Tin Whisker Prevention with SnBi Plating

Issei Fujimura, Manager of R&D Section No. 2,
Ishihara Chemical Co., Ltd.
5-26 Nishiyanagiwara-cho, Hyogo-ku, Kobe, Hyogo 652-0806, Japan

E. Jan Vardaman and Dr. Timothy G. Lenihan
TechSearch International, Inc.
4801 Spicewood Springs Road Suite 150
Austin, Texas 78759
jan@techsearchinc.com

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Abstract

Tin whiskers are “needle-like” crystalline structures of tin that form and grow on surfaces that use pure or nearly pure tin (Sn) as a final finish. This reliability issue has been a significant concern to the electronics industry with the introduction of Pb-free solders with higher Sn content. The failure mechanism is caused by the tin whisker growing and shorting leads due to the conductivity of the Sn. This problem was first documented more than 50 years ago. Today, many believe the tin whisker problem can be mitigated by reducing the stress in the plated films during plating or by baking parts for 1 hour at 150ºC. All of the causes for tin whiskers have yet to be determined based on conflicting data that has been published in the literature. Vigilance is needed to insure that an “old” problem doesn’t become a “new” problem with the introduction of new Sn materials. Groups such as iNEMI, CALCE, and a number of electronics manufacturers continue research in this area to understand the causes for tin whiskers and to find new ways mitigate the problem with the introduction of new finishes for materials such as lead-free solders that contain higher concentrations of Sn.

This presentation examines contributors to tin whisker growth such as internal and external stress. The effect of plating treatments and the relationship between thickness and the observed whisker length are examined. The plating samples were manufactured on copper and Alloy42 surfaces. The resulting differences in void size, after annealing, using Tin (Sn) plating and Tin-Bismuth (SnBi) plating will be discussed using plating cross-sections. Additional work will be reported on Sn and SnBi plating, with and without annealing, after bend testing.

Introduction

<u>Ishihara Chemical. Ltd.</u>

Founding Date - March 3, 1939

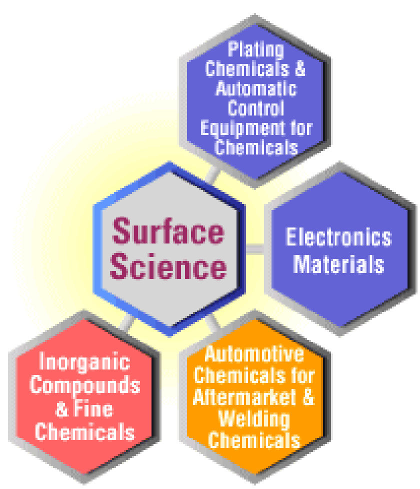
Capital - 1,447 million yen

Executives
President : Kanji Takemori
Senior Managing Director : Motoichi Tokizawa

Number of Employees -199

Head Office/Factory
5-26 Nishiyanagiwara-cho, Hyogo-ku,
Kobe, Hyogo 652-0806, Japan

TEL: +81-78-681-4801
FAX: +81-78-651-6784



Introduction

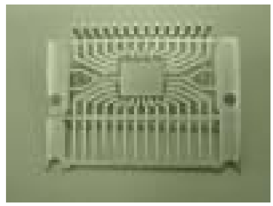
- The introduction of Pb-free solder requirements in the electronics industry is increasing the use of Sn coatings which can result in the potential for whisker growth.
- There have been are few reported incidents of tin whisker reliability failures outside of the military.
- There may be more unreported incidents as companies are reluctant to advertise they have a reliability problem.
- Numerous studies have been conducted to show the electrical short circuit characteristics for tin whiskers. [1]
- Internal stress is accepted as one of the major mechanisms for tin whisker growth.
- The January 2005, October 2006, and January 2007 issues of the IEEE Transactions on Electronics Packaging and Manufacturing provide an excellent set of reference material on tin whiskers.

Whisker Growth

- Tin whisker growth on leadframes in IC packages in generally agreed to be due internal stress in the plated film.
- The whisker growth periods reported for internal stress show a large variation from several hundred hours to several thousand hours.
- This variation is known to be dependent upon environmental conditions such as temperature and humidity.
- External stress whisker growth is another mechanism (versus internal film stress) and can be found on connectors and flex circuits. This mechanism has been reported to have growth periods as low as tens of hours.
- Growth causes for external stress induced whiskers have been reported to be due to mechanical pressure such as contact pressure or initiated from scratches.
- The tendency for whisker growth has also been previously reported for Sn-plated copper and Sn-plated Alloy42 leadframes.

Whisker Growth

- One key question to be answered "Is the IMC (Intermetalic compound) growth the cause of whisker growth on copper substrates under ambient conditions?"
- Observations on leadframes under ambient conditions of up to 12,240 hours show there is very little IMC growth and subsequently no whisker growth.



Experimental Procedures and Results

- Copper(194) and Alloy42 leadframes were plated with $Sn_2BiSn_{3.5}Ag$ and $Sn_{1.5}Cu$ (with and without annealing). Whisker observations were conducted for each plating type under ambient conditions past 4,000 hours; damp testing parts past 4,000 hours; and thermal cycling testing parts past 1,500 cycles.

Test	Test condition	Interval	Terms
Ambient Test	30±2℃, 60 ±3%RH	1000h	4000h
Thermal Cycling Test	- 40+0/-10℃ ⇔85+10/- 0℃ Soaking 10min, 3cyc./h	500cyc.	1500cyc.
Damp Test	55±3℃, 85±3%RH	1000h	4000h

Figure 1: Stress matrix used for plating and annealing experiments.

Experimental Procedures and Results

- Tin-plated Alloy42 ambient and damp test results were found to be acceptable.
- Thermal cycling testing was conducted from -40ºC to 85ºC. After 500 cycles, a 20 micron whisker growth was observed; after 1,000 cycles, a 51 micron whisker growth was observed; and after 1,500 cycles, a 65 micron whisker growth was observed.
- One cause for tin whisker growth, during thermal cycling, is the Cu diffusion rate is greater than the Sn diffusion rate. The CTE of Sn is 23.5 (x 10^{-6}/ºK) versus the CTE of 42 Alloy which is 4.6 (x 10^{-6}/ºK). This can contribute to increased internal stress in the plated films.

Experimental Procedures and Results

Copper diffusion rate to tin > Tin diffusion rate to copper

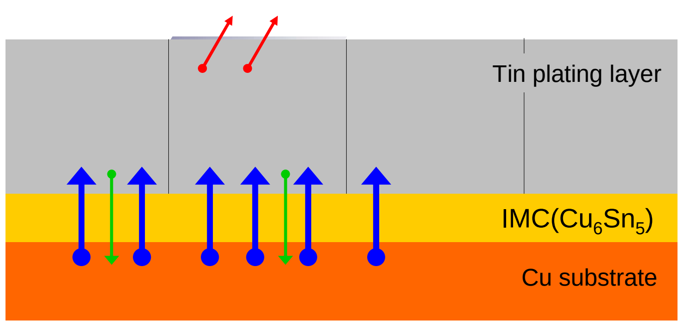


Figure 2: Copper/Tin Diffusion Stress

Experimental Procedures and Results

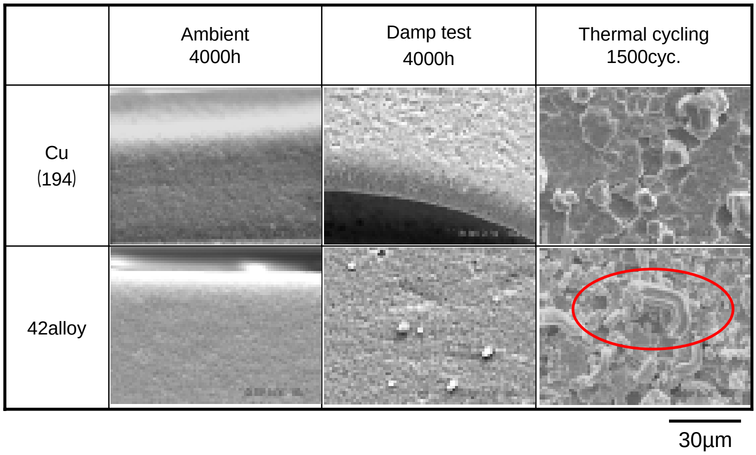


Figure 3: Whisker Observations with Sn-3.5Ag plating.

Experimental Procedures and Results

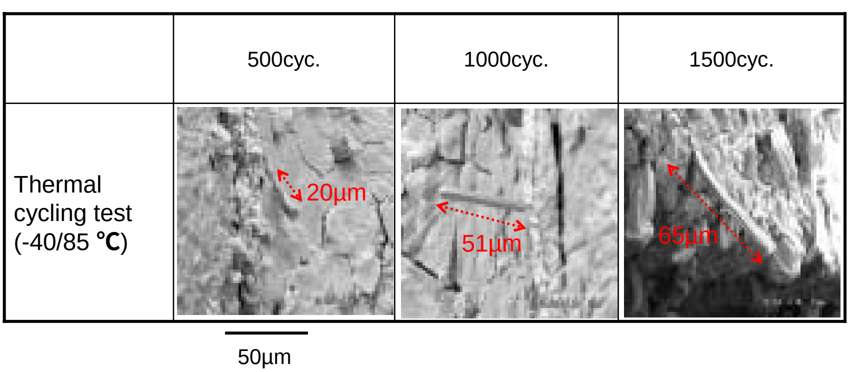


Figure 4: Whisker Observations with Sn plating.

Experimental Procedures and Results

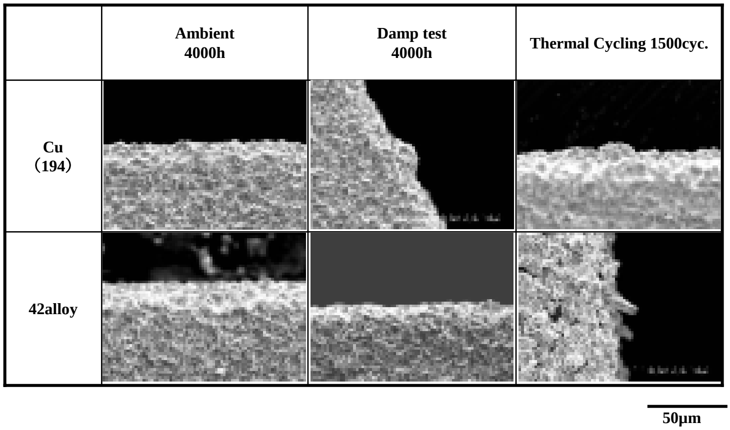
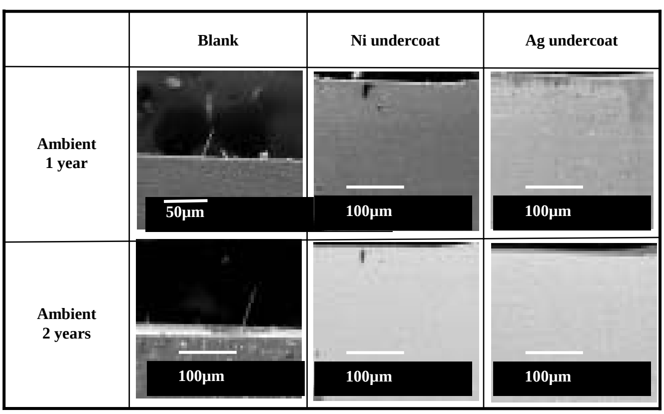


Figure 5: SnBi plated surfaces post stress and anneal.

- The SnBi plated parts showed little whisker growth as compared to the Sn plating. By annealing samples for the standard one hour at 150ºC, tin whisker growth prevention was demonstrated.

Experimental Procedures and Results



Note; Thickness of tin plating is **1mircon.**

Figure 7: Affect of pretreatment with undercoating.

- Pretreatment with a 0.1 micron undercoat of Ni or Ag was also found to be a solution to prevent whisker growth. The effect undercoats of 0.2 micron of Cu, Ni, and Ag, respectively.

Experimental Procedures and Results

• One solution to reduce the potential for tin whiskers has been the adoption of SnBi plating by many Japanese companies (NEC, Panasonic, Fujitsu, Hitachi, Sanyo, Oki, and Sony).

• This has become a popular choice in Japan where IC manufacturing tends to be vertically integrated.

• Outside of Japan, there is a perception that when Bi used with Pb-containing solders, there is a risk of brittle intermetalic formations. This is a concern for companies that are not vertically integrated and use many sources for process materials in their assembly facilities.

• Researchers from the University of Toronto reported there were no issues with SnBi finishes (with a Bi content up to 6 percent) in PbSn finishes. They also reported that the SnBi lead surface finish provided the highest pull strength for both Pb-free and SnPb solder joints. They believed this affect was due to stabilization in the SnPb joint microstructure (during thermal cycling) which reduced grain growth and prevented crack formation. [2], [3], [4]

Experimental Procedures and Results

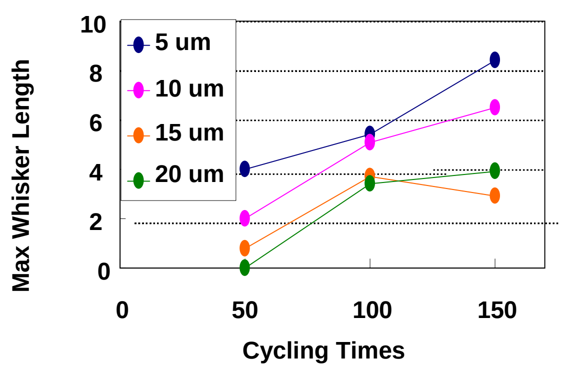


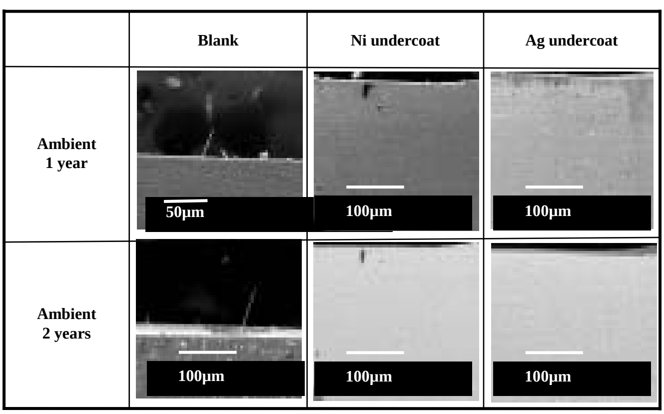
Figure 6: Effect of Plating Thickness on Whisker Growth.

• The effect of plating thickness in the - 45ºC to 85ºC thermal cycling data is shown in above. As thicknesses increased the propensity for tin whisker growth was reduced.

Experimental Procedures and Results

- Because alloying Sn with a second metal reduces the propensity for whisker growth, some companies have investigated the use a number of coatings to mitigate this problem.
- Researchers from Hitachi's Materials Research Lab and Renesas Technology investigated the effect of adding minor elements in copper leadframes on whisker initiation such as electrodeposited SnCu coatings on two different copper leadframe materials. CuFe and CuCr were investigated by FE-STEM, FE-TEM, EDX analysis, and X-ray diffraction.
- Drastically different results in whisker initiation tendencies were reported for the same SnCu coatings after long-term storage at room temperature. They also reported tin whisker growth was completely absent on the SnCu coating for CuCr leadframes after a storage time of 52 months. They did observe 200 µm long whiskers forming on the SnCu coated CuFe leadframes after a storage period of 34 months. [5]

Experimental Procedures and Results



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Experimental Procedures and Results

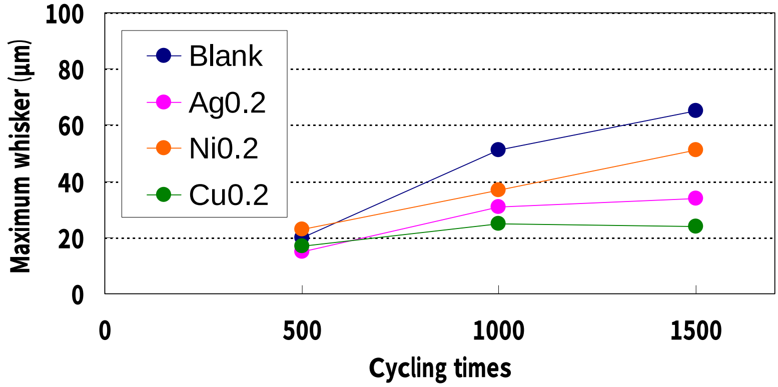


Figure 8: Affect of pretreatment with undercoating (- 45～85℃).

Note; Thickness of tin plating is **10mircons.**

Experimental Procedures and Results

Apparatus for Acrylic Pressure Test

Operational Procedure :

The sample is placed within the acrylic sheets and pressure is applied by tightening the nuts.

Figure 9: Acrylic Pressure Apparatus

Experimental Procedures and Results

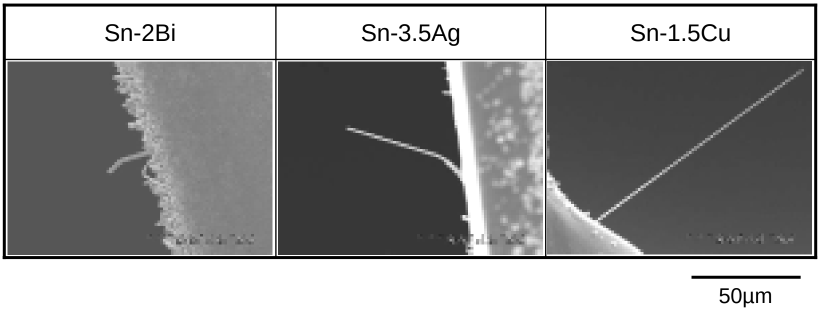


Figure 10: Acrylic pressure test（1.2Nm，280h）results.

Experimental Procedures and Results

Additional testing was done using an Acrylic Pressure testing technique to induce tin whisker growth.

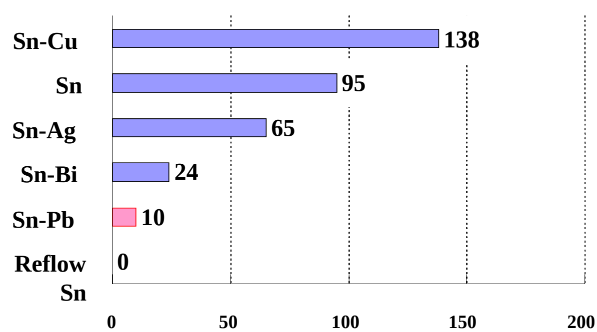


Figure 11: Max Tin Whisker Length (µm)

The best results were achieved with Reflow Sn and PbSn. The SnBi results were also very good compared to SnCu, Sn, and SnAg.

Generation of Voids and Cracks after Annealing

- Research was also conducted to examine void formation in the Sn and SnBi plated leads.
- In this experiment, sample leadframes were plated with Sn and with SnBi. Both sets of samples received a post treatment of annealing at 150°C for one hour. After bend stressing, cross sections of the samples from both groups were polished and SEM photos were taken.
- Samples from both plated groups with the annealing treatment showed non-uniform intermetalic compound (IMC) formation in the bent area of the plated leadframes.
- There were voids and cracks observed in the bent area which were most likely generated by the bending mechanical stress. [6]
- All of the samples showed no voiding or cracking with anneal and without anneal when there was no mechanical stress induced on the Cu or Alloy42 leadframes.

Generation of Voids and Cracks after Annealing

- Sn and SnBi samples that received mechanical bending stress showed voiding at the diffusion boundary and cracking.

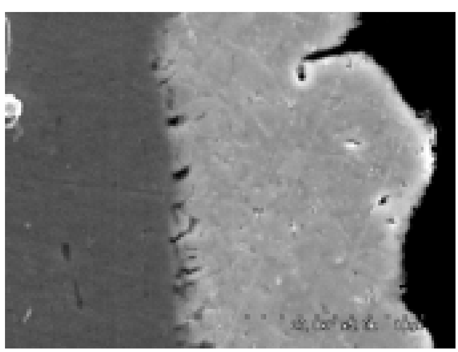
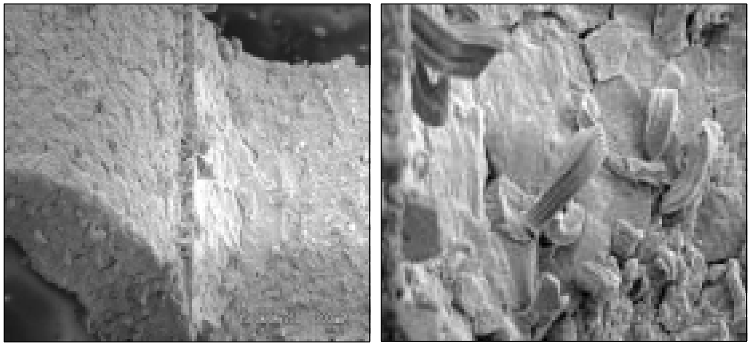


Figure 12: Void Formation Post Anneal.

- It is believed the Cu_3Sn or Cu_6Sn_5 boundary layer cracked during the bending process due to high stress.

Generation of Voids and Cracks after Annealing

• With the addition of the standard 150ºC, 1 hour, anneal for whisker prevention, all of the samples showed an increase in the void and crack size.

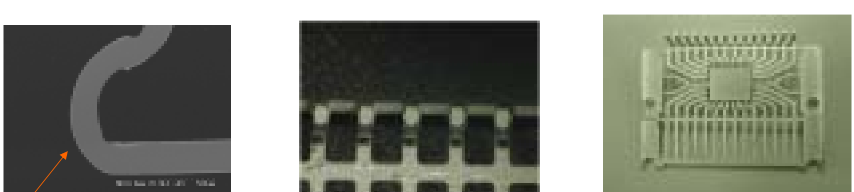


200µm 50µm

Figure 13: Whisker growth from lead frame due to mechanical stress.

Generation of Voids and Cracks after Annealing

• While the SnBi finish also showed the same cracking and voiding phenomenon, the annealing process is not necessary as it is less susceptible to tin whisker growth.



Observation: Bent part.

Figure 14: Post bend stress leadframes.

Conclusions

- The number of "reported" tin whisker failures remains low, vigilance is required as new Sn materials are introduced to assembly processes along with new use conditions for these materials.
- This presentation highlights that it is possible to have a tin whisker problem under the right conditions.
- Efforts need to continue to reduce the risk of tin whiskers such as the adoption of SnBi plating.
- The crack and void problem observed, in areas of high mechanical stress, can be avoided by using SnBi to prevent tin whiskers and eliminating the standard 150ºC anneal process step. Based on the data presented, the risk cannot be avoided with annealing and mounting strength could be a major concern.
- Several tin whisker mitigation techniques are possible with copper substrates.
- No effective technology has been found yet for tin whisker prevention for Alloy42 leadframes under thermal cycling conditions.

Thank you for your kind attention!

Questions?

TechSearch International, Inc.
4801 Spicewood Springs Road
Suite 150
Austin, Texas 78759

Tel: 512-372-8887
Fax: 512-372-8889
www.techsearchinc.com

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[6] E.J. Vardaman, T.G. Lenihan, and I Fujimura, "Generation of Voids in Pb-Free Plating after Annealing," *IMAPS International Conference and Exhibition on Device Packaging*, March 9-12, 2009.