

# Generating behavior of whiskers on Pb free Sn plating and its control

Y. Kimura<sup>1</sup> & Y. Takeshita<sup>2</sup>

<sup>1</sup>*Department of Materials Science and Technology, Kogakuin University, Japan*

<sup>2</sup>*Graduate School, Kogakuin University, Japan*

## Abstract

Until now, electronics materials have mainly been manufactured from Sn-Pb alloy plating. However, there is a problem in that Pb pollutes the environment. Therefore, Sn-Pb alloys are principally prohibited for use in electronic components by RoHS instruction. Therefore, the development of an alternative material to Pb is required from now on. However, whisker generation has become a problem when an alternative material to Sn-Pb alloy is used. In this study, various investigations are conducted employing Sn-Cu, Sn-Bi and Sn-Pb alloys on the basis of microstructure control for the best plating material to prevent whisker generation when used as an alternative material to Pb. As a result, the difference in crystal grain morphology was clarified between these three kinds of plating materials through conducting FIB processing and detailed SIM observation. Therefore, the residual and contact stresses generated by the process of putting the FPC into a connector cannot be easily be relieved in the case of Sn-Cu plating film, the microstructure of which has fine columnar grains. Increasing the Bi contents improved whisker generation and growth characteristics. Whisker generation and growth were suppressed in the case of applying a Sn-Bi alloy whose Bi content was larger than 2wt%. In this case, grain size was also increased with the increase of Bi content. Therefore, material selection and control of grain morphology are extremely important for suppressing whisker generation and growth.

*Keywords: RoHS instruction, prevent whisker generation, an alternative material to Pb, Sn-Bi.*



## 1 Introduction

The development of today's electronic industry is remarkable, as is the miniaturization and higher functionalization that have been achieved. In the plated parts, such as the circuit pattern used in IC and the print circuit board, the demand stemming from environmental issues concerning Pb free plating film has strongly increased [1]. It is not possible to solve this problem by using single metal plating, but a new functional usage of the alloy and compound plating based on peculiar characteristic of the metal is developed [2]. The considerations of environmental pollution and the environmental impact became indispensable, because there is a possibility of polluting the environment when electronic equipment containing Sn-Pb solder is abandoned. In addition, the promulgation of the RoHS instruction requested the material development of substitute alloys for the Sn-Pb alloy [1]. Therefore, an alternative material to Pb is required from now on. However, whisker generation has become a problem when an alternative material to the Sn-Pb alloy is used [3]. Therefore, in this study, various investigations are conducted employing Sn-Cu, Sn-Bi and Sn-Pb alloys on the basis of microstructure control for the best plating material to prevent whisker generation when using as an alternative material to Pb.

## 2 Experimental procedures

### 2.1 Plating species

The situation of connection of a connector with flexible substrate is schematically illustrated in Fig.1. Whiskers were generated from the contact part of the connector and this results in short circuit of the connector as shown Fig.2. The pitch of the connectors generally used is 0.3~0.5mm. Therefore, in cases where whisker length is 10 micrometers or less, the adjacent terminal can almost avoid the possibility of a short circuit.

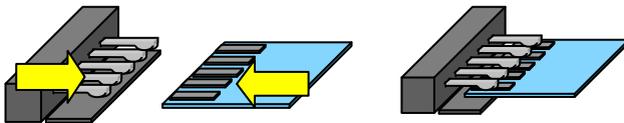


Figure 1: Connection of connector with flexible substrate.

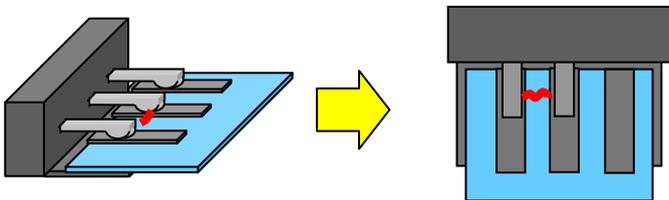


Figure 2: Circumstance of short circuit.

Table 1: Plating species.

Connector	FPC
Sn-1.5wt%Cu	Sn
Sn-2wt%Bi	Sn
Sn-10wt%Pb	Sn

At first, various investigations are conducted using the plating species shown in Table 1 to investigate the generation and growth characteristics of whiskers, because Sn-Pb has a suppressing effect on whisker generation and Sn-Cu easily generates whiskers. In addition, Sn-Bi is given attention as an alternative material to Sn-Pb plating. FPC is employed as the material that was put into the connector, because of its high degree of freedom of flexible elastic deformation.

## 2.2 Experimental procedures

In this study, external stress, generated internal stresses due to plastic deformation and recrystallization of plated film are considered as the governing factors for whisker generation, because some previous studies pointed out the importance of the external stress that was generated when flexible substrate was put in the connector [3]. Whiskers were generated under the connecting condition of flexible substrate and connector. The location where whiskers were generated was examined by SIM. Then, morphology and growth behavior of the whiskers [4] were examined in detail by SIM. In addition, the plating film was minutely process by FIB, and the crystal grain morphology [5] was examined by SIM. The test condition under which whiskers are generated easily is shown in Table 2. 100hrs or more time was needed for whisker generation. Therefore, it is observed by SIM from 100hrs after the connection, and the generation and the growth behavior of whiskers was examined.

Table 2: Test condition.

Temperature	Humidity	Contact force	Time
295K	40%RH	Approximately 1.9N	100hrs~

## 3 Results and discussions

### 3.1 Dependence of generated whisker morphology upon plating species

The dependence of the whisker morphology upon plating species was investigated. As a result, the whisker morphology difference depended upon the plating species was recognized and shown in Fig.3. The whisker morphology of Sn-Cu alloy plating was needle. That of Sn-Pb alloy plating was nodule. In addition, that of Sn-Bi alloy plating was intermediate between needle and nodule. The whisker morphology and mean length are indicated in Table 3.



These results were obtained after 720hrs from the flexible substrate being put in. It was confirmed that the plastic deformation occurred on the plating part due to the insertion process of FPC into the connector, and then the whisker was generated from this part. Moreover, there is the possibility of a short circuit because the whisker from the Sn-Cu alloy plating grew longer than  $30\mu\text{m}$ . On the contrary, it was recognized that the whisker of the Sn-Pb did not easily grow until 720hrs. It is reported that whisker growth begins at 100hrs or more after being put in. However, in this research the whisker generation was already recognized at 100hrs. Therefore, the initial whisker behavior of the whisker depending upon the difference of the plating species was examined in detail through observing growth behavior every 24hrs with SIM.

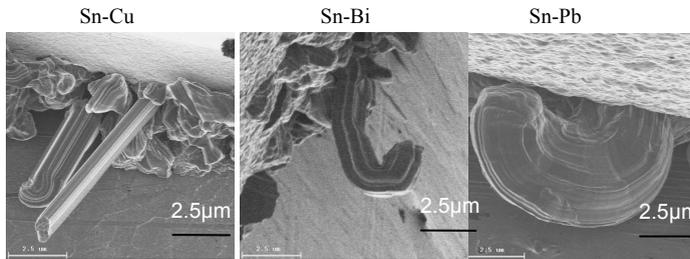


Figure 3: Difference in whisker morphology.

Table 3: Length and morphology of whiskers.

Plating species	Whisker morphology	Length	Time
Sn-Cu	Needle	$32\mu\text{m}$	720hrs
Sn-Bi	Intermediate	$8\mu\text{m}$	720hrs
Sn-Pb	Nodule	$6\mu\text{m}$	720hrs

### 3.2 Dependence of initial whisker growth rate upon plating species

Detailed observation of the growth behavior of the whiskers was conducted every 24hrs. Some examples of whisker morphology change with time, which in the case of the Sn-Cu alloy plating are shown in Fig.4. In Fig.5 the whisker length change [4] detected for the three kinds of plating species with time is indicated. The whisker growth of Sn-Cu and Sn-Bi alloy plating started 24hrs after the FPC was put in and the growth rate was gradually suppressed with time. Moreover, it was confirmed that the whisker grew up from its root. Therefore, the residual stress and contact stress generated when the FPC was put into the connector plays a dominate role in whisker growth. In Fig.5, the remarkable whisker growth of Sn-Cu alloy plating with time was recognized. Next, the contact points of the connector and the FPC was uncoupled to confirm the part where whiskers had been generated through conducting detailed examination by SEM.

### 3.3 Details of whisker generating process

Detailed examination of the whisker generation process was conducted employing Sn-Cu alloy plating, which showed accelerated whisker growth. In Fig.6 it was confirmed that the plastic deformation occurred in the plating part due to the insertion under contact force between the connector and the FPC, and then the whisker was generated from this part.

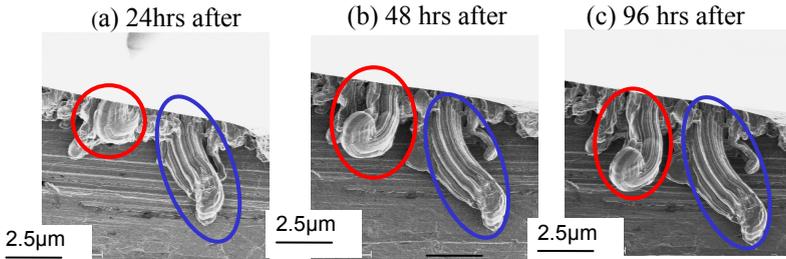


Figure 4: Growth of Sn-Cu whisker from the contact part.

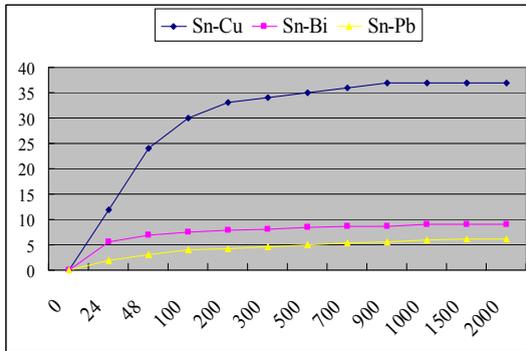


Figure 5: Growth characteristics of whiskers.

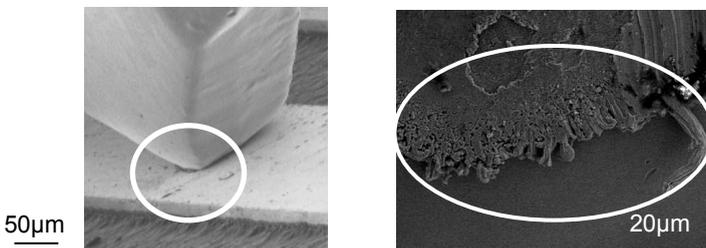
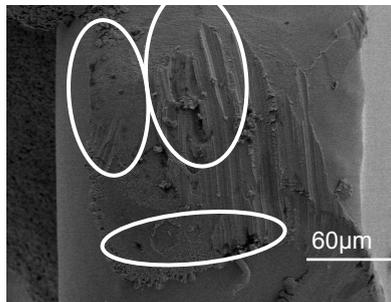
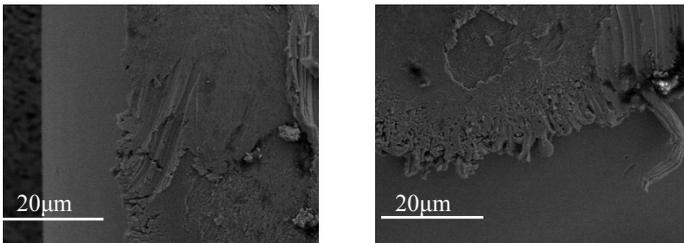


Figure 6: Whisker generating parts.

These figures indicate the following whisker generation process. Plastic deformation of Sn-Cu plating film was generated by the contact force between the connector and the FPC when the FPC was inserted into the connector. From the above-mentioned detailed observation of plastic deformation recognized on plated Sn-Cu film, some amount of plastic deformation and also contact force being held after insertion of the FPC into the connector are considered as the governing factors of whisker generation. In the following, dependence of plastic deformation upon plating species was investigated. First of all, difference in plastically deformed morphology between Sn-Cu alloy plating, which showed accelerated whisker growth, and Sn-Pb alloy plating, which showed a suppressing effect for whisker generation, was examined by SIM observation and shown in Figs.7 and Fig.8.



(a) Outlook of contact parts



(b) Side part close up – cumulative deformation of plating film

Figure 7: Plastic deformation on Sn-Cu plating film.

From these observations, a lot of plastic deformation was generated in the case of Sn-Cu compared with Sn-Pb plated film. As a result, much plastic strain energy was stored in the Sn-Cu plated layer. For this reason, whisker generation may be accelerated in the case of Sn-Cu plated layers compared with Sn-Pb. Just now authors have started evaluating the hardness of plated layers employing nano-indentation method and some results of micro-hardness measurement were obtained. As a result, hardness of Sn-Cu plating film showed relatively larger hardness compared with Sn-Pb plating film as shown in Table 4. For this reason, relief of residual stress was more suppressed in the case of Sn-Cu plating film compared with Sn-Pb plating film.

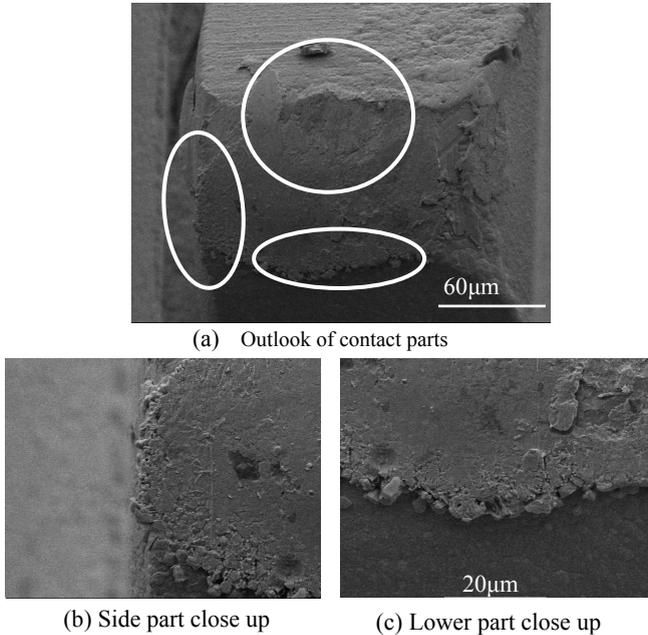


Figure 8: Plastic deformation of Sn-Pb plating.

Table 4: Hardness value of plating film.

Plating species	Hardness value
Sn-Cu	25.4
Sn-Pb	23.1

### 3.4 Dependence of crystal grain morphology upon plating species

Examination of detailed cross sectional crystal structure of plating film [5] was conducted by micro processing of each plated layer by FIB. Fig.8 (a)-(c), shows the observed result of this crystal grain morphology [6]. In Fig.9, a schematic illustration of crystal morphology whose SIM micrograph was shown in Fig.8 is indicated. It was understood from these observations that Sn-Bi had granular crystal grain morphology with random orientation. On the contrary, Sn-Pb and Sn-Cu showed columnar shaped crystal grain. However, Sn-Cu showed finer columnar shape compared with the crystal grain of Sn-Pb.

Therefore, plating film whose microstructure has a finer grain shows relatively higher yield stress. As a result, residual stress and contact stress, which were generated during the input process, were not easily relieved in this case compared with other plating film whose yield stress was relatively low. Whisker generation and growth preferentially occurred in the Sn-Cu plating for the above-mentioned reasons. As a result, generation and growth characteristics of the

whiskers shown in Table 3 and Fig.5 were understood from the viewpoint of residual and contact stress relief. These residual compressive and contact stresses may cause the generation of an inter-metallic compound then initiate Tin whiskers in the grain boundary [7].

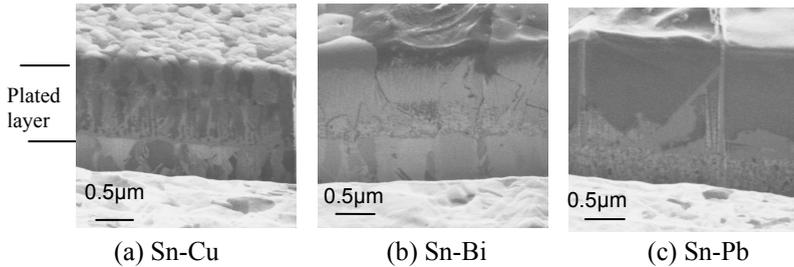


Figure 9: Observation of crystal grain morphology after the FIB process.

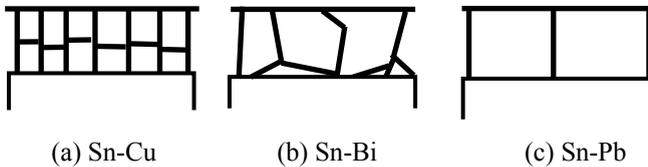


Figure 10: Schematic illustration of crystal grain morphology of plated film.

### 3.5 Dependence of initial whisker growth rate upon Bi content of Sn-Bi plating

Sn-Bi plating showed relatively superior whisker growth suppressing characteristics compared with that of Sn-Cu plating. In this section, the content of Bi was changed from 1 to 4wt% and then the effect of the Bi content on the whisker generation characteristics were examined. Also in this case, various considerations were conducted from the viewpoints of both morphology of the whisker and whisker growth rate.

Growth characteristics of the maximum length whisker that were detected for the first time after 24hrs from the FPC being put in are shown in Fig.11. In Table 5, the morphology and maximum length of the whisker after 168hrs from the FPC being put in are indicated. Also in this table, the number of detected whiskers longer than 5μm is indicated. Judging from these data, the Sn-Bi alloy whose Bi content is 1wt% showed preferential growth of whiskers whose length was around 20μm. On the contrary, in the case of Sn-4wt%Bi, the generation and growth of whiskers was relatively suppressed compared with Sn-1wt%Bi alloy plating. Therefore, a short circuit may be suppressed in the case when applying a Sn-Bi alloy whose Bi content is larger than 2wt% and also the evaluation of various properties such as wettability and so on necessary for plating process may be extremely important.

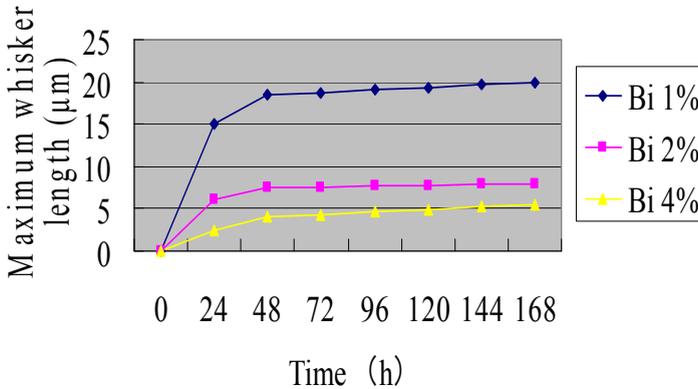


Figure 11: Growth behavior of whisker in Sn-Bi plating.

Table 5: Dependence of whisker morphology upon Bi content.

Plating species	Whisker morphology	Maximum length	Time	Number of whisker*
Sn-1wt%Bi	Needle	20μm	168h	14
Sn-2wt%Bi	Intermediate	8μm	168h	11
Sn-4wt%Bi	Intermediate	6μm	168h	7

\*Number of whiskers longer than 5μm.

## 4 Conclusions

In this study the generation and growth characteristics of whiskers were investigated from the viewpoint of the micro structure of plating species of Sn-Cu and Sn-Bi(1%, 2% and 4%), which are notable as Pb free materials. In addition, Sn-Pb plating was used in this research. Then, the difference in the whisker morphology depending upon plating materials was investigated and the whisker growth rate was evaluated through the plating film being processed by FIB. In addition, the effects of additive elements such as Cu, Bi and Pb upon the physical properties of Sn plating and the morphology of generated whiskers were investigated through SIM observation of a cross sectional area processed by FIB.

The results obtained are summarized as follows;

1. In the case of Sn-Cu plating material, preferential generation and growth of whiskers were recognized compared with Sn-Bi and Sn-Pb.
2. Residual stress generated by the input process of the FPC into the connector and the contact force between the connector and the FPC is a governing factor in whisker generation and growth.
3. The difference in crystal grain morphology was clarified between these three kinds of plating materials through conducting FIB processing and detailed SIM observation. Therefore, the residual stress generated by the input process



of the FPC into the connector cannot easily be relieved in the case of Sn-Cu plating film, whose microstructure has fine grains.

4. Increasing Bi contents improved whisker generation and growth characteristics. Whisker generation and growth were suppressed in the case when applying Sn-Bi alloy whose Bi content is larger than 2wt%. In addition, in this case, grain size was increased with the increase of Bi content.
5. Therefore, the control of grain morphology is extremely important for suppressing whisker generation and growth.

## References

- [1] Minoru Shimada, Outline of European Directives, WEEE and RoHS, Ceramics, Vol.37(11), pp. 866-870, 2002.
- [2] Yoshitou Hayashida, Yoshiyuki Takahashi, Takao Ohno and Ikuo Shohji, Whisker-Free Pb-Free Solder through Alloying, J. Japan Inst. Metals, Vol. 70(3), pp. 220-225, 2006.
- [3] Shinobu Ohzone et al., Whisker of Sn system plating in connector, Technological report of Japan Aviation Electronics Industry, No.28, p. 19-29, 2005.
- [4] Yuki Fukuda, Michael Osterman, and Michael Pecht, Length Distribution Analysis for Tin Whisker Growth, IEEE Transactions on Electronics Packaging Manufacturing, Vol. 30(1), pp.36-40, 2007.
- [5] Asa Frye, George T. Galyon, and Larry Palmer, Crystallographic Texture and Whiskers in Electrodeposited Tin Films, IEEE Transactions on Electronics Packaging Manufacturing, Vol. 30(1), pp.2-10, 2007.
- [6] Joe Smetana, Theory of Tin Whisker Growth: "The End Game", IEEE Transactions on Electronics Packaging Manufacturing, Vol. 30(1), pp.11-22, 2007.
- [7] Katsuaki Suganuma and Masami Terauchi, Quantitative Analysis of Intermetallic Compound and TEM Specimen Preparation for Sn Whiskers, Proceeding of 2nd International Symposium on Tin Whiskers 2008, paper No.1-1-3, Japan Electronics and Information Technology Industries Association, 2008.

