NEMI TIN WHISKER TEST METHOD STANDARDS

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ABSTRACT

The need to better understand whisker growth has dramatically increased as component suppliers convert from tin-lead (SnPb) finishes to Pb-free finishes of Sn and low-alloy-content Sn-based finishes. Whiskers are spontaneous growth of metal filaments emanating from the finish surface. The issues with whiskers are they may grow long enough to cause short circuiting or break off and interfere with other devices in an application. Currently, there is not an industry-accepted test to assay the propensity of a plating finish to whisker and to estimate the risk of whisker growth for a given plating finish. The Whisker Test Method Standards Committee was formed under the sponsorship of the National Electronics Manufacturing Initiative (NEMI) to evaluate different environmental factors influencing whisker growth and to recommend test methods to assess whisker growth propensity of plating finishes.

The Committee has completed two phases of testing. The initial Phase 1 evaluations, performed with lab-plated bright Sn samples, provided some insight on which environments would cause a plating finish to whisker but very few occurrences of whiskers were observed which made the results inconclusive. A Phase 2 evaluation was performed with production plated matte Sn from two integrated circuit (IC) suppliers. The results revealed that several environments were very effective in forming whiskers.

Based on the results of both Phase 1 and 2 evaluations, NEMI is recommending three tests (two storage conditions and one temperature cycle condition) to evaluate the whisker growth propensity of plating finishes. The Committee is preparing a test method document to be presented to JEDEC, the Solid State Technology Association (once known as the Joint Electronic Device Engineering Council), for release.

Key words: Pb-free plating finish, Leadframe package, Whisker growth

INTRODUCTION

Many IC suppliers are evaluating and implementing Pb-free finishes acting in accordance with the industry movement to eliminate Pb in the use of electronics. There are several commercially available tin-based finishes that are being considered as replacement finishes to the current SnPb finish. These include: tin (Sn), tin-bismuth (SnBi), and tin-copper (SnCu). Sn-based finishes are being considered because they provide good corrosion protection and a solderable surface. However, a drawback of Sn-based finishes is whisker growth. Although this phenomenon was observed and studied (quite extensively) in the past when pure Sn was the prevailing component finish, standard whisker test methods were never established. Now that Sn and its alloys with low content of the alloying element are being considered to replace SnPb, the concern for whisker propensity has raised a need for standard test methods. Standard test methods will help the industry move more quickly in the evaluation and development of Sn-based Pb-free finishes. In addition, standard tests will permit meaningful comparison of whisker propensity for different plating systems and processes, provide a consistent inspection protocol for tin whiskers examination, and provide a standard method to compare and report results.

Under the auspices of NEMI, a team was formed to identify an accelerated test method for whiskering by evaluating various known methods. At the writing of this paper over 40 companies were participating in different capacities on this committee. The project was initiated with a benchmark study to collect all existing methods for growing whiskers. Also, the team identified and discussed theories behind whisker formation in order to compare test method to whisker growth mechanism and fundamentals. The fundamentals of whisker growth proved to be more complex than anticipated and a separate committee was formed to evaluate different whisker growth theories. However, the test standard committee proceeded with evaluations of test methods which members reported to have resulted in whisker growth. Four principal methods were reported to successfully grow whiskers on some, but not all, tin plated samples. These test methods were: storage at ambient office conditions; storage between 50 °C and 85°C; storage at high relative humidity (85-95%); and -55C/85°C air-to-air temperature cycling.

Two phases of testing have been completed. In Phase 1, samples (brass coupons and 8 lead small outline integrated circuit packages (SOICs) were prepared with bright Sn along with SnPb alloy as a control. Based on past literature, bright Sn is more prone to whisker growth, so it was chosen to improve the likelihood of whisker growth. The samples were then subjected to assorted combinations of the four environments identified. The results of the Phase 1 study were inconclusive. Whiskers formed only on the bright Sn-plated coupons, and were few in number - much less than expected. Some odd-shaped eruptions formed on the 8 lead SOICs but no confirmed whiskers. It is speculated that because the samples were plated in a lab the level of impurities and/or contamination were maintained very low and thus helped to retard whisker growth. A second hypothesis is that when the terminations of the 8 lead SOICs were formed the plating finish cracked, reducing stress in the finish and thus helped to retard whisker growth.

The results of the Phase 1 study were inconclusive. The team felt it was necessary to perform an additional study of the test methods with packages (8 lead SOICs) plated at an assembly house using production baths.

EXPERIMENT

Two IC suppliers volunteered and plated 8-lead SOIC samples for the Phase 2 study. One supplier (Supplier A) provided samples plated with a Methane Sulfonic Acid (MSA) bath and samples plated with a Sulfate-based electrolyte. The second supplier (Supplier B) provided samples plated with a second MSA bath. Thick (10-12 micron) and thin (2-3 micron) Matte Sn samples, as well as, SnPb samples were included in the evaluation. The list and the description of the samples are presented below.

A=2 to 3μm, Matte Sn (Sulfate) on OLIN194 Cu SOIC molded/singulated
B=10 to 12μm, Matte Sn (Sulfate) on OLIN194 Cu SOIC molded/singulated
C=2 to 3μm, Bright Sn on brass coupon
D=10 to 12μm, 90Sn/10Pb on OLIN194 Cu SOIC molded/singulated (control)
E=2 to 3μm, Matte Sn (MSA) on OLIN194 Cu SOIC molded/singulated
F=10 to 12μm, Matte Sn (MSA) on OLIN194 Cu SOIC molded/singulated

The samples described above were subjected to different environment combinations presented in Table 1.

Table 1. Test conditions and sample description for whisker tests with 8 lead SOICs.

Legs	Temp Cycle (°C)	Temp (°C) & Relative Humidity (%)	Supplier Plating Site	Remarks
6	-	60, 95	A	Temp & Humidity
7	-	60, 95	B	Temp & Humidity
8	-	30, 90	A	Humidity
9	-	30, 90	B	Humidity
10	-55 to 85	30, 90	A	Temp Cycle + Humidity
11	-55 to 85	30, 90	B	Temp Cycle + Humidity
12	-55 to 85	Ambient	A	Test Temp Cycle
13	-55 to 85	Ambient	B	Test Temp Cycle
14	Ambient	Ambient	A	Ambient
15	Ambient	Ambient	B	Ambient

A parallel study was performed with chip fuses by a supplier of passives. Table 2 lists the samples in the passive study. Electrolytic barrel plating was used to plate the chip fuses. The fuses were first plated with a nickel barrier layer, 2.54 to 12.7μm in thickness; then with 100% Sn, 2.54 to 15.24μm in thickness. The fuses were subjected to the environment conditions presented in Table 3. With the exception of the pulse plated fuses, the as-plated microstructure of the barrel plated fuses was severely cold-worked due to the peening action between parts during tumbling, whereas the lead frame strip, generally, contained only localized regions of plastic deformation.

Table 2. Sample description for whisker tests with fuses.

Plating Group #	SEM Puck #	Ball Size 1/8 or 1/16 (Ni)	Ni Thickness (μm)	Sn Thickness (μm)	Plating Metho
1	1–6	1/8	6.68-8.38	10.67-13.36	Barrel
2	7–12	3/32	5.56-9.22	9.58-11.43	Barrel
3	13–18	1/16	7.82-10.54	10.62-13.56	Barrel
4	19–24	3/32	5.82-7.62	7.67-9.85	Barrel
5	25–30				Pulse

Table 3. Test conditions for whisker evaluation with chip fuses (sample size: 10 fuses/split).

Plating Group #	SEM Puck #	Temp Cycle (°C)	Temp. (°C) & Humid.	Fuse Type	Remarks
1	1–2	-40 to 90	60, 90	1206FA	Only puck 2 at temp/humidity
	3–4	-	60, 90	1206FA	
	5–6	-	Ambient	1206FA	
2	7–8	-40 to 90	60, 90	1206FA	Only puck 8 at temp/humidity
	9–10	-	60, 90	1206FA	
	11–12	-	Ambient	1206FA	
3	13–14	-40 to 90	60, 90	1206FA	Only puck 14 at temp/humidity
	15–16	-	60, 90	1206FA	
	17–18	-	Ambient	1206FA	
4	19–20	-40 to 90	60, 90	1206FA	Only puck 20 at temp/humidity
	21–22	-	60, 90	1206FA	
	23–24	-	Ambient	1206FA	
5	25–26	-40 to 90	60, 90	0603FA	Only puck 26 at temp/humidity
	27–28	-	60, 90	0603FA	
	29–30	-	Ambient	0603FA	

EQUIPMENT

An air to air temperature cycling equipment capable of cycling from –55°C (+0, -10°C) to +85°C (+10°C, -0) was used to carry out thermal cycling procedure. A temperature humidity chamber capable of 60°C/95±5%RH and 30°C/90±5%RH environments was utilized for temperature/humidity experiments. Ambient storage was defined as ~23°C and ~30-60% RH conditions (air-conditioned office environment). Scanning Electron Microscope (SEM) was used for whisker inspection.

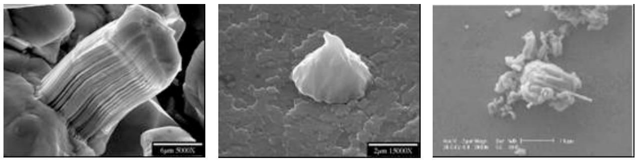
In addition, for the passive study an air to air thermal shock chamber, cycling from –40°C to +90°C (±5°C), was used for thermal cycling. A temperature humidity chamber, capable of 60°C/90%RH environment, was used for temperature and humidity storage. SEM was also used for whisker inspection.

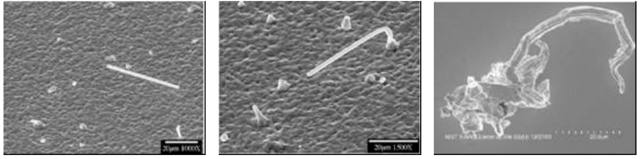
TIN WHISKER DEFINITION

For inspection purposes, the following definition of a whisker was developed, "A spontaneous columnar or cylindrical filament, which rarely branches, of mono-crystalline tin emanating from the surface of a plating finish". Furthermore, tin whiskers may have the following characteristics:

- An aspect ratio (length/width) >2
- Can be kinked, bent, twisted
- A consistent cross-sectional shape
- Rarely branch
- May have striations or rings around it

See Figures 1 for pictures of tin whiskers.


Column (consistent cross-section)
Hillock
Odd-Shaped Eruption (OSE) or Flower


Needle (consistent cross-section)
Needle growing out of hillock
Needle growing out of OSE

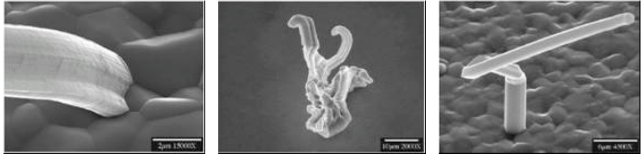

Striation on whisker
Very rarely, whiskers may branch
Kinked whisker

Figure 1. SEM photos illustrating different whisker types and characteristics.

INSPECTION PROCEDURE

The inspection protocol outlined here has been used to inspect numerous samples of the types described. Example images are included to illustrate the typical results of the method.

Leaded Packages

Three packages randomly chosen from the test sample mounted in upright, inverted and inverted rotated positions. Carbon tape or paint was used to create conductive paths, or carbon was evaporated on the parts if inspection was made immediately. At 300x magnification, three randomly located fields from a) underside of lead, b) top of lead and c) side of lead (Figure 2) were inspected. The stage was tilted to 45 degrees for the latter two images. The fields were selected as representative of the overall condition of the parts as determined by the first inspection.

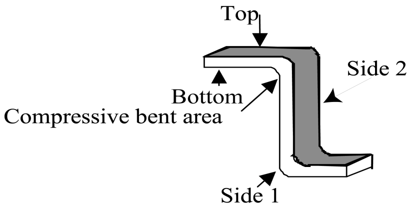


Figure 2. Schematic of package lead.

Coupons

On each of 3 coupons randomly selected from the test samples, at least three images were collected at 300x and data was recorded as above. Similarly, image at 3000x was collected for grain size determination.

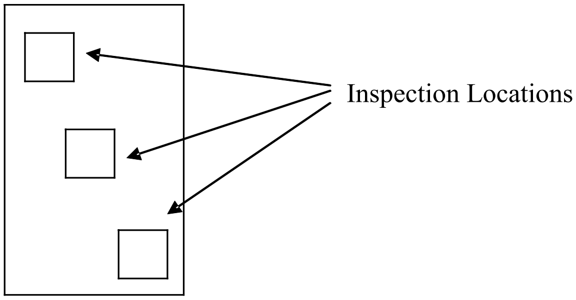


Figure 3. Schematic of test coupon.

Passive components

Five or ten samples were mounted onto SEM mounts (Pucks) depending on the chip fuse size. These mounts were used for both processing the fuses through the test conditions and for SEM analysis. Data was kept in a similar manner to the leaded packages.

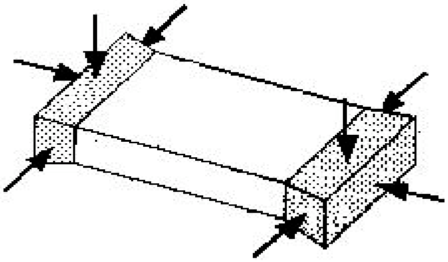


Figure 4. Schematic of passive component.

REPORTING INSPECTION RESULTS

All whiskers in the three fields were counted and recorded. The longest whisker in each field was measured and recorded, using higher magnification if necessary. Finally one image at 3000x from an undisturbed region of plating was collected. The estimated grain size range of the deposit was reported. The average number of whiskers from the three fields and the length of the longest whisker found in those fields were reported. The date of plating, whisker test conditions (duration, temperature, humidity, number of cycles, etc.) and the date of inspection were included.

BATH CONTROL

Each plating bath was maintained at the optimum conditions specific for each process. Level of metallic contamination was measured by Atomic Absorption Analysis prior to plating (t_0) and after the plating was complete (t_e). The results for both suppliers are presented in the table 2.

Table 4. Impurity levels (parts per million) in Sn plating bathes for samples A, B, D, and E. Note, t_o = before plating, t_f = after plating.

Supplier A										
	Pb		Fe		Cu		Zn		Ni	
ppm	t_o	t_f	t_o	t_f	t_o	t_f	t_o	t_f	t_o	t_f
Sulfate (A&B)	6	6.3	9.7	11.9	0.4	0.6	0.4	0.5	0.44	0.5
MSA (D&E)	N/A	N/A	5.2	5.2	0.7	0.7	0.6	0.7	0.41	0.48
Supplier B										
MSA (D&E)	8.2	8.3	13.9	15	0.3	0.3	0.3	0.3	10	13

PHASE 2 TEST RESULTS

The results of the 8 lead SOIC whisker test for three plating processes (two MSA-based and one Sulfate-based plating chemistries) and for two deposit thicknesses (2.5 and 10 micron) subjected to all test conditions are shown in Figure 5. The bars in each graph depict the average number of whiskers in the field of view at 300x magnification and the line charts depict the lengths of the longest whiskers.

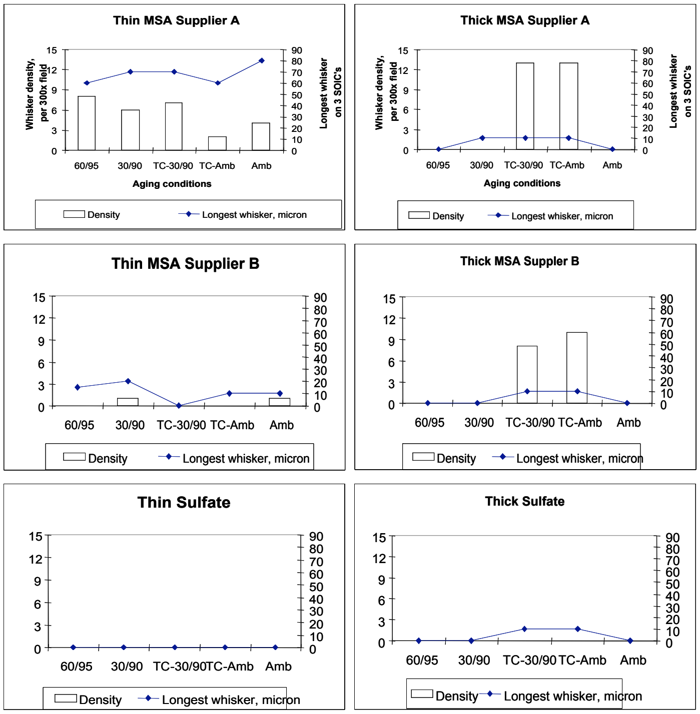
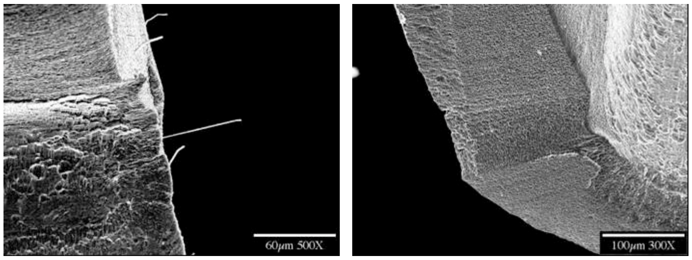


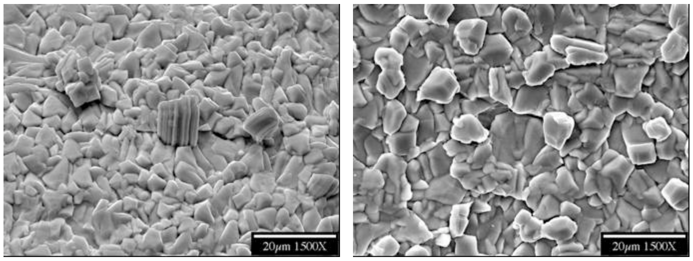
Figure 5. Whisker test results for various test conditions, deposit thickness, and bath chemistries.

SEM photos of whiskers from the 8 lead SOIC study are provided in Figure 6. The results indicate that the thin samples from Supplier A exhibit significantly higher whiskering under all tested conditions comparing to the other two samples. However, thick samples plated with both MSA-based processes show comparable whisker performance. It is somewhat surprising because thick samples from Supplier B have more whiskers than thin ones plated with the same process. For thick samples, the test conditions that included thermal cycling, followed by both ambient and 30°C/90% RH storage, produced significantly higher whiskering than either ambient or 60°C/95% RH conditions. Deposits produced with sulfate-based process, both thin and thick, did not produce significant whiskers. SnPb (control) samples showed no whisker growth in all test conditions.



Thin MSA, Supplier A
long whiskers
(60°C/95%RH storage only)

Thin MSA, Supplier B
no whiskers
(60°C/95%RH storage only)



Thick Sulfate
short whiskers
(temp cycle + ambient)

Thick MSA, Suppler A
many short whiskers
(temp cycle + 30°C/90%RH)

Figure 6. SEM photos of whiskers from the 8 lead SOIC evaluation.

The results for the chip fuse whisker test are provided in Table 5. No tin whiskers were found after four weeks at ambient temperature and humidity conditions or after four weeks at 60°C/90%RH. Table 5 only shows results from temperature cycling and then extended temperature and humidity storage. Very little change occurred after the additional temperature and humidity storage.

Table 5. Chip fuse whisker test results for whisker frequency and maximum length.

Plating Group #	After 500 Temp Cycles (-40°C to 90°C)		After 500 Temp Cycles (-40°C to 90°C) & 4wks storage (60°C & 90%RH)	
	Whisker Frequency 200µm x 260µm area	Max Length (µm)	Whisker Frequency 200µm x 260µm area	Max Length (µm)
1	223	31	159	22
2	54	44	66	25
3	137	28	144	38
4	66	34	93	34

5	6	9	3	9

All groups were plated with Ni and matte Sn. Current densities were varied slightly for each group. Groups 1-4 were barrel plated and group 5 was plated in an automated pulse plating system.

PREFERRED ORIENTATION

An attempt was made to correlate the whisker performance of deposits plated from various chemistries with thickness of 2.5 and 10 micron and their crystal structure. Crystal structures of the deposits were measured by Powder X-Ray Diffraction method and described in terms of their preferred orientation factors. Preferred orientation factor for an orientation [hkl] was calculated using the formula,

$$P(hkl) = \frac{I(hkl)/\ I_o(hkl)}{(1/n)\ ?\ [I(hkl)/\ I_o(hkl)]}$$

Where

$P(hkl)$ = Preferred Orientation Factor

$I(hkl)$ = measured intensity of hkl reflections

$I_o(hkl)$ = theoretical intensity of hkl reflections

n = number of reflections used in analysis

If P=1 for all orientations, the deposit has no preferred orientation and represents random polycrystalline structure characteristic for tin powder. Figure 7 shows Preferred Orientations Factors (P) for samples of different thickness plated from various chemistries – three orientations with highest P per sample. One can see that deposit thickness as well as plating chemistry affect the type of preferred orientations and it is difficult to correlate the preferred orientations with whisker performance.

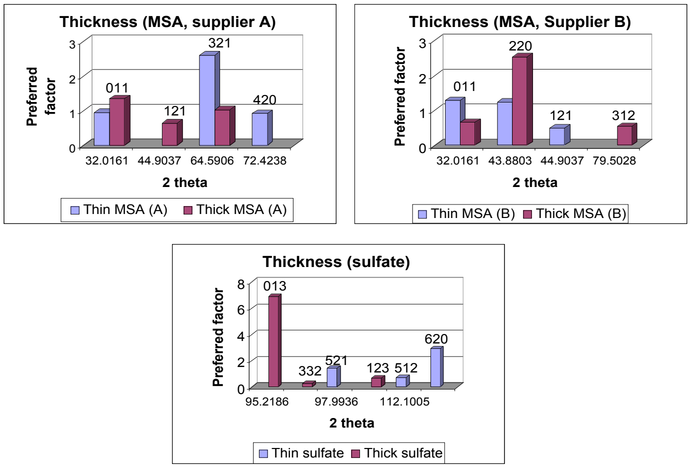


Figure 7. Effect of deposit thickness on crystal orientation for various plating chemistries (crystal orientations are given in Miller indices above the bars).

Another way of interpreting these data is to analyze whether highly textured deposits produce fewer whiskers. The hypothesis was proposed that in highly textured deposits, majority of grains have the same crystal orientation and their grain boundaries are well-aligned and have lower number of dislocations and lower energy. Thus, those deposits should whisker less. To do this analysis, the volume fraction was determined by taking the highest value of P divided by the sum of all the Ps for each plating. Table 6 shows only the highest volume fraction of preferred orientation for each type of deposit, thick and thin.

Table 6. Type and volume fraction of preferred orientation in test samples (highlighted numbers for the samples with highest whiskering).

	MSA Supplier A		MSA Supplier B		Sulfate	
	Thin	Thick	Thin	Thick	Thin	Thick
Preferred Orientation	**[321]**	[011]	[011]	[220]	[620]	[013]
Volume Fraction (%) of grains with highest P	**58**	45	43	68	58	88

There is only one highly textured sample – thick deposit plated from the sulfate-based chemistry which showed no noticeable whiskering. However, other deposits with more random orientation exhibit similar whisker growth. Again, there is no visible correlation between deposit orientation and texture and whisker performance. Probably, other factors contribute to the mechanism and may become dominating under various circumstances.

CONCLUSIONS

The Phase 2 results were more conclusive. The environmental stress conditions evaluated in this study were sufficient to create whiskers on 8 lead SOICs and on chip fuses. In general, more whiskers grew with the -55°C/85°C or -40°C/90°C temperature cycle methods. Ambient, 60°C/95%RH and 30°C/90%RH storage methods also grew whiskers but were not as effective as the temperature cycle methods.

Whiskers resulting from temperature and humidity storage were only observed for the 8 lead SOICs. Ambient storage and temperature and humidity storage alone did not grow whiskers on the chip fuses for the period evaluated (four weeks).

The addition of temperature and humidity exposure did not add significantly to the whisker length or frequency when temperature cycle was performed first.

Differences in whisker performance within the deposit thickness range tested were not observed.

The results suggest that the bath chemistry/plating process has the most significant influence on whisker growth. There appears to be substantial difference between the two MSA-based processes from the suppliers; and in general the sulfate-based chemistry seems to have better whisker performance over one of the MSA-based bath but only slightly better performance over a good-practice MSA bath.

Similar process-whisker correlations were observed for the chip fuses. The barrel plating media diameter, current density, and pH level were observed to affect whisker frequency. The whisker lengths were, however, similar in all four barrel plating groups.

Impact of media to the product was thought to induce more whiskers. An automated pulse plating system was tested that imparted less surface impacts and minimal whiskers grew on the chip fuses. The frequency was low and the whiskers were shorter than the barrel plated groups. (More studies are required for verification.)

All tested plating process parameters have strong effect on the deposit crystal orientation but the degree of deposit texturing for all tested samples was similar. The sample with highest whisker growth had preferred orientation [321]. Other samples with various orientations exhibited comparable whisker growth. Based on the data generated in this experiment, it is difficult to establish correlation between crystal orientation of the deposit and its whisker performance.

The fact that whiskers formed on the tin-plated samples under all environmental conditions tested in the Phase 2 experiments indicates that the proposed test methods are adequate for evaluation of whisker propensity of tin deposits.

FUTURE WORK

A Phase 3 experiment is currently in the planning stage to verify the results of the Phase 1 and 2 evaluations. One of the goals of the Phase 3 evaluations is to show that the three recommended tests can consistently produce whiskers with similar samples. A second goal of the evaluation is to confirm that it is applicable for other Sn-based (SnBi and SnCu) finishes and possibly other sample types (connectors, special design coupons, etc.). The tests will be carried out to extended durations to determine appropriate end points for each test method. The endpoints will be defined by the saturation of growth (growth saturation definition to be determined).

An attempt to correlate the test methods to application life will also be examined. Since the mechanism for whisker growth is not known, subjecting samples which have been produced with Sn (and/or Sn-based Pb-free) finishes to the recommended test methods may provide some correlation to application life (risk) in applications where these current Sn-plated products are used.

Work is also continuing in the NEMI Whisker Fundamentals Group to develop a better understanding of whisker formation which may lead to better test methodology or validate that these are the best tests that can be carried out.

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