BY GEORGE MILAD, NATIONAL ACCOUNTS MANAGER FOR TECHNOLOGY, UYEMURA USA, SOUTHINGTON, CONN.

The Elimination of Whiskers from Electroplated Tin

As the implementation of RoHS continues to affect the industry, tin and tin alloys remain the first choice for replacing tin/lead. Lead-free soldering and LF solder, are presently well implemented in the industry. There is a good understanding of LF solders like: the family of SAC alloys and the tin/copper for Lead-free hot air solder leveling (HASL). The understanding extends to the type of intermetallic compound (IMC) formed, its propagation, and the integrity and reliability of the solder joint that is formed. There is a continuous effort to come up with even better products that may lower the reflow temperature or reduce the IMC propagation for greater solder joint reliability and for a wider assembly window. Some of these efforts involve small amounts of dopants to presently used LF alloys.

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. Tin is easy to apply, is readily solderable and economical to use. Tin works well as a soldering surface; however any part of the lead or the connection surface that is not soldered to has shown a propensity to form tin whiskers over the life of the part. Internal stresses in the deposit, coupled with IMC formation along grain boundaries as well as external stresses on the deposit, are known to initiate whisker formation.

A lot of time and effort has been directed at tin whisker "mitigation." There are a series of methods to determine the propensity of a tin finish to whisker, as well as recommendations on how to evaluate the same. This article describes successful efforts on how to *eliminate* whisker formation.

This article describes the two approaches that were successful in eliminating whisker formation. Both approaches dissipate the stress that is formed from the interaction of IMC formation and the inherent structure of electroplated tin. 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. Controlling the IMC thickness was achieved by micro-roughening the copper substrate before tin deposition. The modification of the crystal structure was accomplished by the use of specific organic additives that

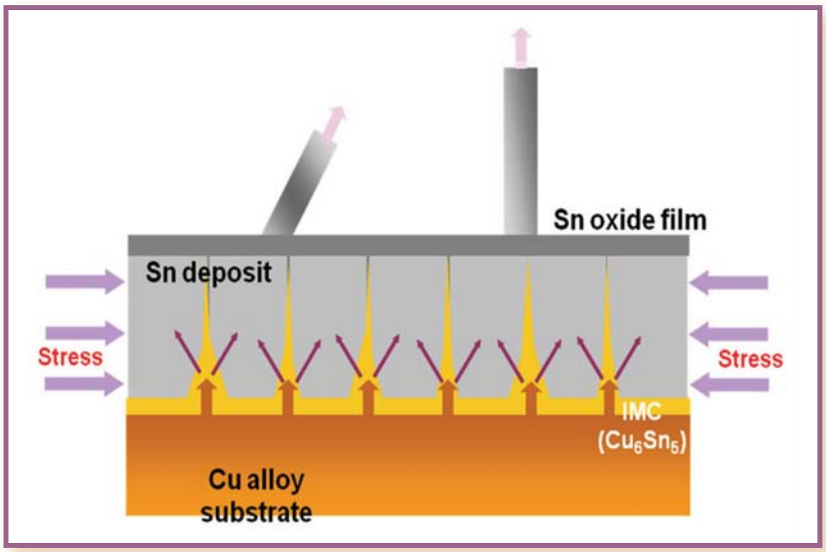


Figure 1. A schematic illustrating tin whisker formation.

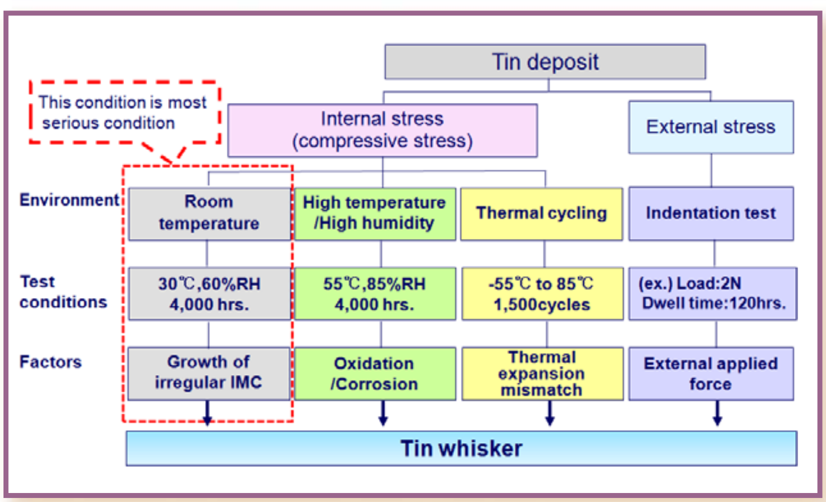


Figure 2. Four different paths that lead to stress and whisker formation.

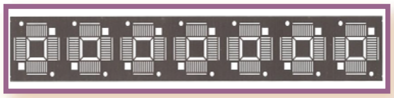


Figure 3. Test Vehicle

disrupt the columnar growth and give rise to smaller equiaxed crystals.

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 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.

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 (see 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°c, 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°c to 85°c 1,500 cycles) due to mis-

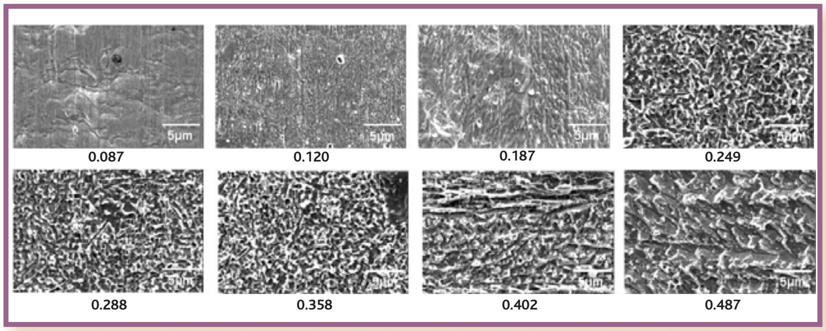


Figure 4. SEM micrographs of different Ra values.

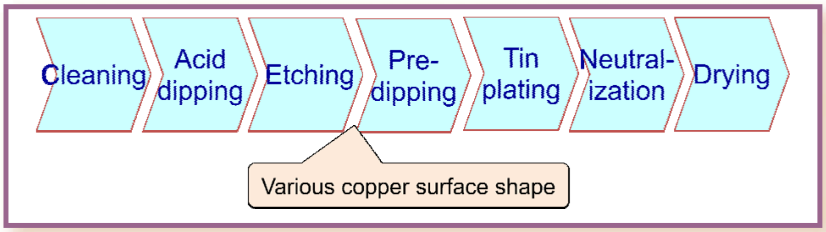


Figure 5. Illustration of the process used for this study (typical plating sequence).

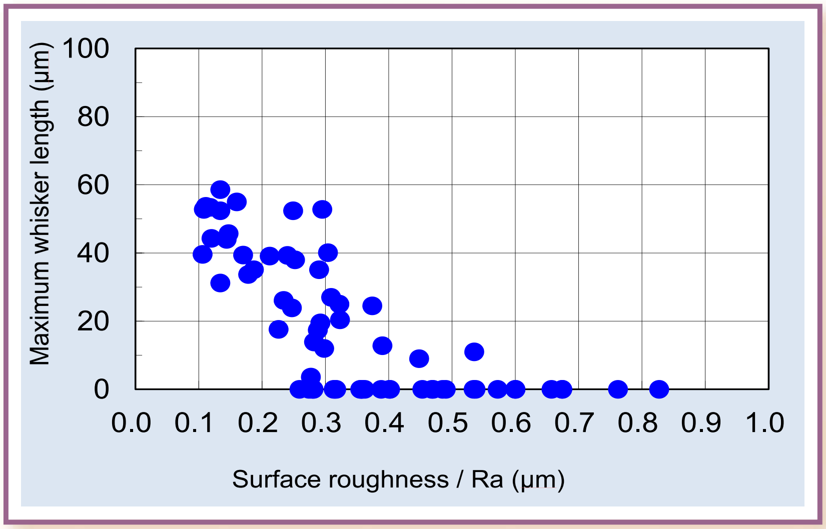


Figure 6. Maximum whisker length vs surface roughness (1000 Hrs at 30°C/60%RH).

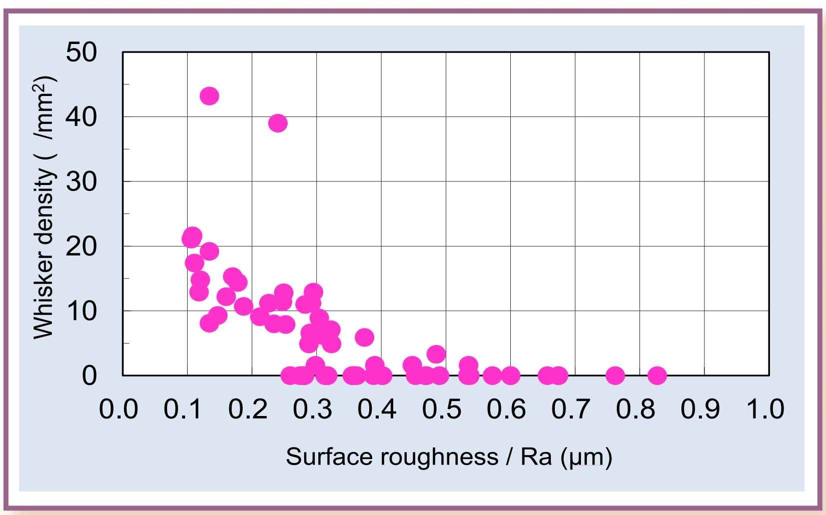


Figure 7. Whisker density vs surface roughness (1000 Hrs at 30°C/60%RH).

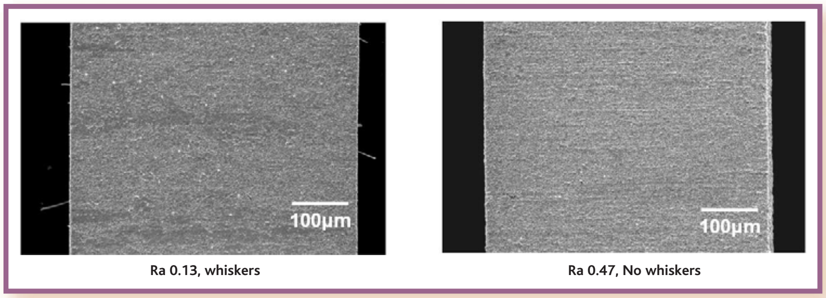


Figure 8. SEM illustrating 3 µm Tin after 1000 hours at 30^{o}C/60%RH.

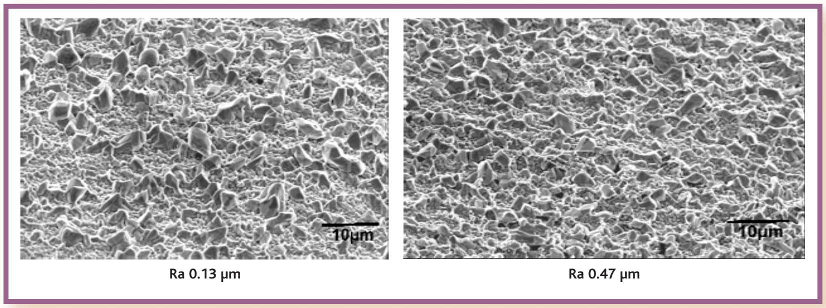


Figure 9. Morphology of IMC surface after tin stripping.

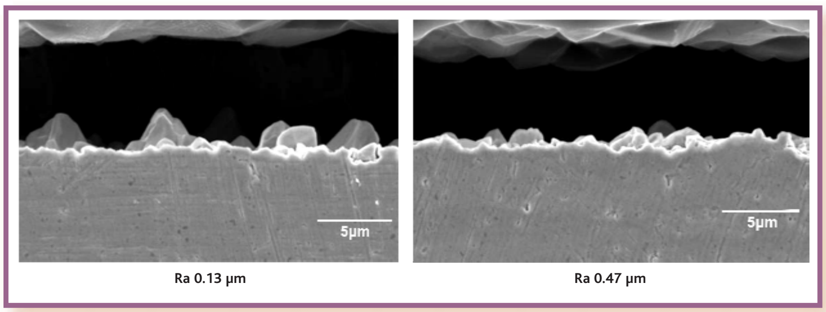


Figure 10. Cross-section showing the IMC after tin strip.

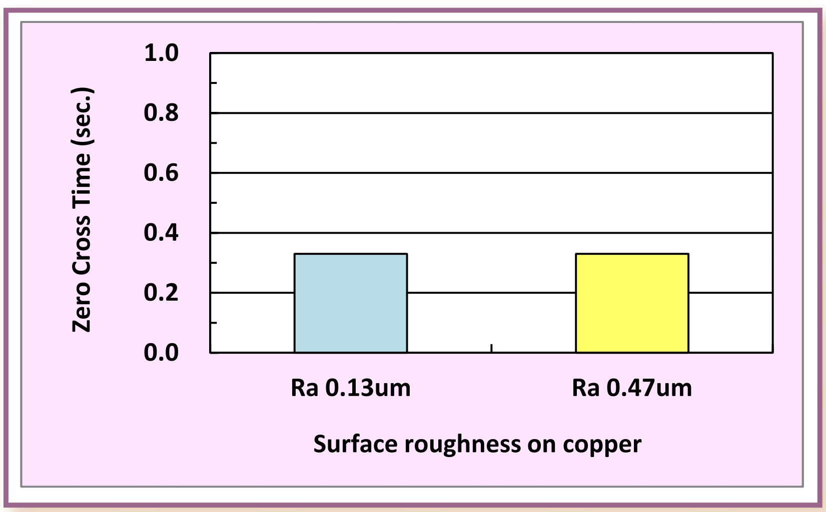


Figure 11. Comparison of zero cross time of 10 µm tin deposit for two levels of roughness.

matched 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.

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, 0.47µm Ra has a much larger surface area compared to 0.13µm Ra. The propensity to whisker was evaluated as follows:

Test Vehicle

The test vehicle - CDA19400 (Cu-2.3Fe-0.03P-0.12Zn) lead frame (see Figure 3).

Tin plating

The plating bath was MSA-based matte tin. The plating was run at a current density of 10A/dm^2. Plating time was varied to produce a 3 micron and a 10 micron 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 through 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.

Definition of a "Whisker"

A whisker is a protrusion >10µm 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.

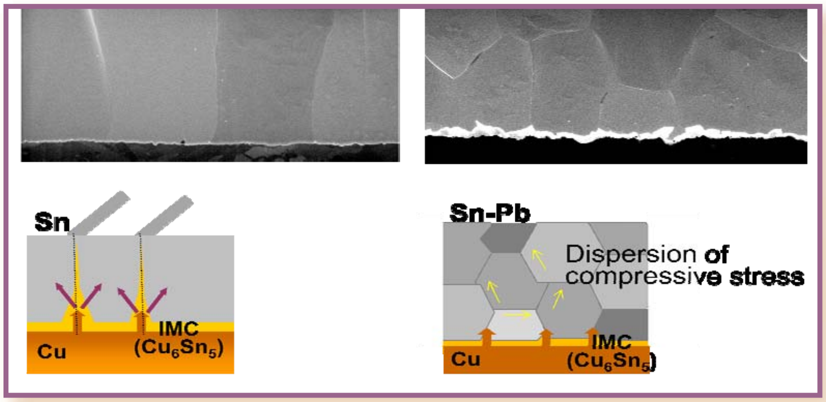


Figure 12. SEM and schematics of the tin vs the tin-lead deposit structures.

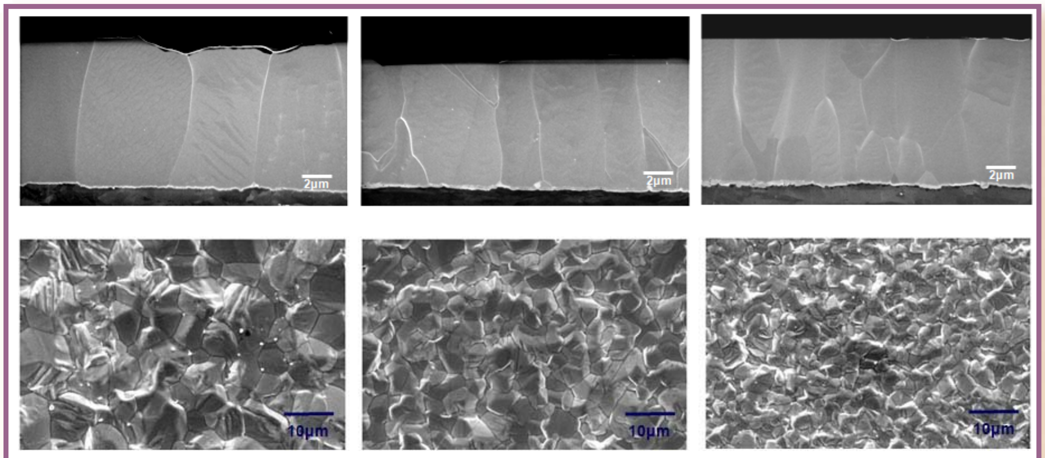
Results and Discussion

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.

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 3µm of tin plated on smoother copper (Ra 0.13) compared to no whiskers on the rougher surface (Ra 0.47)

Samples with a tin deposit thickness of 10µm 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.

Figure 9 shows the top view of the IMC after tin stripping on two extremes of Ra, namely Ra 0.13µm and Ra 0.47µm. Figure 10 shows cross-sections of the same Ra values. It is clear that the rougher Ra of 0.47µm produced a thinner, more uniform IMC, compared to the smoother Ra of 0.13µm, 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 0.47µm) 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.



Type A Type B Type C

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

The solderability and the ductility of a 10µm tin deposit on the two extremes of surface morphology were examined using “Wetting Balance Testing” as well as the “Bend Test.” There was virtually no difference in performance (see Figure 11).

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 two 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

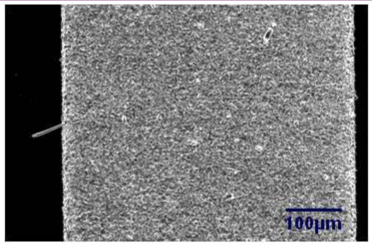


Figure 14. Type A, Whiskers (long).

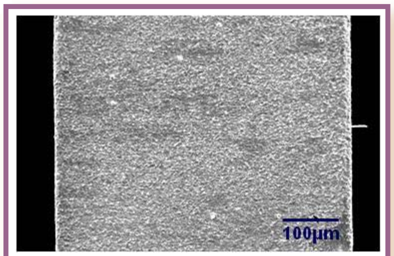


Figure 15. Type B, Whiskers (short).

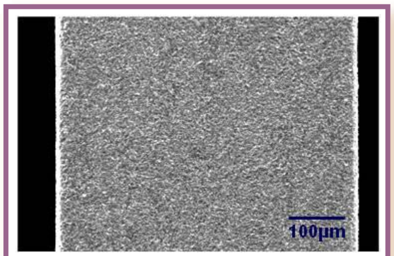


Figure 16. Type C, No Whiskers.

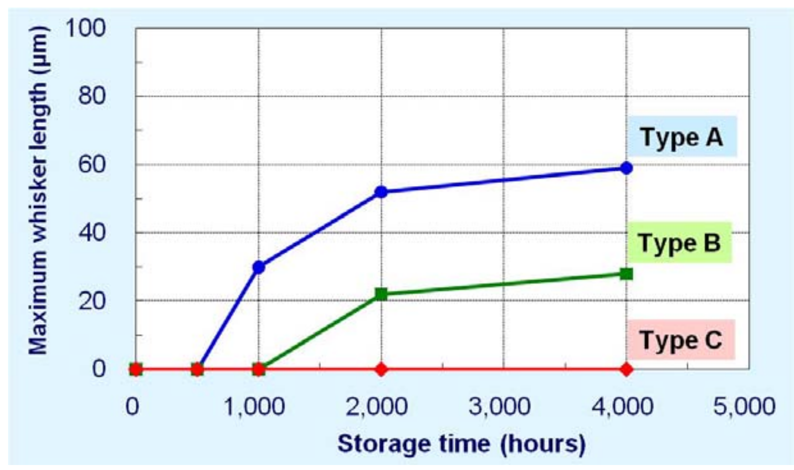


Figure 17. A graph depicting the length of whisker vs storage time of the three crystal types of tin deposits.

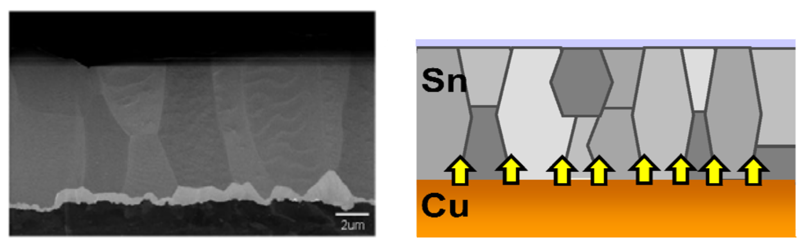


Figure 18. The actual SEM of a cross-section and a graphic presentation of the same.

the copper surface roughness study.

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 (see Figure 13). 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.

Results and Discussion

All three types were plated to the typical thickness of 10 µm (thickness typical of lead frames) and were placed in an ambient environment (30°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 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, and 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 22,000 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. This was achieved by the use of commercially available, proprietary additives. 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.

TECHNICALLY speaking

REFERENCES

[1] P. Oberndorff, M. Dittes, P. Crema, and S.Chopin ; "Whisker Formation on Matte Sn Influence of High Humidity", 55thECTC, 2005.

[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.

[3]W. Zhan and F. Schwager: "Effects of Lead on Tin Whisker Elimination - efforts toward lead-free and whisker-free electrodeposition of tin", *Journal of The Electrochemical Society*, Vol. 153 (5), pp. C337-C343, 2006.

ACKNOWLEDGEMENTS

The development work was done at R & D department at C. Uyemura & Co., Ltd.Hirakata Japan. The research team was headed by Masanobu Tsujimoto with input from: Shigeo Hashimoto, Masayuki Kiso, Raihei Ikumoto,Toshikazu Kano, and Genki Kanamori .

BIO

George Milad is the National Accounts Manager for Technology at Uyemura USA. he may be reached via at gmilad@uyemura.com.