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Tin Whisker Growth - Substrate Effect Understanding CTE Mismatch and IMC Formation

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Abstract
The hypothesis that the "whisker growth phenomenon" in electrodeposited tin is a re-crystallization process driven by stress has gained popularity among leading research institutes and industrial laboratories. However, there exist varying opinions as to the type of stress responsible for this phenomenon. Recently, various studies have demonstrated that compressive stress, whether intrinsic or externally applied, is most likely the cause of whisker growth.

There are three main sources of compressive stress that a component finish experiences *after plating*. They are: stress generated by intermetallic compound formation between the tin finish and the copper alloy substrate; mechanical stress such as trim-and-form introduced in current manufacturing practice; and thermal stress generated by temperature cycling and propagated into tin layer due to CTE mismatch among the constituent materials of a component.

It is well recognized that both IMC formation and CTE mismatch are largely affected by the substrate material and underlayer/barrier between Sn and substrates, as well as aging conditions. In this paper, we attempted to understand the relative contribution of stress generated from IMC and from CTE mismatch on various leadframe and connector substrates at both isothermal and temperature cycling conditions. Ultimately, we hope to delineate the whisker accelerating factors to provide input for the industry to derive a set of standard yet realistic whisker test methods.

Key words: tin, tin whisker, whisker formation, temperature cycling, thermal cycling, CTE mismatch, intermetallic compound formation, compressive stress, tensile stress

Introduction
The whisker growth phenomenon was discovered by Hunsicker and Kenspf in 1947.[1] Since then many studies were carried out to understand the seemingly "unpredictable" nature of this phenomenon. More than fifty years later, we are still plagued and intrigued by tin whisker growth.

In the "early days", internal stress was postulated as the driving force for whisker formation. However, there was no clear-cut understanding of the type of stress, i.e., compressive or tensile, responsible for spontaneous whisker growth. In addition, there was no available data on direct stress measurement of electroplated Sn film. In 1998, Lee and Lee[2] made the first stress measurements using a "deflection method" which correlated whisker growth with compressive stress measured as a function of storage time. They attributed the compressive stress to the formation of irregular *intermetallic compound* (IMC) at Sn grain boundaries. Xu et al[3] in 2001 utilizing X-ray diffraction to measure stress in electrodeposited tin demonstrated that depending on the nature of the sub-layers, the stress in the Sn layer could be either compressive or tensile. Specifically, it was shown that stress in Sn deposited directly on Cu, and "aged" at ambient temperatures, became compressive or progressively more compressive, and eventually exhibited whisker growth. The incubation time and growth rate varied depending on the specific nature of the Sn electrodeposits (e.g., matte or bright).[4] On the other hand, if Sn was deposited over a Ni barrier layer, and "aged" at ambient temperatures, the stress in Sn layer became tensile. Consequently, no whiskers were observed with this layered structure independent of storage time and whether the Sn layer was matte or bright. In this and earlier studies,[5, 6] it was also shown that mechanically induced compressive stress further accelerated the whisker growth rate of both matte and bright Sn finishes, yet an mechanically applied tensile stress reduced whisker growth.

In a recent study, Zhang et al[7] investigated the formation of intermetallic compounds with Sn/Cu and Sn/Ni couples at ambient and elevated temperatures by examining cross-sections of the interfaces. Specifically, in the case of Sn/Cu couple, Cu diffuses predominantly into Sn, whereas for the Sn/Ni couple, more Sn diffuses into Ni than Ni diffuses into Sn. The diffusion of Cu incorporates additional mass in the same volume of the Sn layer and thus results in a compressive stress. Alternatively, in the case of the Sn/Ni couple, a tensile stress builds up in the Sn layer because of the depletion of Sn resulting in a mass deficiency in the same volume of the Sn layer. They also confirmed Lee and Lee's work, i.e., at ambient temperatures, intermetallic compound layer (Cu_6Sn_5) forms predominantly in the Sn grain boundaries for the Sn/Cu couple, resulting in an irregular interface. Coupled with the stress measurements and whisker cross-sections by focused ion beam,[8] this group showed unambiguously that compressive stress in the Sn layer was directly responsible for whisker formation. Furthermore and more specifically, it was the formation of irregular IMC which was the key source of compressive stress.

At elevated annealing temperatures, the growth behavior of the IMC with the Sn/Cu couple is quite different. In this case, a denser and relatively uniform IMC "front" is formed. Subsequent stress measurements showed little to no residual stress, indicating that stress has been relieved during the annealing process. Close examination of the IMC interface showed that in addition to a uniform IMC layer, the grains for both IMC and Sn had increased significantly thus resulting in stress relaxation of the Sn layer. Recently, other groups have published similar findings concerning IMC formation.[9, 10]

In the case of the Sn/Ni couple, at both ambient and elevated isothermal temperatures, the stress in the tin layer was tensile. These samples did not show any whisker growth for as long as four years. It is important to point out that this observation is not unique, similar results have been published by others.[11, 12]

Approximately two and half years ago, researchers at NASA began to show a drastically different whisker behavior concerning Sn/Ni couple.[13] Specifically, they demonstrated that chip capacitors grew many whiskers after either *thermal cycling* (TC) or *thermal shock* (TS). These chip capacitors consisted of pure Sn plated terminations over a Ni barrier layer, as previously described. This observation generated quite a controversy which centered on the validity that a Ni barrier generates tensile stress which is beneficial for whisker reduction.

The NASA report prompted scientists from government labs, OEMs, subcontractors and plating suppliers to investigate this phenomenon to assess the impact of TC or TS on real-life product reliability. A number of publications in the last two years demonstrated that whisker growth under TC and TS conditions is caused by *coefficient of thermal expansion* (CTE) mismatch among the layered materials. The most noteworthy paper is by Dittes et al,[14] who investigated various parameters associated with TC and TS experiments including temperature range, absolute temperature, ramp rate, dwell time, and number of cycles (up to 1000). In their study, they included a matte tin plated on Alloy 42 (FeNi42) substrate; work was also performed on a Cu based substrate for reference. In the TC case, single-chamber equipment was employed, and the samples were cycled between a cold and a hot temperature at a ramp rate of ca. 10°K/min. In the case of TS, two-chamber equipment was utilized, and samples were transferred between the hot and cold chamber in air or in the liquid phase which takes a few seconds. The most frequently cited dwell time at each holding temperature is 10 min. In the Results and Discussion section, unless otherwise specified, we will not differentiate thermal cycling and thermal shock, we will call it *temperature cycling.*

Dittes and his coworkers found that under temperature cycling condition, significantly higher whisker growth was exhibited on Alloy 42 than on copper. This could be explained by the larger CTE mismatch between Sn/FeNi42 (ca. $19 * 10^{-6}\,K^{-1}$) than between Sn/Cu (ca. $6 * 10^{-6}\,k^{-1}$). They found that whisker length may have a parabolic relationship to the number of thermal cycles. Furthermore, temperatures below - 15°C do not appear to influence the whisker growth at moderate dwell times (e.g., 10 min), although they may affect the timing for whisker growth decay. In addition, they observed a linear relationship between ΔT and whisker length.

This work undoubtedly provided much needed experimental data for better understanding of whisker growth behavior under temperature cycling conditions. However, it should be expanded to include the following:
1) substrates such as Olin 194, 151, 7025, brass and phos bronze besides Alloy 42, with and without a Ni barrier layer,
2) matte *and* bright Sn finishes of various thicknesses

Typically, the connector industry uses a Ni barrier layer beneath the SnPb (now lead-free) layer over brass or phos bronze substrate. As we have demonstrated earlier, under ambient and elevated temperatures, stress in the Sn layer is tensile therefore the deposit does not grow whiskers; however, it is important to understand whisker growth behavior under temperature cycling conditions. Secondly, even though IC leadframe plating has not typically utilized a Ni barrier layer over Olin 194, 151 and 7025, there are large OEMs requesting a Ni sub-layer underneath the leadfree finish.

Since both matte and bright Sn have been identified as lead-free alternatives, and in some cases, are specified by semiconductor IC packaging and connector companies as replacements for Sn/Pb finishes, they should be included in temperature cycling tests. On that note, it is equally important to include common connector substrates such as brass and phos bronze. As we know, connector plating specifies Sn thickness from 3 to 5 μm, whereas IC leadframe plating specifies Sn thickness from 7 to 12 μm.

In summary, in this paper, we investigated the different stress generation pathways in electrodeposited tin layer by varying the nature of the tin deposit and its thickness, the substrate materials and the aging conditions. It is our objective to delineate whisker accelerating factors to provide input for the industry to establishing a set of standard yet realistic whisker test methods.

Experimental

In this study, we included three matte and two bright chemistries. Among them, two matte and bright chemistries are methane sulfonic acid (MSA) based, one matte is sulfuric acid based. These chemistries along with the substrates used in this study are summarized in Table 1.

The Sn finishes, bright and matte, with or without a Ni barrier layer, were plated on substrate materials including commonly used alloys for making electronic connectors (brass and phos bronze) and IC leadframes (C 194, C151 and A42). Sn finishes were plated at 200 ASF to a thickness of 3 um on connector substrates, and 3 and 10 um on IC leadframes materials. Matte Sn finishes have an average grain size of ca. 5 µm, whereas bright finishes have an average grain size of ca. 0.2 µm.

Ni was plated at 100 ASF to a 2 µm thickness typically from a Ni sulfamate bath. The thickness for both Ni and Sn was measured by x-ray fluorescence.

Table 1 - Whisker Test Matrix

SUBSTRATE	MATTE 1	MATTE 2	MATTE 3*	BRIGHT 1	BRIGHT 2
C194	w & w/o Ni	w & w/o Ni	w & w/o Ni	—	—
C151	w & w/o Ni	w & w/o Ni	w & w/o Ni	—	—
A42	w & w/o Ni	w & w/o Ni	w & w/o Ni	—	—
Brass	w & w/o Ni	w & w/o Ni	w & w/o Ni	w & w/o Ni	w & w/o Ni
Phos Bronze	w & w/o Ni	w & w/o Ni	w & w/o Ni	w & w/o Ni	w & w/o Ni

*Sulfuric/sulfate***Sample Preparation***

Thermal Shock

An air-to-air ESPEC thermal shock chamber was used. A cycle of the thermal shock is defined as 10 minutes at – 55°C followed by 10 minutes at 85°C. The transition time from one temperature zone to another was a few seconds. The samples were removed for whisker examination at 500, 1000, and 2000 cycles.

Whisker Examination

Inspection of whiskers was performed by SEM. The samples were tilted 45° for optimum observation. Each sample size is 1 square inch. The first stage of the examination involves scanning through the entire surface to identify the area that exhibited the longest and most number of whiskers. The second stage involves examination of the “target zone” at 1000 and 3000 magnifications and covering an area of ca. 1/8 square inch (0.8 square centimeters) for flat samples, and 1/16 square inch (0.4 square centimeters) for bent samples. Due to the large sample size, we did not use The Whisker Index[5, 7] to quantify whisker growth propensity. SEM micrographs recorded the observed whiskers and their length. In the Results and Discussions section, we plotted all figures (maximum length vs. substrate material) with the same Y scale for easy comparison unless otherwise specified.

Mechanical Deformation

A compressive 90 degree bend was introduced with matte and bright Sn finishes on connector substrates. For Sn plated on brass, the sample thickness was 15 mils (375µm) with a bend radius of 74 mils (1.85mm). For Sn plated on phos-bronze, the sample thickness was 8 mils (200µm) and the bend radius was 35 mils (875µm). This fulfills the $R/r < 6$ requirement specified in reference 15.

Results and Discussions

Whisker Observation after Temperature Cycling – Leadframe Substrates

In this section, we shall discuss the observations from three matte electrolytes on C194, C151 and Alloy 42 (Table 1). Figures 1 – 3 displays the results without a Ni underlayer. As mentioned previously, Matte 1 and 2 are MSA based chemistries, matte 3 is sulfuric acid based chemistry.

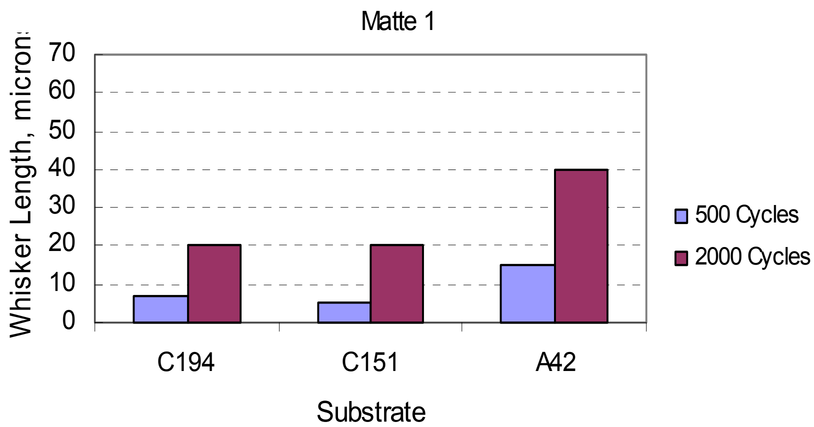

Figure 1 – Matte 1 Without Ni Underlayer

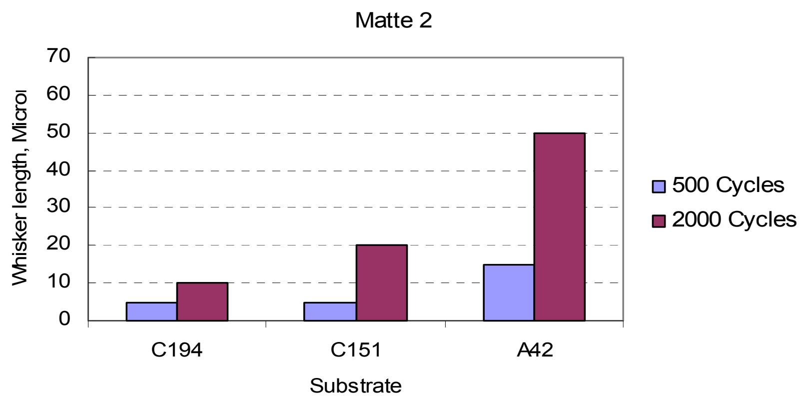

Figure 2 – Matte 2 without Ni Underlayer

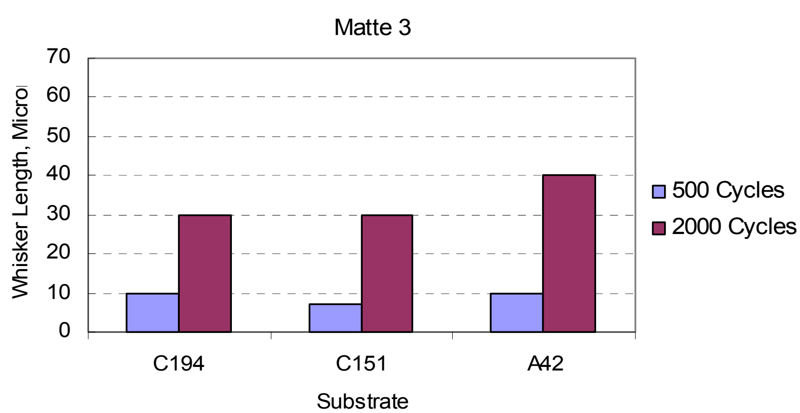

Figure 3 – Matte 3 without Ni Underlayer

As expected, increasing the number of cycles resulted in an increase in the whisker length, whisker frequency, and diameter as shown in Figures 4 – 6. Indeed, the dependence of length, diameter, and frequency on the numbers of cycle is quite significant. It is interesting to note that among C194, C151 and Alloy 42, the whisker growth behavior is the worst on Alloy 42 independent of the electrolytes. There is appreciable difference of longest whiskers among the three matte chemistries. The matte 2 electrolyte appears to be slightly better than matte 1 & 3 especially taking into consideration size and frequency of whiskers.

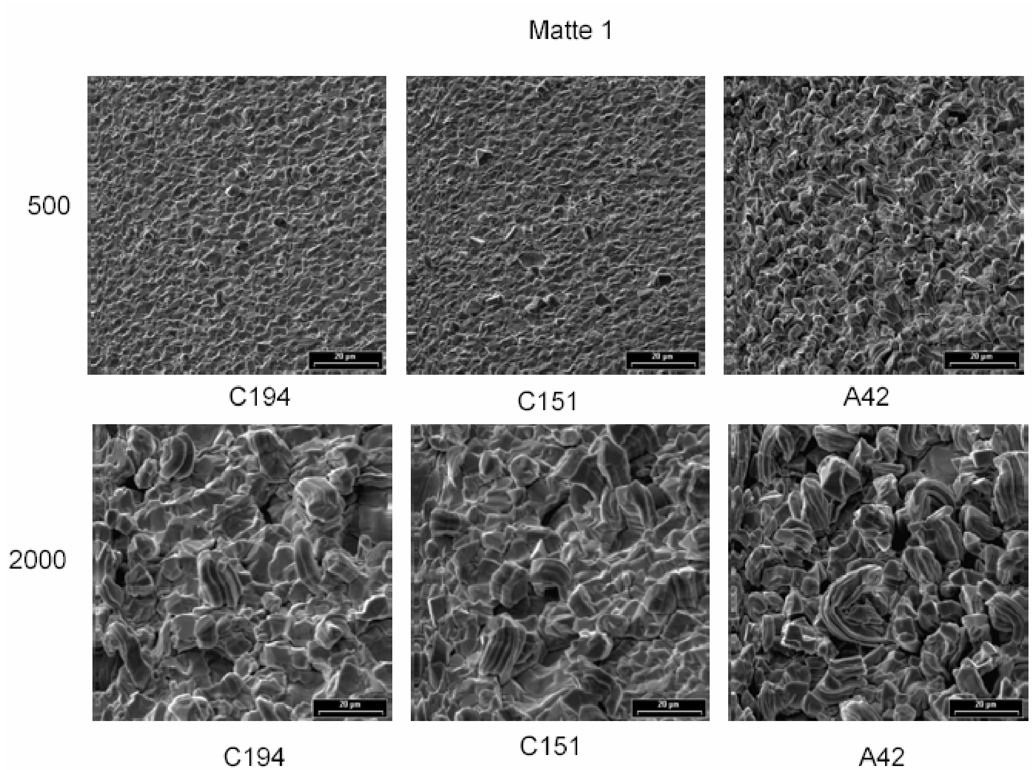

Figure 4 – Whisker Growth as a Function of Cycling (SEM at 1000X)

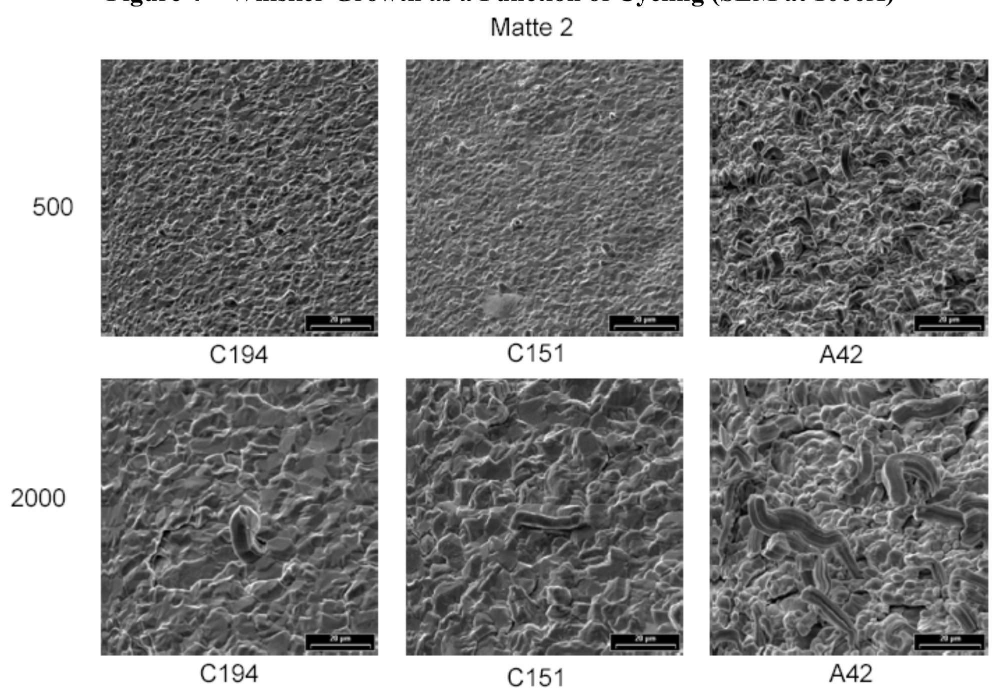

Figure 5 – Whisker Growth as a Function of Cycling (SEM at 1000X)

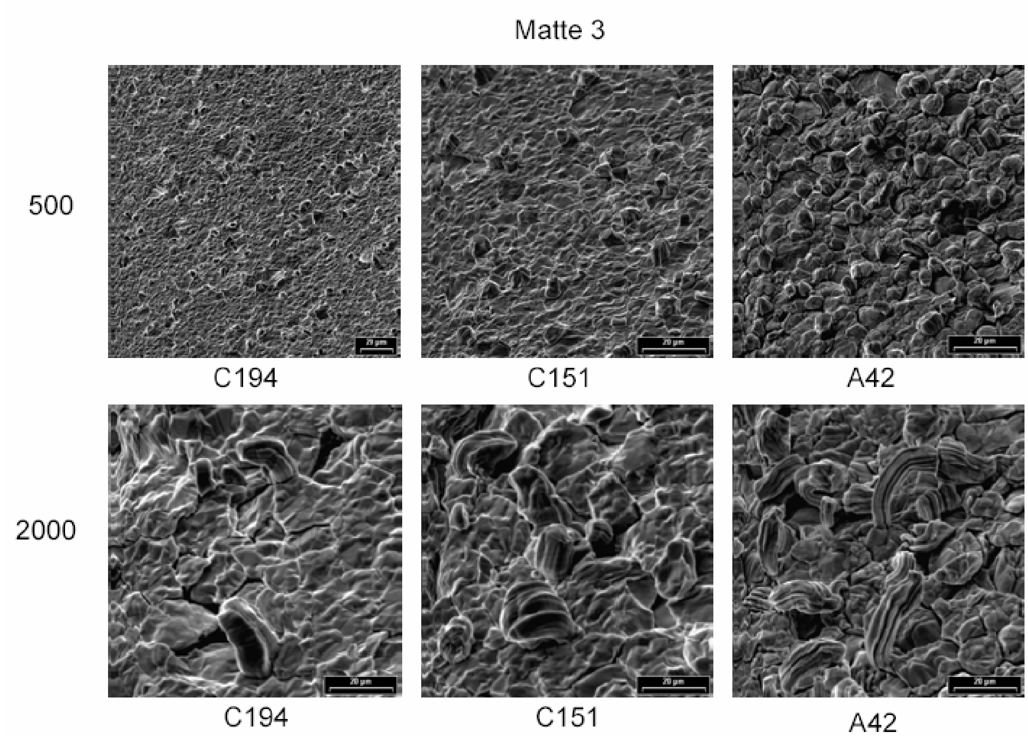

Figure 6 - Whisker Growth as a Function of Cycling (SEM at 1000X)

Utilizing a Ni barrier layer uncovered some interesting phenomena. Figures 7 – 9 display the relationship between whisker length and substrate material. Figures 10 – 12 display representative SEM micrographs of these samples. Matte 1 and 3 electrolytes exhibited an increased whisker growth. On the other hand, with matte 2 electrolyte, the whisker growth is somewhat reduced. Further investigation is in progress to confirm the observations.

On Alloy 42 with a Ni barrier layer, we observed an increase in whisker growth with all electrolytes. This is somewhat unexpected! Because the CTE difference between Sn and Ni (10×10^{-6} K^{-1}) is less than Sn and FeNi42 (19×10^{-6} K^{-1}), therefore we expected to see a slight reduction of whisker growth rate in the presence of a Ni barrier over FeNi42 substrate.

When we compare the three electrolytes, we do see some appreciable differences especially after 2000 cycles, the matte 2 electrolyte again appears to have lower whisker growth.

In summary, we found that under the temperature cycling conditions, all matte Sn finishes grew whiskers. After 500 cycles, the longest whisker was about 20 µm. After 2000 cycles, the longest whisker was about 50 µm. This trend holds true in general terms, i.e., longer cycle time produces longer, more and “thicker” whiskers. A Ni barrier under the temperature cycling condition did not help reduce whisker growth. However, whisker growth appeared to be slightly worse with a Ni barrier layer in some cases. This result may seem contradictory to our understanding of Ni’s role in inducing tensile stress in Sn layer under isothermal conditions. However, we think that in this case the stress generation mechanism is determined by CTE mismatch rather than IMC formation.

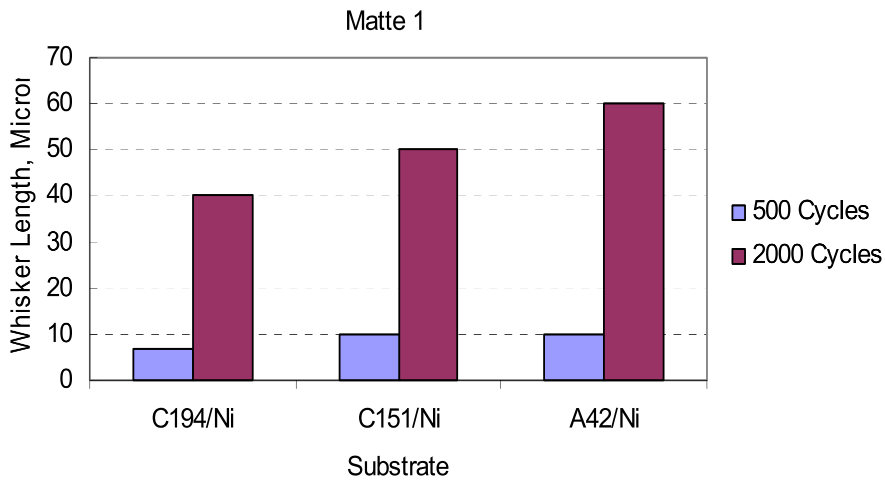

Figure 7 – Whisker Length by Substrate Type

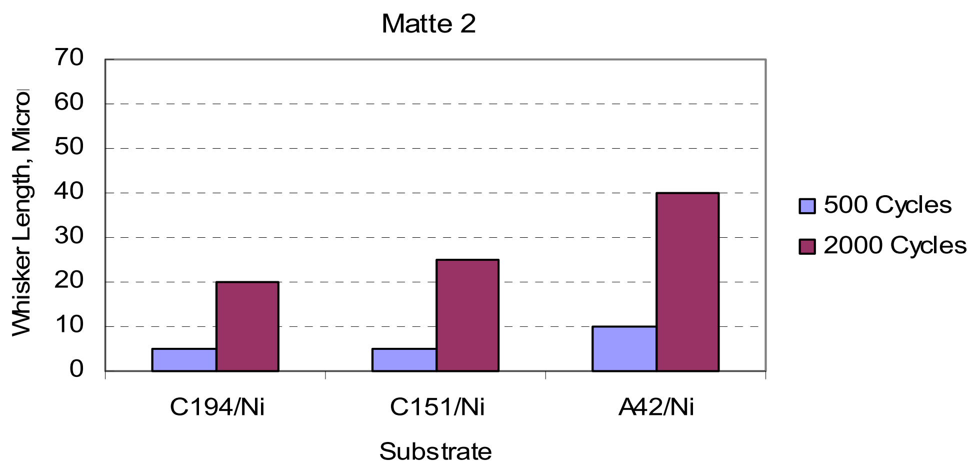

Figure 8 - Whisker Length by Substrate Type

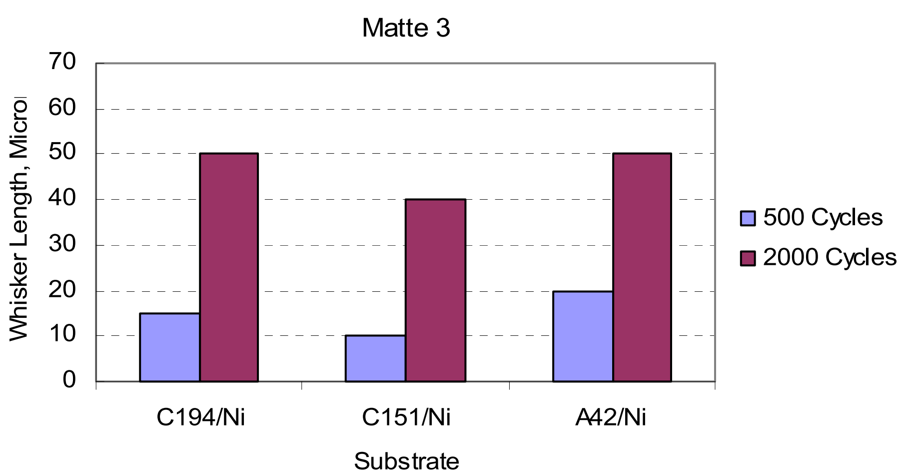

Figure 9 - Whisker Length by Substrate Type

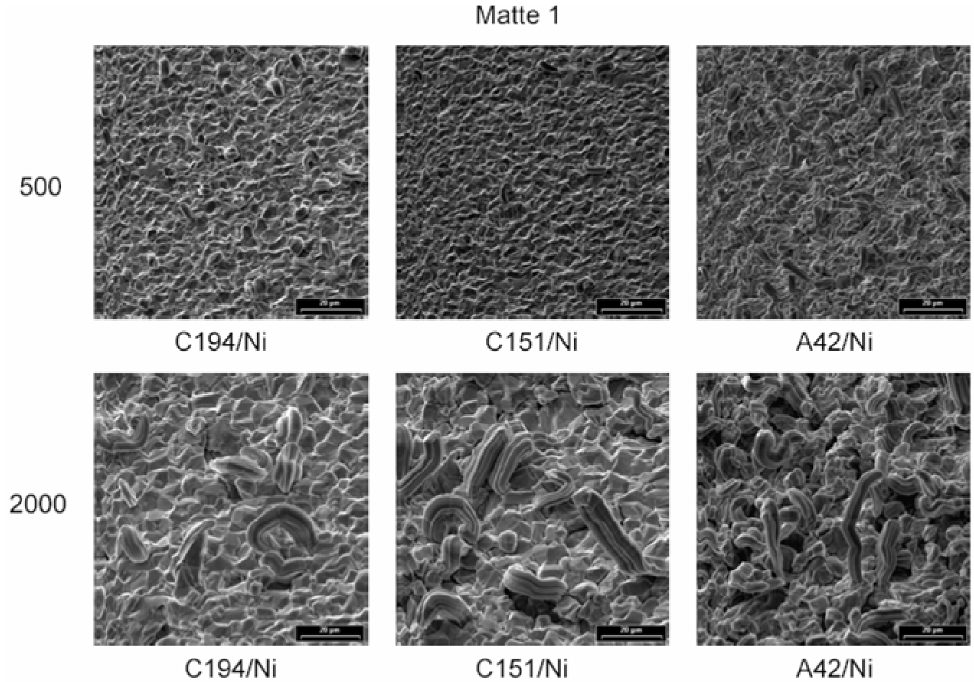

Figure 10 - Whisker Length by Substrate Type (SEM at 1000X)

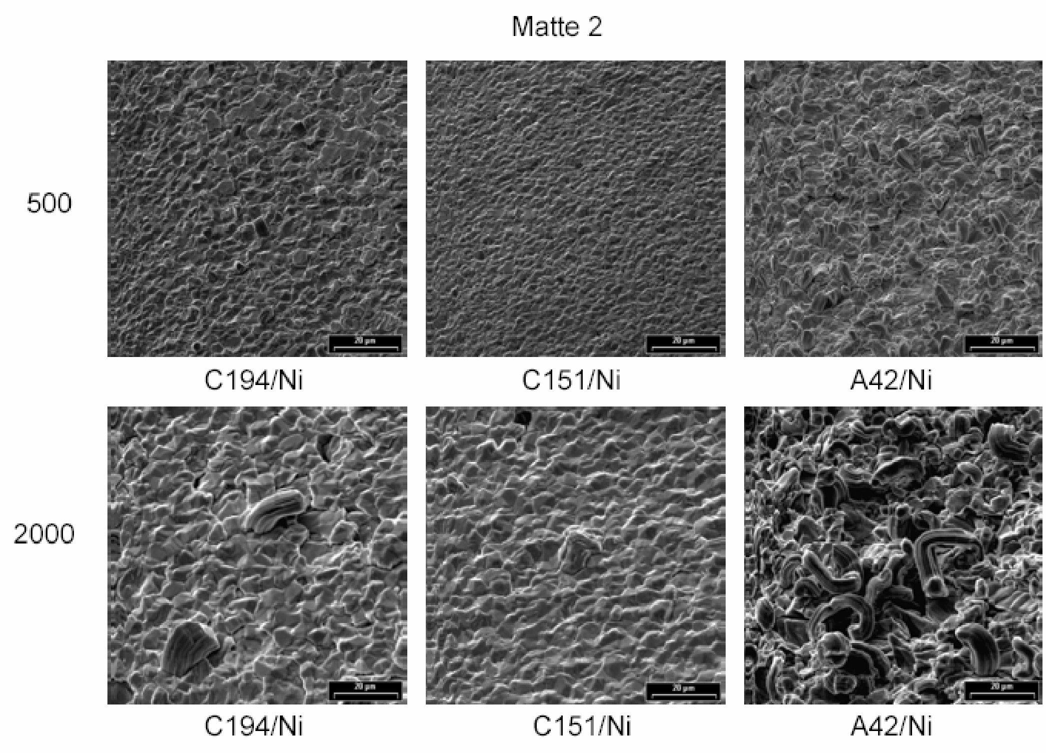

Figure 11 - Whisker Length by Substrate Type (SEM at 1000X)

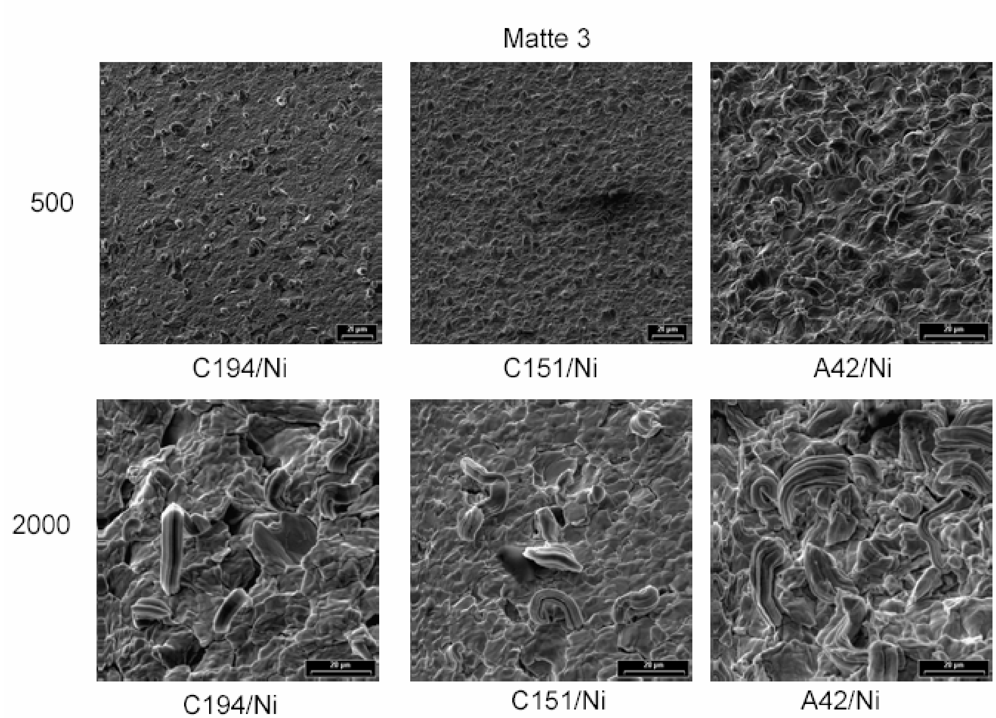

Figure 12 - Whisker Length by Substrate Type (SEM at 1000X)

Whisker Observation After Room Temperature Aging – Leadframe Substrates

Identical sets of samples showed different whisker growth behavior when "aged" at room temperature up to four months. In this case, we selected one Cu leadframe, C194, and Alloy 42. Figures 13 to 15 display the results with and without a Ni barrier layer. As can be seen clearly, at room temperature, all Sn finishes are whisker resistant in the presence of a Ni barrier layer – no whiskers were observed. On the other hand, there is some whisker growth on all three matte finishes plated directly on a Cu substrate, although the maximum length was relatively short, ca. 15 µm.

On Alloy 42, matte 2 electrolyte did not show any whiskers after four months, the other two electrolytes did. The longest whiskers observed are less than 15 µm.

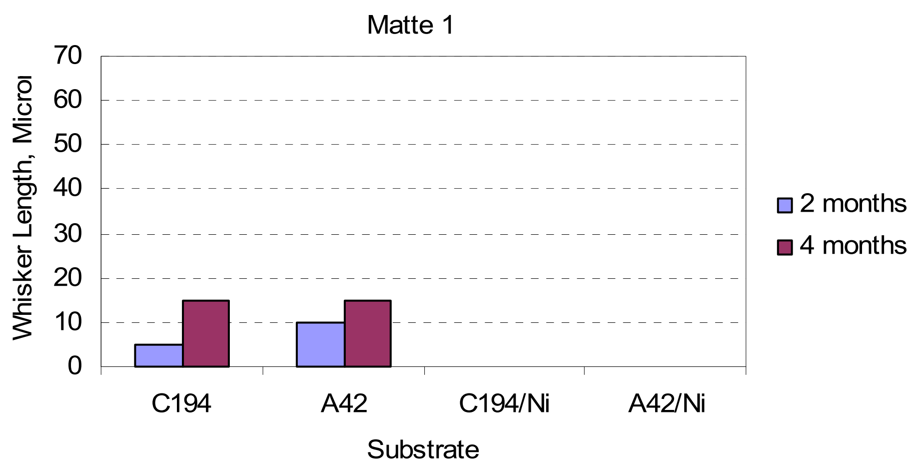

Figure 13 – Results With and Without Ni Barrier

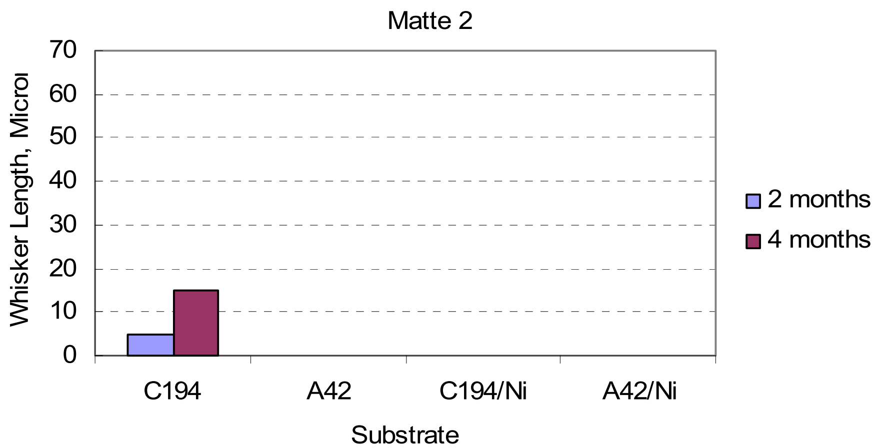

Figure 14 – Results With and Without Ni Barrier

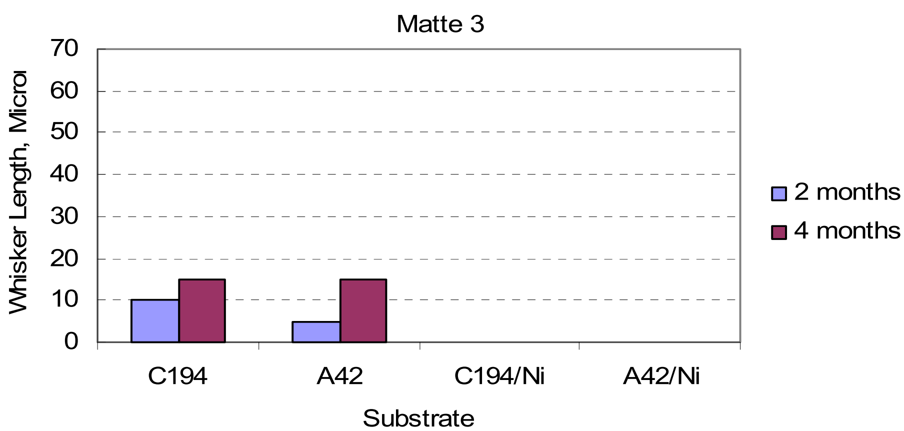

Figure 15 – Results With and Without Ni Barrier

In summary, at room temperature, Sn whisker growth rate on Cu is significant slower than under temperature cycling conditions. The mechanism of compressive stress generation in this case is caused by irregular Cu_6Sn_5 IMC formation.[3, 6] When a Ni barrier layer is introduced, instead of compressive stress, tensile stress is generated in the Sn layer,[3] inhibiting whiskers growth regardless of the nature of the electrolytes and substrates utilized. There is no appreciable difference among the three matte electrolytes with the exception of matte 2, which did not exhibit whisker growth on Alloy 42 for four months.

A few conclusions can be drawn so far, i.e., temperature cycling condition is significantly more severe in promoting whisker formation. Under temperature cycling conditions, whisker growth is faster in terms of frequency, diameter and length. Ni barrier layer did not produce positive effect in whisker reduction. Instead, it appears to result in worse whisker growth caused most likely by thermal stress due to CTE mismatch generated during temperature cycling.

Beside whisker growth rate, there is a distinct difference in whisker morphology depending on whether samples were stored at room temperature or have gone through temperature cycling. In the former case, we observe mostly “column-like” whiskers, which have relatively smooth body without too many striations on the sides (Figure 16a). It is also true that the number of whiskers is significantly fewer at room temperature than under temperature cycling conditions.

\On the other hand, in the latter case, we observe many more whiskers and they are longer with grooved striations along their sides (Figure 16b and 16c). In many places, one observes micro cracks near or at grain boundaries in addition to recessed areas (Figure 16b and Figure 17). We will come back to this point when we discuss the results obtained on connector substrates, where “voids” were developed during/after temperature cycling.

Close examination of SEM micrographs suggests that the recessed areas occur for all three electrolytes independent of substrate materials; they seem to be located right next to or in close proximity of whiskers. It has been suggested that recessed areas result from near surface diffusion of Sn which provides the material needed to form these extrusions. This may be plausible; however there is another possibility that recessed areas are tensile stressed areas. Further investigation is in progress in understanding this interesting phenomenon.

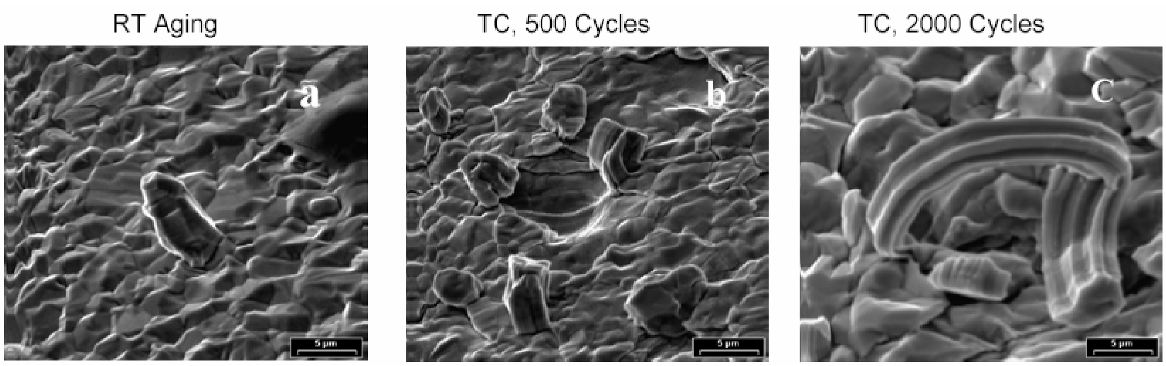

Figure 16a, b, c – Growth at RT and Under Cycling (at 3000X)

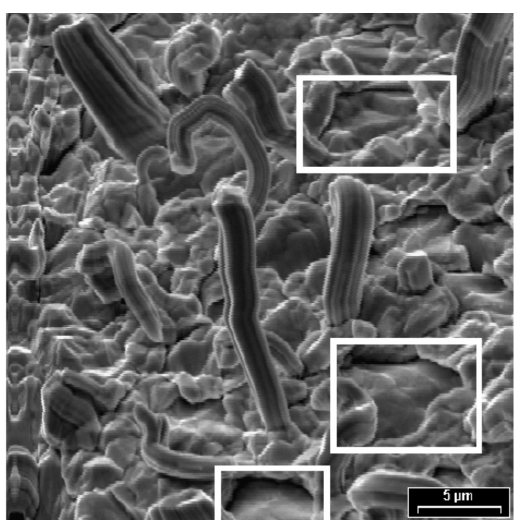

Figure 17 - SEM Micrograph Demonstrating the Recessed Areas besides Whiskers after 500 Cycles of Temperature Cycling

Whisker Observation after 500 Temperature Cycles – Connector Substrates
We plated both matte and bright tin finishes on phos-bronze and brass (Table 1) substrates. The thickness of the tin layer was 3 µm in all cases. Two sets of experiments including temperature cycling were performed. The first set includes 500 cycles of thermal shock from -55°C to 85°C, and SEM examination for whiskers. The second set includes an additional 500 cycles (1000 cycles total) of thermal shock with the previously mentioned samples, and then these samples were bent 90° compressively per specifications given in reference 14. After bending, samples were divided into two groups; one group was aged at RT, the other group was aged at 52°C/90° RH. We will examine the results after 500 cycles of thermal shock first, Figures 18 and 19.

Unlike the case of leadframe substrates, the same matte electrolytes did not shown any whisker growth in the presence of a Ni barrier layer. It is also interesting to note that while matte 1 performs better on brass substrate, matte 2 appears to fare well on phose bronze. For the bright electrolytes, bright 1 performs better on phos bronze (there was no whisker growth after 500 cycles!), bright 2 appears to perform better on brass substrate. Regardless of substrate material, when Ni barrier is absent, temperature cycling resulted in whisker growth. The maximum whisker length was 50 microns for bright electrolytes

In addition, whisker morphology is substantially different in this case, Figure 20. Whiskers observed on matte electrolytes appear to be fewer but longer than on leadframe substrates. Please bear in mind that there is a difference in tin thickness; 3 µm in this case but 10 µm on leadframe substrates. Further investigation is in progress to understand this behavior.

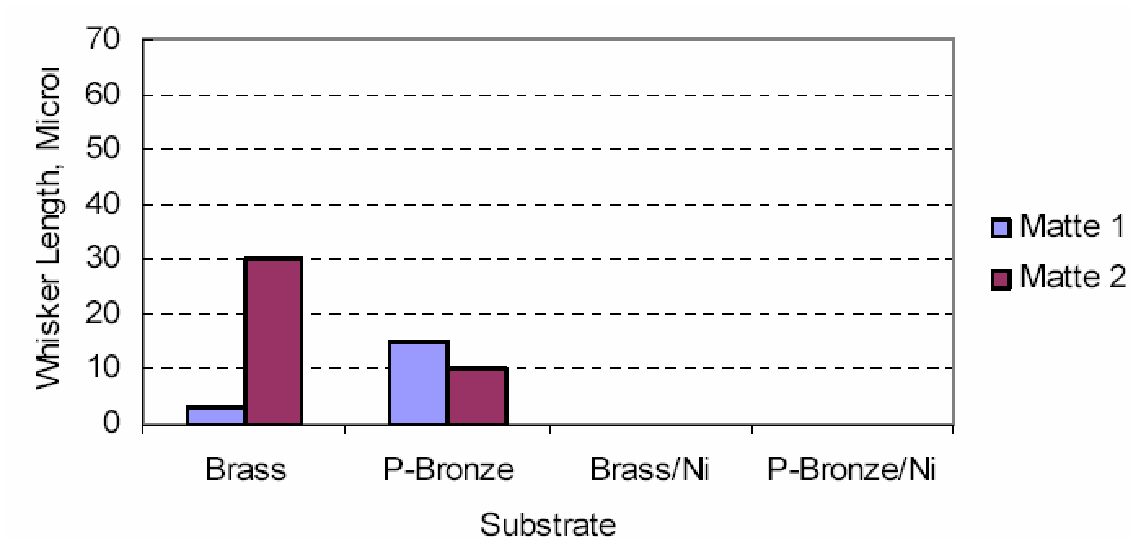

Figure 18 – Whisker Growth after 500 Cycles

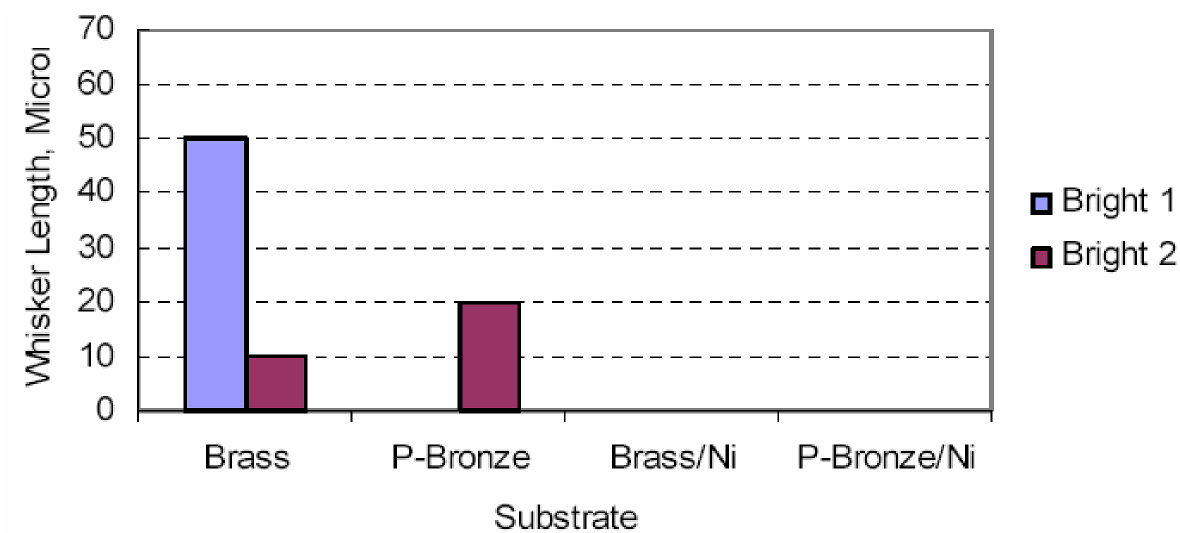

Figure19 – Whisker Growth after 500 Cycles

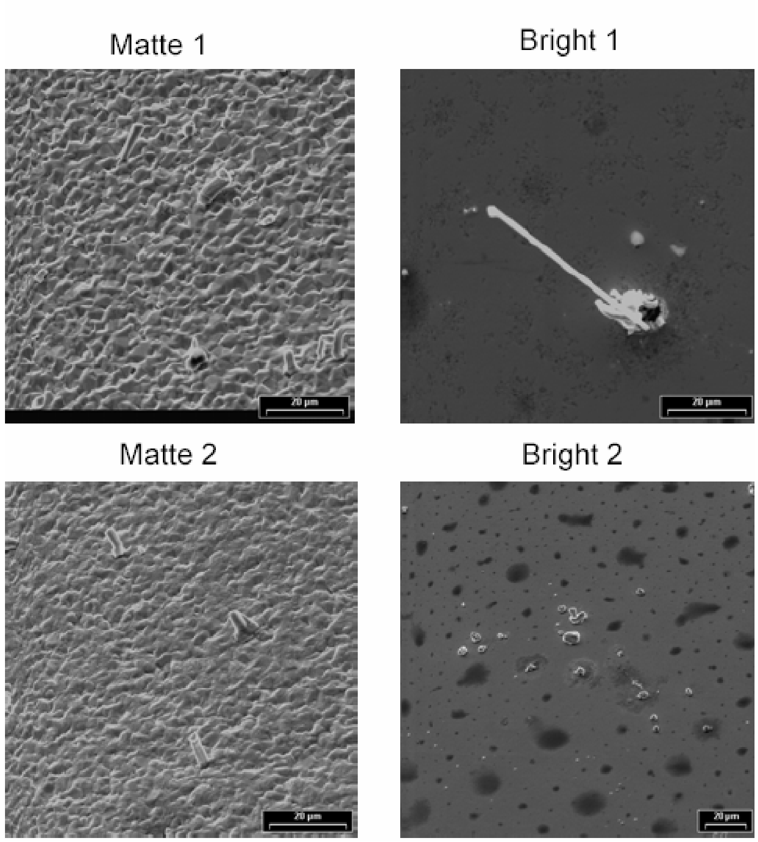

Figure 20 - Effect of Ni (SEM at 1000X, top and bottom right, and 500X, bottom left)

When a Ni barrier layer is utilized, we did not observe any whiskers from bright finishes. However, we did observe some interesting surface transformation – besides dark spots which look like material depletion areas (Figure 21a), we also observed "voids" on the surface (Figure 21b). These features were absent right after plating and they are the consequences of the treatment. As previously mentioned, these features could be the result of near surface diffusion of tin atoms and/or the result of material depletion due to tensile stress build up in the tin layer.

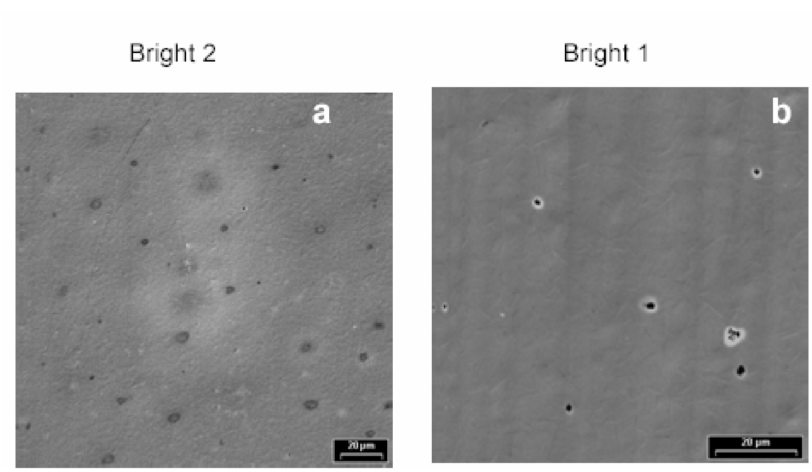

Figure 21a, b – Depletion and Void Areas (SEM 500X, left, and 1000X, right)

Whiskers observed on matte electrolytes appear to be fewer but longer than on leadframe substrates. Please bear in mind that there is a difference in tin thickness; 3 µm in this case but 10 µm on leadframe substrates. Further investigation is in progress to understand this behavior.

Whisker Observation After 1000 Temperature Cycles + Bend + 20 Days RT Aging – Connector Substrates

For matte electrolyte, additional temperature cycling and subsequent treatments did not appear to greatly increase whisker growth as shown in Figure 22. It is important to point out that no whiskers were observed when matte Sn was deposited over a Ni barrier layer. This finding was different from the results obtained on leadframe substrates, where more and longer whiskers were observed in the presence of Ni. As we have pointed out earlier, this may be due to different Sn thickness.

For bright electrolytes, additional temperature cycling and subsequent treatments did not produce appreciable more whisker growth on all other substrates except brass; it appears to have significantly accelerated whisker growth for both electrolytes as shown in Figure 23. Even though we began to observe whisker growth from bright 1 electrolyte in the presence of Ni, whisker length and frequency was significantly reduced compared with no Ni barrier. For bright 2 electrolyte, no whisker was observed in the presence of Ni even under such severe conditions.

Closer look at the whisker morphology indicates that most whiskers maintained the "column-like" structure and is relatively straight. Figure 24. They are thinner in diameter and in most cases longer and fewer than those observed on leadframe substrates.

In the case of bright electrolytes, we observed material depleted areas (Figure 25b) as well as voids (Figure 25c), in addition to filament whiskers and nodules. It appears that when there are many nodules (Figure 25a), their length is relatively short. On the other hand, when a long filament exists like in the case of 25b, there are few whiskers observed. When we observed many voids on the surface, we typically did not observe any whiskers or very few short nodule whiskers.

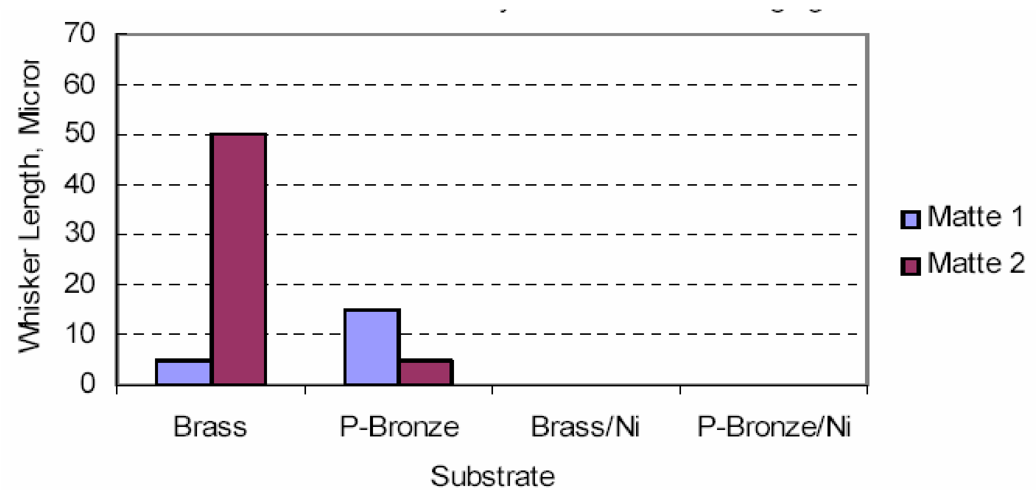

Figure 22 – Whisker Growth after 1000 Cycles + Bend + RT Aging

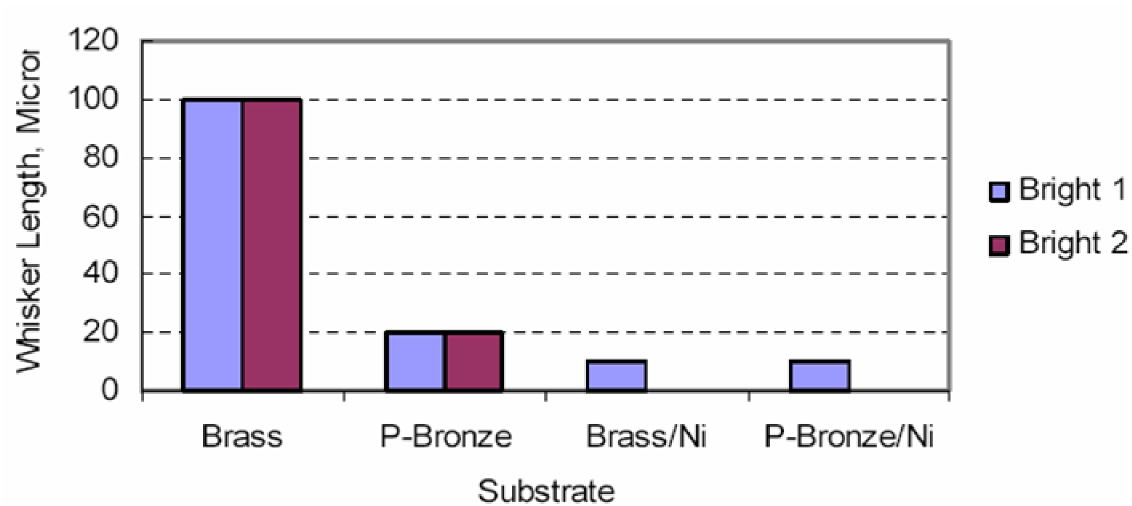

Figure 23 – Whisker Growth after 1000 Cycles + Bend + RT Aging
(Please note the change in Y_{max} from 70 to 120 µm)

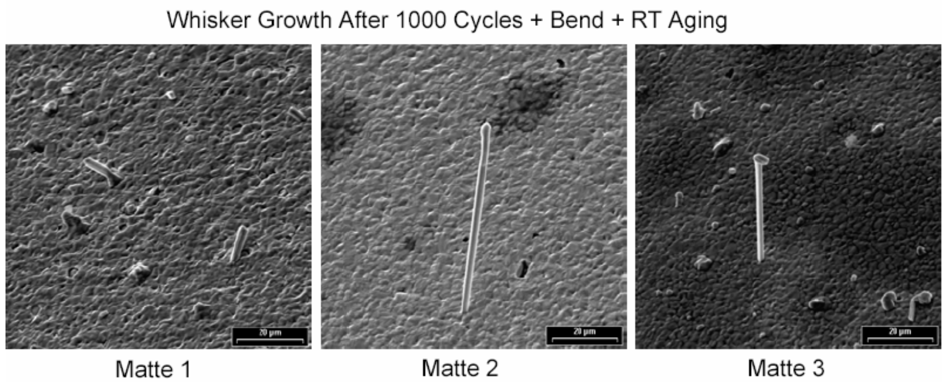

Figure 24 – Whisker Growth (SEM at 1000X)

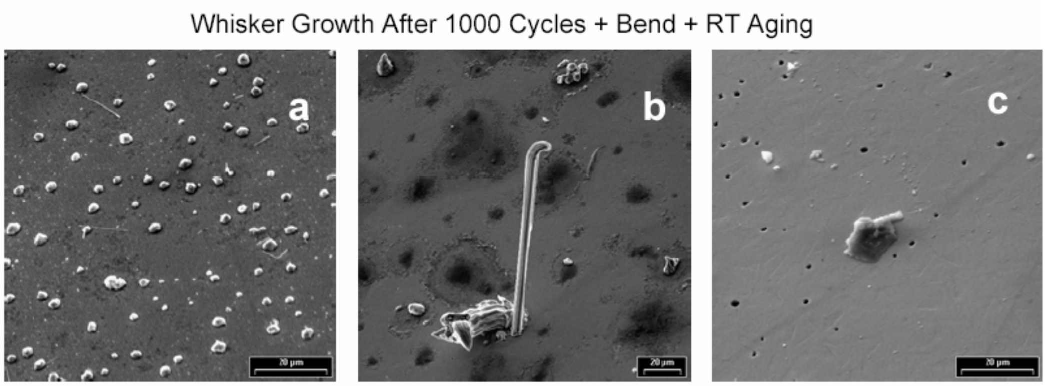

Figure 25a, b, c – Whisker Growth (SEM at 1000, 500 and 1000X Respectively)

Whisker Observation after 1000 Temperature Cycles + Bend + Steam Aging – Connector Substrates

For bright finishes, samples that were subjected to 41 days of steam aging at 52°C/90°RH after temperature cycling exhibited significant accelerated whisker growth in length, Figure 26, though whisker frequency and diameter did not seem to have grown proportionally, Figures 27 and 28.

While no whiskers were observed on these bright finishes with the presence of a Ni barrier layer while aged at RT after temperature cycling, we did observe very few small nodules (See Figure 28) on brass over Ni. It is not clear to us what the cause of this growth, since it is observed after the treatment, we count it as a whisker. More importantly, on Ni over P-Bronze, the surface morphology has changed significantly from those aged at room temperature (Figure 25). As can be seen clearly, both bright surfaces exhibit a flake-like texture. On the other hand, the accelerating factors of temperature and humidity did not seem to have as nearly big an effect on matte finishes as on bright, shown in Figures 29 – 31.

In summary, on connector substrates, whisker growth follows the following order (from worst to best) regardless of the nature of the finishes (i.e., matte or bright); TC + Bend + Steam Aging > TC + Bend + RT Aging > TC. Secondly, a Ni barrier layer is undoubtedly beneficial in whisker reduction despite aforementioned severe aging conditions. Under all conditions, in the presence of Ni, the maximum dimension of whiskers was ~ 10 µm. Bright finishes exhibited significantly worse whisker growth behavior than matte finishes. The biggest concern with the bright finish is long filament as well as nodule whiskers with large diameters. On the other hand, for matte finishes, whiskers maintained "column-like" structures. They are far less frequently formed and significantly shorter under the same aging conditions. In the absence of Ni, the longest whisker was ~ 60 µm; in the presence of Ni, the longest whisker was less than 10 µm.

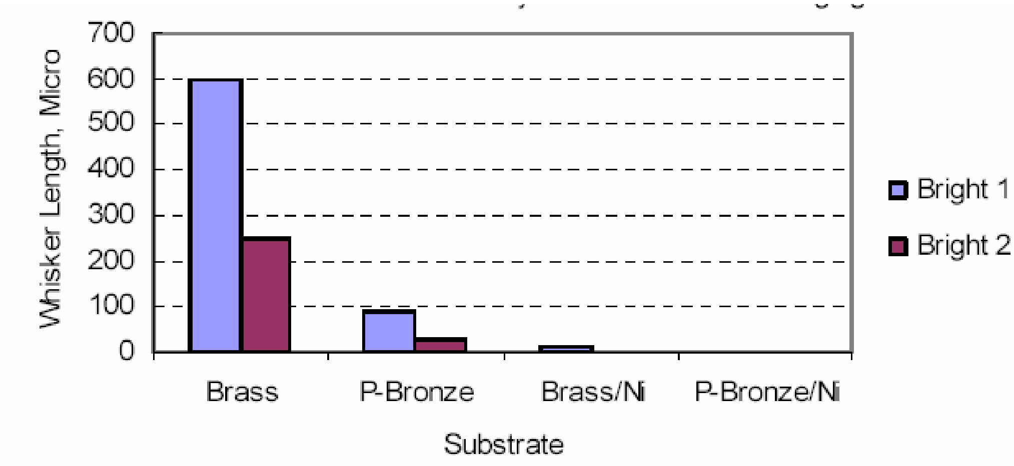

Figure 26 – Whisker Growth after 1000 Cycles + Bend + Steam Aging (Please note the change of Y_{max} from 70 µm to 700 µm)

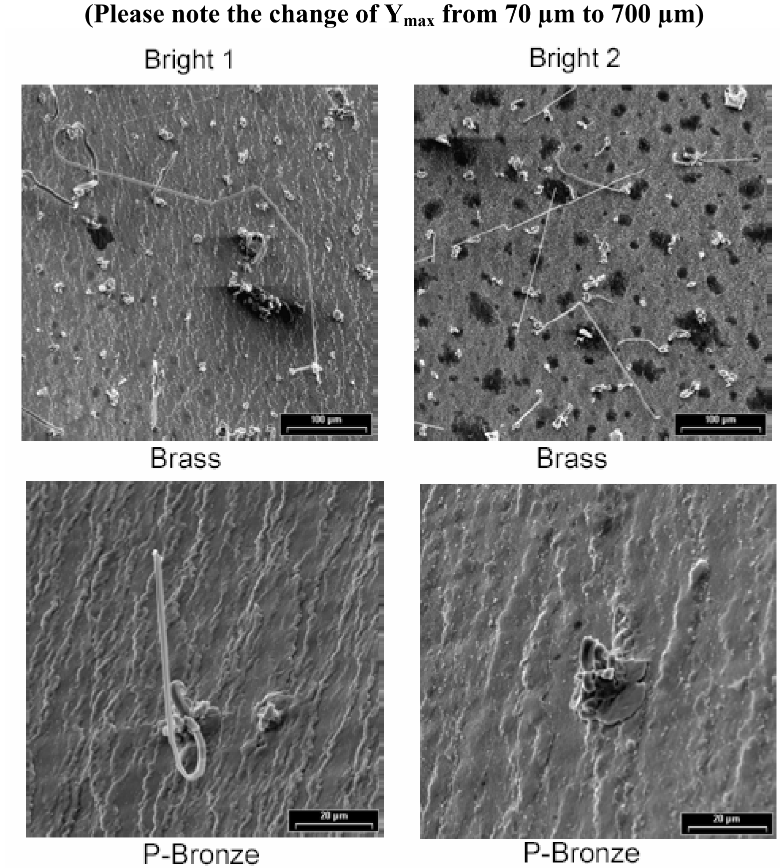

Figure 27 – Whisker Growth after Cycling and Steam Aging (SEM at 250X, top, and 1000X, bottom)

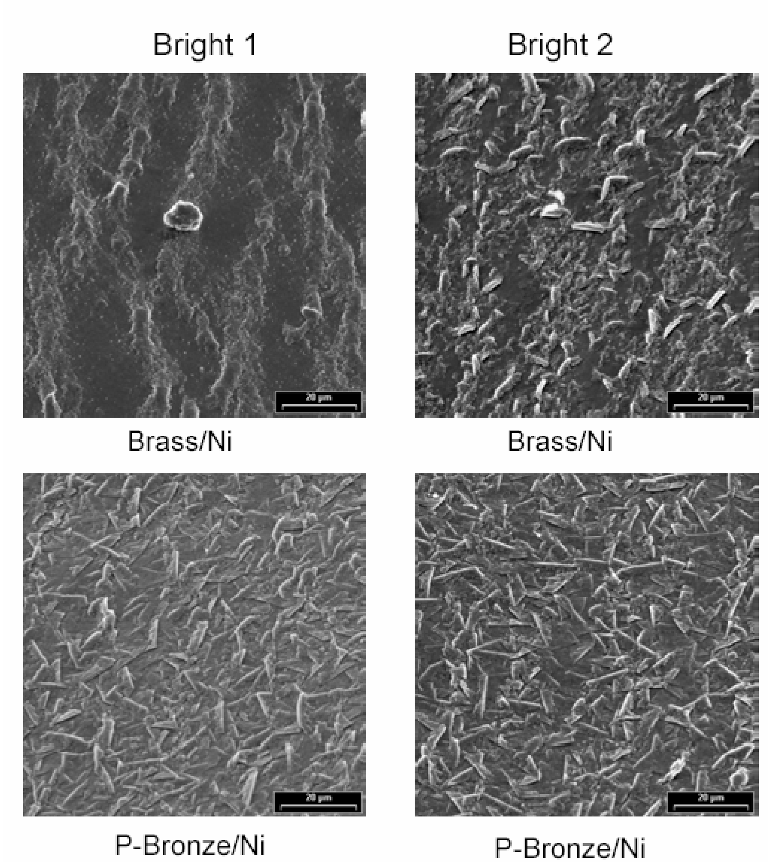

Figure 28 – Whisker Growth on Brass over Ni (SEM at 1000X)

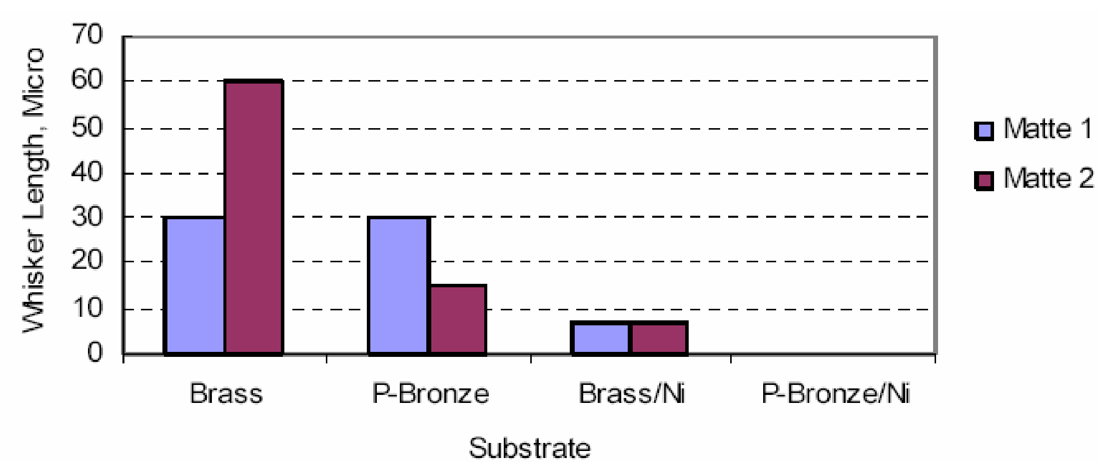

Figure 29 – Whisker Growth after 1000 cycles + Bend + Steam Aging

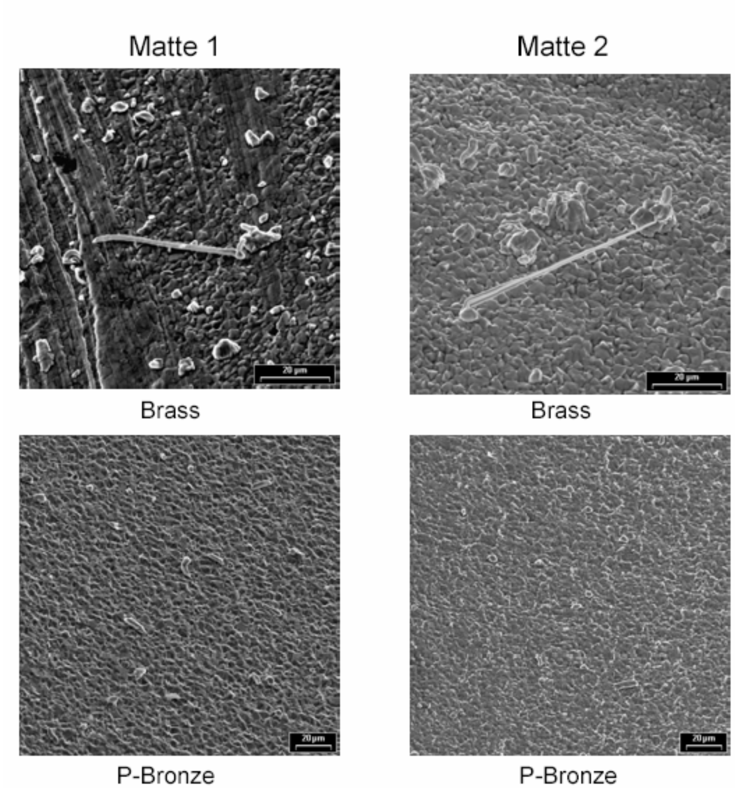

Figure 30 – Whisker Growth by Finish Type (SEM at 1000X, top, and 500X, bottom)

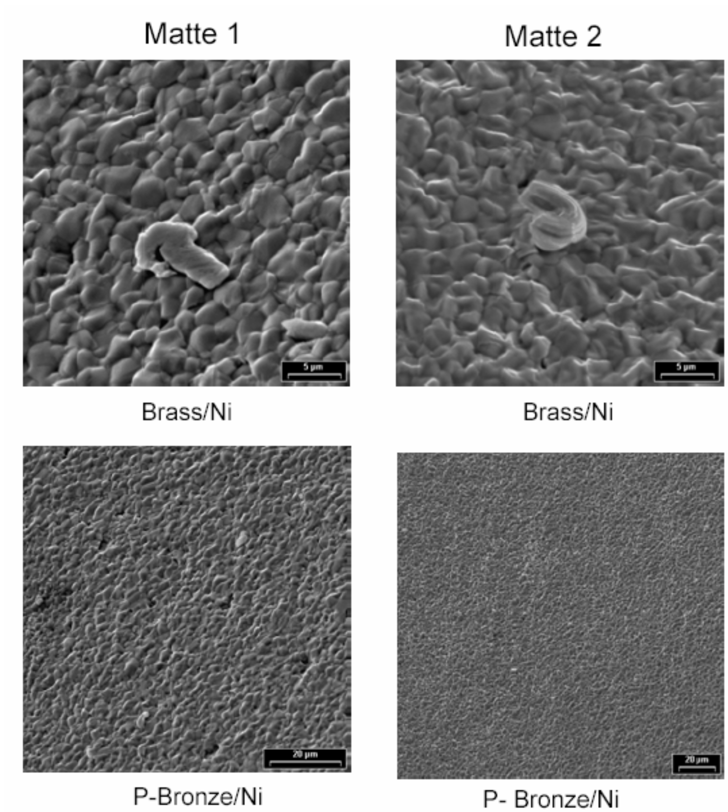

Figure 31 - Whisker Growth by Finish Type (SEM at 1000X, top and bottom right, and 500X, bottom left)

Summary Remarks

This work demonstrated that substrates have significant influence on whisker growth propensity depending on aging or whisker test conditions. A Ni barrier layer is very effective in eliminating tin whisker growth under isothermal conditions by eliminating the driving force, that is, compressive stress generated by IMCs. However, this Ni barrier layer will not eliminate the thermal stress generated during temperature cycling due to CTE mismatch. Consequently, it is not necessarily a panacea for eliminating whisker growth.

Temperature cycling effectively generated whisker growth on tin deposits. Increasing the number of cycles produces a higher whisker density of greater length and thicker diameters. After 500 cycles, the longest whisker on leadframe substrates was about 20 µm; whereas on connector substrates lengths of about 30 µm and 50 µm for matte and bright Sn, were obtained respectively. Samples utilizing a Ni barrier and exposed to identical testing conditions exhibited the following behavior. After 500 cycles, on leadframe substrates, similar or worse whisker growth was observed on all matte electrolytes, yet on connector substrates, no whiskers were observed. Additional temperature cycling in the presence of Ni produces more, longer whiskers (up to 50µm after 2000 cycles) on leadframe substrates, and a few, small whiskers (up to 10 µm after 1000 cycles) on connector substrates.

We also observed worse whisker growth on A42 compared with C194 and C151 under temperature cycling conditions regardless of whether a Ni barrier was present. This is in agreement with other published work and as previously discussed could be explained by CTE mismatch. What we have yet to explain, given the data in this work, is the whisker growth behavior on leadframe compared to connector substrates. We are not certain if the differences in CTE of these Cu alloys can rationalize the data. Rather, we are inclined to investigate the relatively large difference in Sn thickness.

Furthermore, we demonstrated the significant difference between the two pathways or “mechanisms” from which compressive stress could build up in the Sn layer. Under isothermal conditions, stress generation is dominated by IMC formation whereas under temperature cycling conditions, stress generation is dominated by CTE mismatch. In real life, electronic products are exposed to isothermal and temperature cycling conditions. In most cases, the temperature cycling excursions are not as severe as conditions utilized in this work.

Therefore we should be keenly aware of the existence of both “mechanisms”. In some cases, both mechanisms are operative, however, in other cases, it could be either one. The key is to identify whisker growth accelerating factors which are operative under each of these conditions. For instance, the IMC pathway is accelerated by temperature, Sn deposit microstructure, and substrate material. The CTE mismatch pathway is most likely accelerated by CTE difference between Sn and substrate material, temperature, and dwell time.

We would need to understand these key accelerating factors of each pathway independently as well as in concert. With this understanding, the Industry will be able to derive a set of standard yet realistic whisker test methods.

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