surface roughness and whisker propensity. The rougher surface produces lower whisker length and also lower density per $mm^2$. Figure 8 shows whisker growth on 3 um of tin plated on smoother copper (Ra0.13) as compared to no whiskers on the rougher surface (Ra 0.47)




***Ra 0.13, whiskers*** ***Ra 0.47, No whiskers***

***Figure 8. 3 um Tin after 1000 hours at 30$^o$C/60%RH***

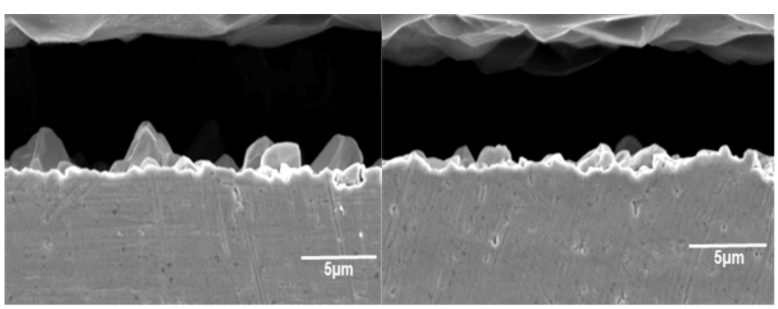
In an effort to explain this more work was done. Samples with a tin deposit thickness of 10 um were stored for 7000 hours at 30$^o$C/60% RH. The tin was then stripped by chemical means and the IMC morphology was examined. In addition cross sections were prepared and examined to verify the top down observation.




***Ra 0.13 um*** ***Ra 0.47 um***

***Figure 9. Morphology of IMC surface after tin stripping***

Figure 9 shows the top view of the IMC after tin stripping on two extremes of Ra namely Ra:0.13 um and Ra:0.47 um. Figure 10 shows cross-sections of the same Ra values. It is clear that the rougher Ra of 0.47um produced a thinner more uniform IMC, compared to the smoother Ra of 0.13um which showed increased IMC thickness in localized areas. A plausible explanation is that the IMC is spread over a much larger area on the rougher morphology (Ra 0.47um) as compared to the smaller area of the smoother surface (Ra 0.13um). It follows then that the stress resulting from IMC formation would be highly reduced and dissipated with increased surface roughness of the underlying copper substrate.




***Ra 0.13 um*** ***Ra 0.47 um***

***Figure 10. Cross section showing the IMC after tin strip***

The solderability and the ductility of a 10 um tin deposit on the 2 extremes of surface morphology were examined using "Wetting Balance Testing" as well as the "Bend test". There was virtually no difference in performance Refer to Figure 11.

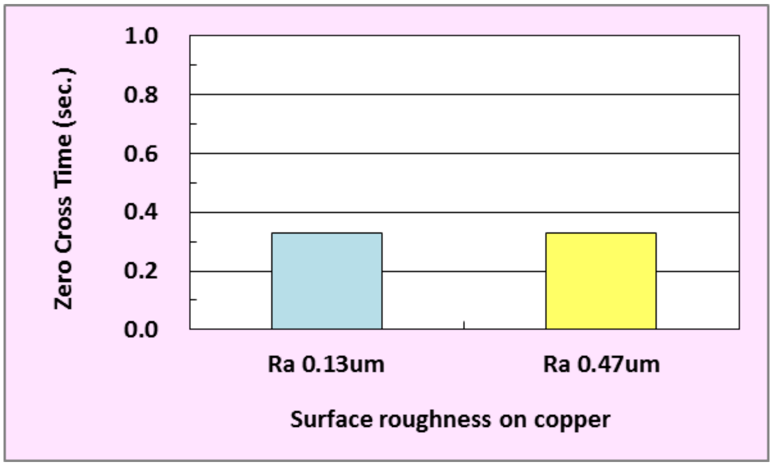



***Figure 11. Comparison of Zero Cross Time of 10 um tin deposit for 2 levels of roughness***

**B. Modifying the Crystal Structure of the Tin Deposit**

A close examination of the crystal structure of both tin and tin-lead alloy shows a clear difference between the 2 deposits. The tin-lead which does not whisker has an equiaxed relatively fine grained deposit. The tin on the other hand shows larger columnar crystals. Figure 12 shows the difference in crystal structure between tin and tin-lead alloy (10 wt%Pb).

It is believed that if the crystal structure of the tin deposit can be modified to the tin-lead crystal structure, the stresses will be dissipated and whiskers will not form.

Tests were conducted using the same test vehicle and the same plating conditions as outlined earlier in the copper surface roughness study above.

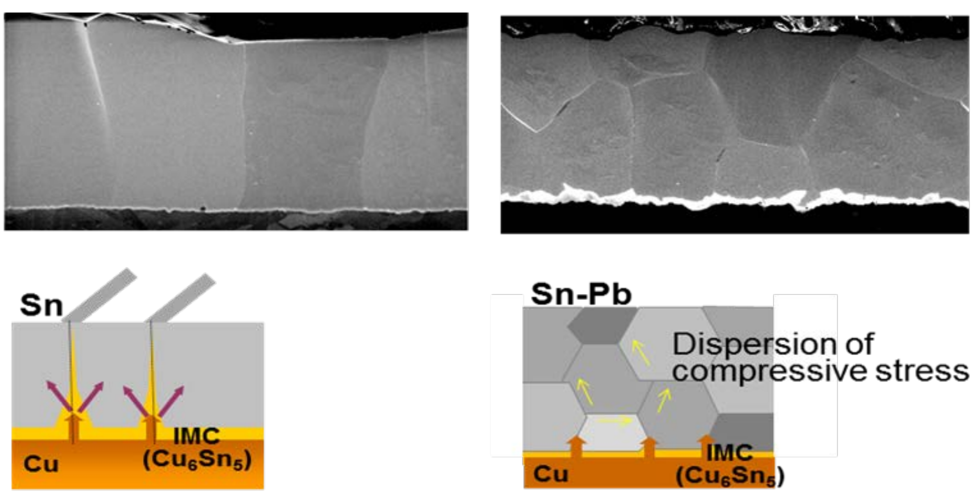
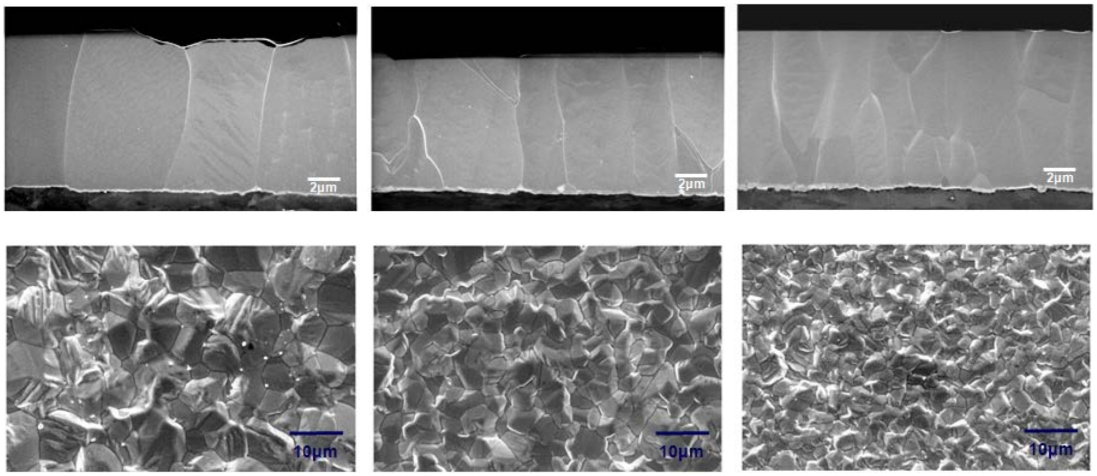



***Figure 12. SEM and schematics of the tin vs the tin-lead deposit structures***

Three types of tin deposits were produced by the use of specific plating additives to the bath; type "A" is a standard tin deposit characterized by large columnar crystals, type "B" is modified to produce smaller columnar grain structure. Type "C" was further modified to produce a still smaller grain that is both columnar as well as equiaxed, almost mimicking the tin-lead structure. Refer to Figure 13 below. The level of additive in the bath is maintained by continuous dosing. Dosing is based on AmpHrs of plating and results on consistent crystal structure throughout the life of the bath.




*Type A* *Type B* *Type C*

***Figure 13. shows the SEM of a cross-section and surface morphology in the 3 types of tin deposits.***

Results and Discussion

All three types were plated to the typical thickness of 10 um (thickness typical of lead frames) and were placed in an ambient environment (30$^{o}$C/60%RH) for 4000 hours. Figure 14 shows Type A tin deposit with relatively long whiskers developed. Figure 15 shows type B, with whiskers that are shorter than the type A whiskers. Figure 16 shows no whisker formation with a Type C crystal structure stored under the same conditions.

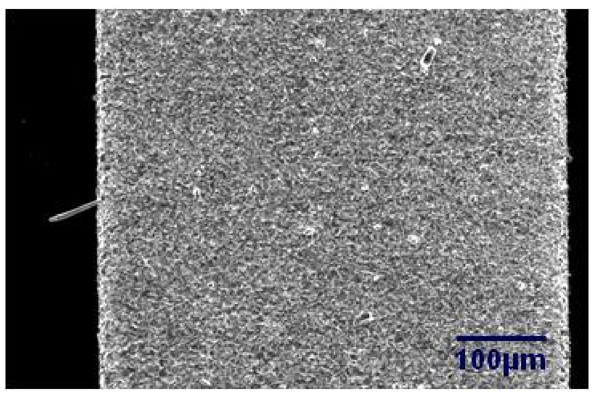



***Figure 14. Type A, Whiskers (long)***

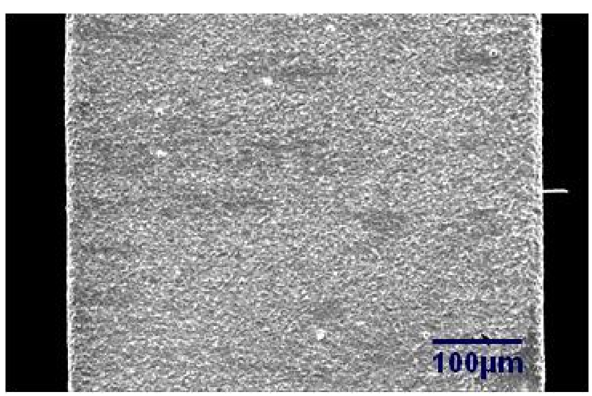



***Figure 15. Type B, Whiskers (short)***

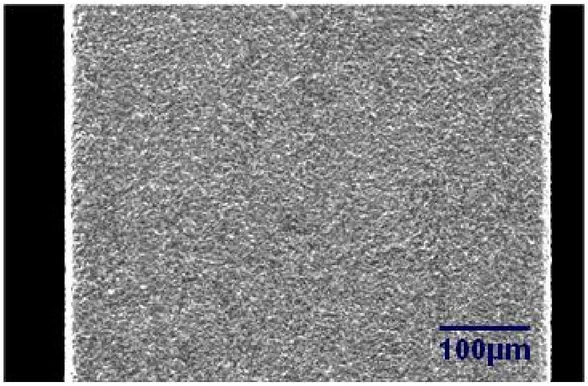



***Figure 16. Type C, No Whiskers***

Figure 17 shows a graph depicting the length of whisker vs storage time of the 3 crystal types of tin deposits.

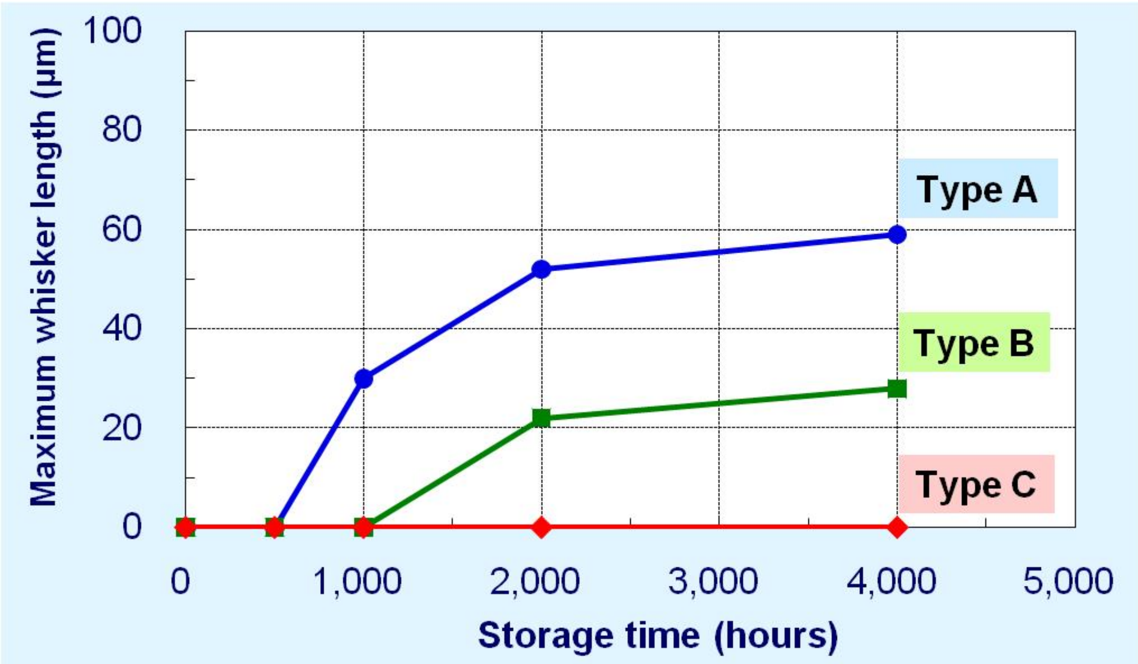



***Figure 17. Storage time vs Maximum whisker length of 3 types of tin structures***

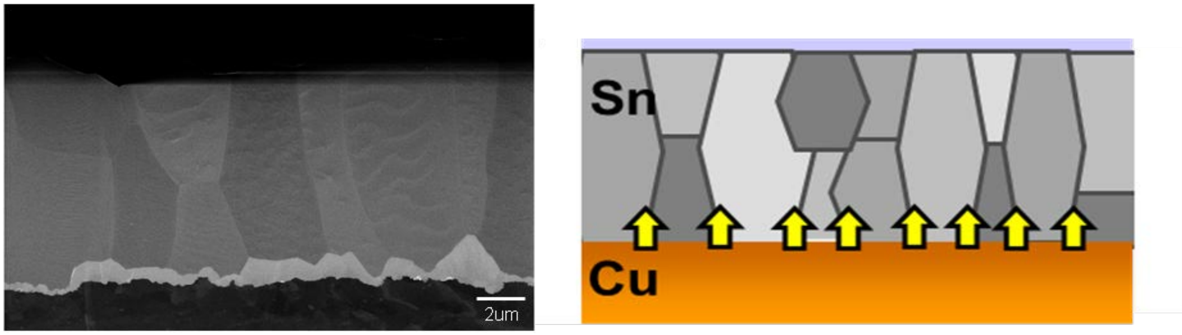



***Figure 18. shows the actual SEM of a cross-section and a graphic presentation of the same.***

Figure 18 is the result of the fine grained equiaxed crystal structure (type C deposit) achieved by modifying the plating bath with specific types of additives.

The result is a very controlled evenly distributed relatively thin IMC, producing minimum stress. The equiaxed crystal structure dissipates the stress resulting in no whisker formation. In this study no whiskers were observed with fine grained equiaxed tin deposits stored under ambient conditions for up to 22000 (twenty-two thousand) hours.

**Conclusion**

In this study two distinct approaches were attempted to restrain whisker growth in tin deposits over copper. The first approach was to create a uniform IMC, by mico-roughening the copper substrate before tin deposition. A uniform IMC would eliminate high stress in localized areas. The second approach was to modify the grain, from a large columnar structure to a fine grained equiaxed structure, resembling the structure of tin-lead deposit. Tin deposit which had crystal structure similar to tin-lead deposit restrained tin whisker formation effectively. Crystal structure modification of the tin deposit was demonstrated to be a very effective way to restrain tin whisker formation.

**Reference**

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[2] W.J. Boettinger, C.E. Johnson, L.A. Bendersky, K.-W. Moon, M.E. Williams, and G.R. Stafford: "Whisker and hillock formation on Sn, Sn-Cu and Sn-Pb electrodeposits", Acta Mater., Vol.53, pp.5033-5050, 2005.

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