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Analysis of plating grain size effect on whisker †

Seung-Jung Shin[1,*], Jae-Jung Kim[2] and Young Kap Son[3]

[1]*Division of Information Technology, Hansei University, 435-742, South Korea*
[2]*Reliability analysis research center, Hanyang University, 133-791, South Korea*
[3]*School of mechanical engineering, Andong National University, 760-749, South Korea*

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Abstract

Whisker is a single beard-shape crystal filament, and it would be a main cause of producing electrical short circuits. Re-crystallization of both plating grain and base metal grain caused by internal and external stresses affects whisker growth. In this paper, we analyzed effect of grain size and structure of plating on whisker growth through whisker acceleration tests of ICs used in the electronic products. Samples with different package types, base metal, and plating thickness were used in the tests, and both structure and size of plating, and whisker were examined using SEM. From the test results, internal and external stresses produce more grain boundaries of plating when the grain size is smaller. And based on *t*-test, we found that there is a significant negative correlation between grain size and whisker growth. Therefore, smaller grain size of plating produces higher possibility of whisker occurrence, and whiskers grow in the grain boundaries of plating.

Keywords: Tin whisker; Re-crystallization; Grain boundary; Plating; Intermetallic compound; Grain size

1. Introduction

Whisker is a single beard-shape crystal filament, and grows on lead finger's plating layer surface in semiconductor IC. Cadmium whisker has been studied since the whisker caused electrical short circuit in 1940s [1]. Compton *et al.* showed that whisker grows not only in plating material of cadmium, but also in one of either tin or zinc [2]. Both tin and tin alloy have been used as plating material since these materials have strong adhesive force in solder paste, high corrosion resistance, and low contact resistance even though they could cause whisker growth. Tin alloy containing Pb material, therefore, has been used to restrain whisker growth since 1959. Pb material was classified as a hazardous substance after European Directive in 2002 enacted the RoHS (Restriction of Hazardous Substances) in 2002, and its use has been restricted. Thus, either tin alloy containing Ni, Bi, Cu and Ag, or pure tin free of Pb is used to replace Pb material. However, even pure tin could be a cause of whisker growth producing electrical short circuit.

Open literature shows that re-crystallization of both plating grain and base metal grain caused by internal and external stresses affects whisker growth. Intermetallic compound (IMC) formation by stresses was explained according to types of plating and base metal [3]. In the aspect of whisker growth mechanism, Ellis *et al.* proposed a re-crystallization process model of grain [4]. Boguslavsky and Bush applied the re-crystallization process to find whisker growth mechanism using bright tin [5].

External stresses such as temperature and humidity during manufacturing processes change metal grain. Change in metal grain would influence whisker growth. In this paper, we analyze effect of grain size and structure of plating on whisker growth through a whisker acceleration test of ICs used in the electronic

† This paper was recommended for publication in revised form by Associate Editor Jooho choi
*Corresponding author. Tel.: +82 31 450 5274, Fax.: +82 31 450 5172
E-mail address: expersin@hansei.ac.kr
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products. The test is based on JEDEC standard for tin whisker test [6].

2. Whisker growth mechanism

Lead finger structure of Semiconductor IC and the plating grain are shown in Fig. 1. Whisker is usually seen in the lead finger. The finger, an external package bridge of lead frame provides an electrical signal route for the IC as shown in Fig. 1(b). Fig. 1(c) shows plating grain, and whisker grows on the plating. Compressive stresses, chemically and mechanically generated in the finger would affect plating and base metal, thus cause whisker growth. These stresses can be categorized as internal stress and external stress. The internal stresses vary with types of plating and base metal [3]. Both Sn and Cu are mainly used in IC, and high ionization tendency of Cu forms IMC between Sn layer and Cu layer as shown in the Fig. 2. Then, IMC forms the Cu_6Sn_5 through combining Cu ion with Sn, following Kirkendall Effect. The stresses due to Cu_6Sn_5 formation cause whisker growth. Further, whisker growth occurs due to CTE (thermal expansion coefficient) mismatch. CTE mismatch frequently occurs in alloy-42 which is known as alloy of Fe and 42% Ni. The alloy metal is used to replace Cu of high ionization tendency. Stress in the interface surface between Sn with CTE 22 ppm/℃ and A42 with CTE 4ppm/℃ cause whisker growth at the surface. External stresses generated during IC manufacturing process is from bending stresses due to trim and forming processes, and from plating oxidation due to contact of plating surface with oxygen. These external stresses change grain and grain boundary of plating and base metal. It follows that change in the grain and grain boundary causes whisker growth. Fault tress for these stresses affecting whisker growth is shown in Fig. 3.

Whisker grows when stress due to compression and expansion process of Sn through the grain boun-dary of plating is relieved judging from Fig. 2. It is evident that internal stress in the lead finger due to IMC formation between plating and base metal would force created whisker to grow along whisker grain boundary. Simplified section of grain in plating is shown in Fig. 4 to explain whisker growth on grain in plating. Both columnar boundary and oblique boundary are shown in Fig. 4, and oblique boundary is more affected by compressive or tension force induced by various stresses. The oblique bound ary is formed by the external chemical and mechanical stresses, and it is commonly found in Sn plating [7]. The boundary randomly formed by Sn grains provides a moving path for Sn atom. Actually, Sn moves along grain boundary, and creates whisker grain as shown in Fig. 4 since melting temperature of Sn with 231.9℃ is lower than other metals. In addition, SnO_x produced by combination of plating surface with oxygen, and Cu_6Sn_5 produced in the boundary of base metal weaken cohesion of plating grain as shown in the Fig. 4, and thus accelerate whisker growth. Length of

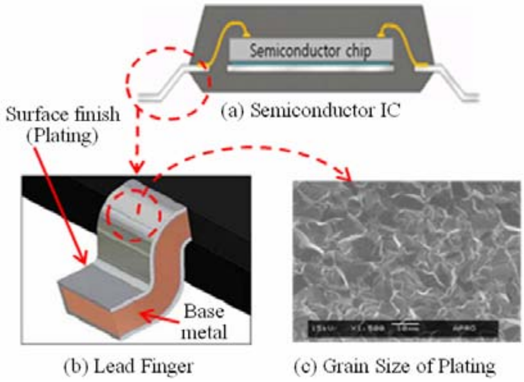


Fig. 1. Lead finger and its plating grain structure for semiconductor IC.

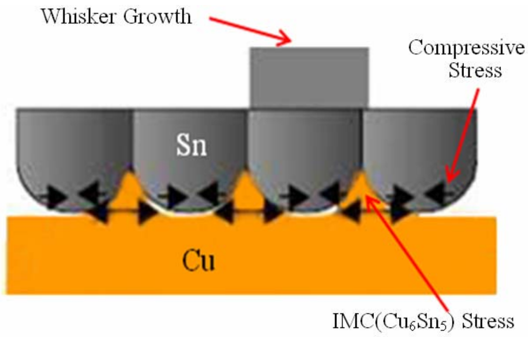


Fig. 2. Whisker Growth by IMC.

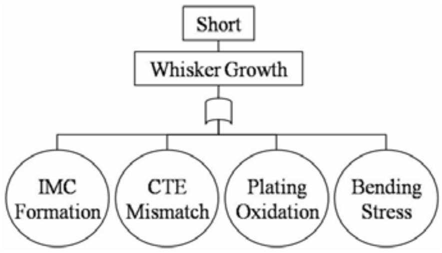


Fig. 3. Fault tree of electrical short circuits due to whisker growth with stresses.

Table 1. Test samples.

Name	Package type	Surface finish	Base metal	Plating thickness
A	7L To -220	Matte Tin	Cu (97%), Sn, P	12.1
B	28L LLP	Matte Tin	Cu (97%), Fe, Zn, P	11.4
C	5LSOT-223	Matte Tin	Cu (97%), Fe, Zn, P	12.0
D	SO-20 WB	Matte Tin	Cu (97%), Fe, Ag, Zn	11.9
F	PDIP-16	Matte Tin	Cu (96%), Fe	12.2
H	DPAK	Matte Tin	Cu (99%), Ni	11.6

Table 2. Thermal cycling test condition.

Cycle condition	Inspection interval	Total duration
-65～95℃ air to air. 20min/cycle	500 cycles	2000 cycles

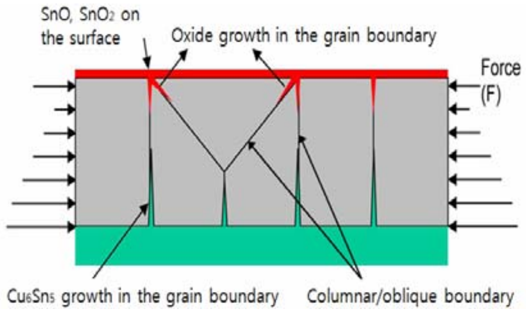


Fig. 4. Sn moving along the grain boundary of plating.

whisker produced from the Sn movement above a specified, allowable length is a cause of short circuits between lead fingers.

3. Whisker acceleration test for IC

A thermal cycling test based on JEDEC standard for tin whisker test was conducted to analyze effect of change in both grain size and structure of plating and base metal on whisker growth. Test samples with different (a) package types, (b) base metal, and (c) plating thickness are shown in Table 1. The samples are used as amplifier ICs for electronic appliances, and they are named from “A” to “F”. Plating elements of the samples consist of 100% matte tine, and base metal element contains over 95% Cu with high electric conductivity. Whisker growth is affected by plating thickness. Each sample has plating thickness more than 6 since plating thickness with over 6 does

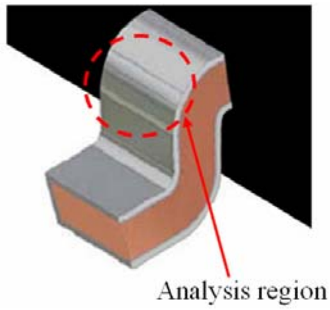


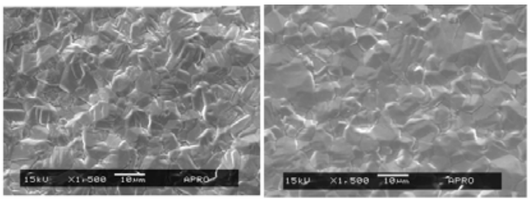
Fig. 5. Analysis region in IC.

not affect whisker growth [8].

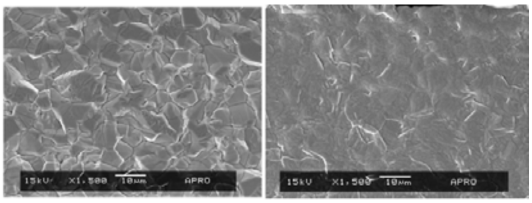
Test conditions for thermal cycling test are shown in Table 2 with both inspection interval and total test duration. 20 samples were kept under -65~95℃ per cycle in the thermal impact tester for 2000 cycles with the inspection interval of 500 cycles. Each cycle takes 20 minutes. Then 2 ~ 4 samples were extracted and examined after each inspection interval. SEM (Scanning Electron Microscope) with high magnification of x1, 500~x20,000 times were used to examine structure and size of plating, and whisker. Analysis region is chosen as shown in Fig. 5 for efficiency in using SEM since the region is more affected by internal and external stresses, and thus more whiskers grows in the region.

4. Result analysis

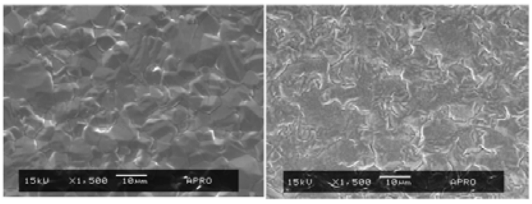
Acquired images of plating grain for each sample before the acceleration test using SEM with magnification of x1500 are shown in Fig. 6. Fig. 6 shows that more grain structures in the plating for samples A and B exist than one for samples D and F even though each sample has various shapes and sizes of grain. The images of each sample after the test are also shown in Fig. 7. Element analysis of created whisker after the test using EDX showed that the main element of whisker is Sn as shown in Fig. 8. For each sample, grain size and average number of whiskers per area of 200μm^2 are evaluated to analyze effect of grain size on whisker growth. The grain size is defined as the number of grains divided by diagonal length of SEM images. Both grain sizes and average number of whiskers produced are shown in Table 3. Relation of grain sizes to the number of whiskers is shown in Fig. 9 as well. In this paper, a correlation coefficient is considered to find a linear relationship between grain size and whisker growth. The correla-



(a) Sample A (b) Sample B

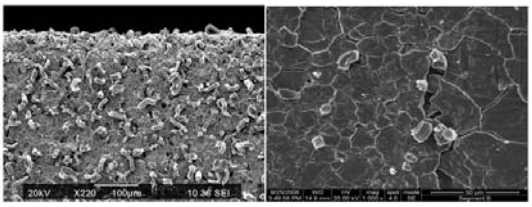


(c) Sample C (d) Sample D

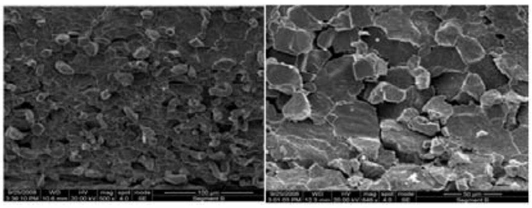


(e) Sample E (f) Sample F

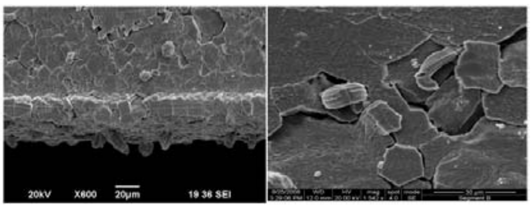
Fig. 6. Grain structure of plating for each sample.



(a) Sample A (b) Sample B



(c) Sample C (d) Sample D



(e) Sample E (f) Sample F

Fig. 7. Whisker shape for each sample.

Table 3. Grain size and the number of whisker produced for each sample.

Sample	Grain Size	The number of Whisker
A	5.2 ㎛	32
B	6.9 ㎛	24
C	5.7 ㎛	28
D	20.3 ㎛	4
E	7.2 ㎛	12
F	17.3 ㎛	9

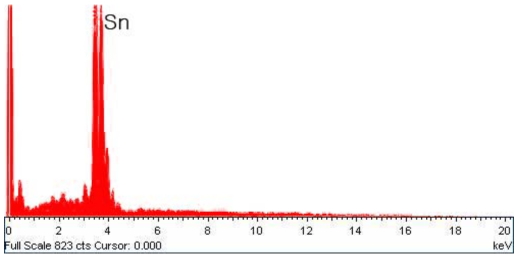


Fig. 8. Elements analysis of whisker using EDX.

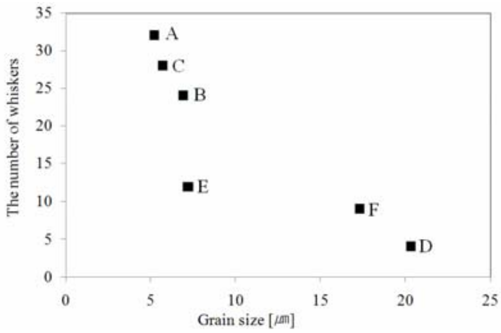
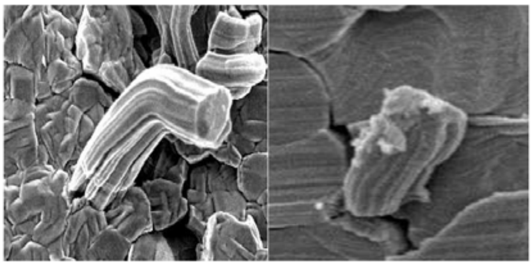


Fig. 9. Relation of plating grain size to the number of whiskers.

tion coefficient (r) for the relation is about -0.86 that indicate a strong negative correlation. Based on t-test, we can reject the null hypothesis testing for the coefficient at 5% level since the standardized test statistic $t = r\Big/\sqrt{(1-r^2)/(n-2)}$ with n = 6 is in the rejection region. Therefore, there is enough evidence to conclude that there is a significant negative correlation between grain size and whisker growth. Now, it can be stated that smaller grain size of plating produces higher possibility of whisker occurrence. Plating grain boundaries that Sn moves along due to induced stresses by either IMC or CTE mismatch are more produced when the grain size is smaller. Therefore, more whiskers grow for smaller grain size. Further, Fig. 10 indicates that whiskers grow in the grain



(a) Sample A (b) Sample D

Fig. 10. Whisker growth along plating grains at 2,000 cycles.

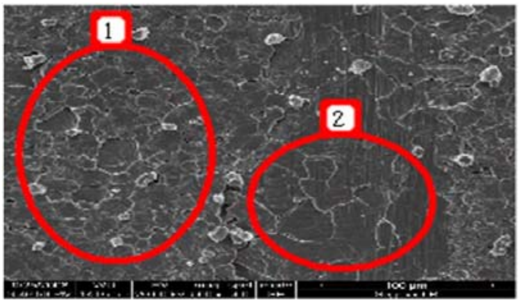


Fig. 11. Different plating grain size for sample B.

boundaries of plating for samples A and D.

Change in grain size and boundary of plating as the consequence of the grain structure change due to recrystallization of plating explains random whisker growth. This random growth is shown in Fig. 11. The sample B had the nearly same grain size of plating before the acceleration test, but different grain sizes of sample B have been produced after the test as shown in Fig. 11. More whiskers grow in the region 1 since the region 1 has more grains than the region 2. It follows that regions with larger grain sizes require more energy for whisker to grow than ones with smaller grain sizes. For example, plating containing Pb prevents whisker growth more efficiently than one containing Sn since the grain size of Pb is larger than Sn [7, 9].

5. Conclusions

In this paper, we analyzed effect of grain size and structure of plating on whisker growth through whisker acceleration test of ICs used in the electronic products. Samples with different package types, base metal, and plating thickness were used in the acceleration test, and both structure and size of plating, and whisker were examined using SEM. From the acceleration test results, we can conclude that Sn is the main element of whisker. And more plating grain boundaries that Sn moves along due to induced stresses by either IMC or CTE mismatch are produced when the grain size is smaller. Based on *t*-test, we found that there is a significant negative correlation between grain size and whisker growth. It follows that smaller grain size of plating produces higher possibility of whisker occurrence. In addition, whiskers grow in the grain boundaries of plating. Moreover, random whisker growth is induced by change in grain size and boundary of plating followed by recrystallization of plating.

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Seung-Jung Shin received his Ph.D. in 2000 at the University of Kookmin in Korea. He is currently a Professor at the School of Information Technology Division at Hansei University. His current research interests include reliability, Security, and Programming.

Jae-Jung Kim received his M.S degree from the Mechanical Engineering in 1999 at the University of Hanyang in Korea. He is currently a Research Professor at Reliability Analysis Research Center at Hanyang University. His current research interests include reliability, electronic cooling, and failure analysis.

Young Kap Son received his PhD from the Department of Systems Design Engineering in 2006 at the University of Waterloo in Canada. Currently he is a Professor in the School of Mechanical Engineering at the Andong National University. His current research interests include economic-based design for reliability, and physics of failure for general engineering systems.