Tin-Bismuth Pre-Plating Technology for Alloy 42 LeadFrames

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There are many lead-free finish options such as pure Sn, Sn-Ag, Sn-Bi and Sn-Cu post-mold plating and Pd pre-plating. In the present work, Sn-Bi pre-plating technology for alloy 42 leadframe have been investigated. The electrodeposition was done by two-tone selective plating, namely, Ag was plated on internal lead only and Sn-Bi on external lead using various Sn-Bi plating solution. Surface and cross sectional morphology was observed by SEM. Finally solderability, bending crack and whisker performance after temperature cycles have been evaluated.

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Introduction

Tin-lead alloy has been electrodeposited on the external lead of semiconductor package to secure the wettability with solder paste for board mounting and protect the leadframe from corrosion. Many countries drive the bans for the hazardous materials worldwidely on public demand. Lead is detrimental to human body and assigned as hazardous material. Therefore, lead must be substituted for another material like pure tin(Sn), tin-silver(Sn-Ag), tin-bismuth(Sn-Bi), tin-copper(Sn-Cu) etc. Many studies have been carried out to find the substitute for Sn-Pb[1~4]. Among these candidates, pure Sn shows the best performance in the viewpoint of easiness of process control, cost, availability of plating solution and compatibility of lead-free solder paste. But the only obstacle to adopt pure Sn in volume production of component lead finish is whisker which has single crystal structure formed on plated tin. Many Asian companies utilize Sn-Bi as the second best solution[5~8].

Semiconductor package assembly process is composed of many detailed processes; die attach, wire bonding, molding, plating, trim/form and so on. The adoption of in-line from wafer sawing to tube or tray loading process provides process innovation due to reduction of lead time and labor. In in-line process, products are moved by conveyor but plating process uses another carriage system. Therefore in order to fulfill in-line, assembler should get rid of plating process. Pre-plating technology by lead-frame maker can solve this problem and offer cost saving and improvement of reliability by elimination of chemical process. Nowadays NiPd PPF technology gets stabilized and prevalent for copper leadframe. Fe-42Ni, alloy42, leadframe used in various memory packages is subject to corrosion due to large potential difference between Pd and Fe-42Ni. Plating engineers make an effort to overcome this problem in NiPd PPF. As an alternative, we suggested pre-plating technology using tin based material and studied the possibility of Sn-Bi pre-plating technology with various commercial plating electrolytes. The criticals to quality are bending crack, solderability and whisker propensity.

1. Experimental procedure

1.1. Selection of Plating Solution

A preliminary experiment was carried out to determine the optimal plating solution. Sn-Bi electrolytes were obtained from three solution makers, samples of various current densities were prepared, various qualities were evaluated and the best plating solution was selected.

Sample Preparation

A reel of Fe-Ni raw material was stamped with 66TSOP2, heat treated to reduce residual stress of stamped reel, cleaned to eliminate stamping oil and cut off to cut strips. Then Sn-Bi alloy was electroplated on leadframe cut strip using the pilot plating machine which consists of plating cell, cathode movement unit, two pumps, 30 liter tank, separate filtering unit with a 1 μm pore PP filter, heating unit and rectifier. The Sn-Bi plating solutions were obtained from three suppliers named A, B and C hereafter. The variable is current density from 15 to 35 ampere per square decimeter(ASD) and some parameters like thickness and content of electrodeposit were determined with 10 μm and 2.5 wt% of Bi respectively through a former test. The other conditions were suggested by supplier.

Evaluation

The thickness and content of electrodeposit were measured at 12 different points of outer leads by x-ray fluorescence. Plated surfaces have been studied with both optical microscope and scanning electron microscope(SEM). For investigating grains of cross-sectioned part, samples were notched, freezed with liquid nitrogen, shocked to be broken brittlely and observed. Leadframe was bent with gull wing shape by a proprietary bending machine to generate crack on Sn-Bi layer and observed with optical microscope & SEM. The solderability tests of two types were done after oven baking at 175 ˚C for two hours, steam aging at 93 ˚C for 8 hours and bending. Wetting balance test was fulfilled to estimate the wetting speed and dip & look test the solder coverage using Sn-Pb solder bath of 235 ˚C. In case of alloy42 substrate, the most accelerating condition for whisker growth was known with temperature cycling(TC). Therefore TC 500 cycles which have one cycle time of 30 minutes and range from -55 to 125 ˚C were applied to evaluate the maximum whisker length.

1.2. Assembly Tests

Sample Preparation & Evaluation

Samples were prepared with two-tone plating using the plating solution selected at the first stage. Silver was plated on the inner lead and tin-bismuth alloy outer lead by masking tool. The samples were evaluated equal to the preliminary test except for TC condition of temperature range from -35 to 125 ˚C.

Package Assembly

The pre-plated leadframes were assembled to check the feasibility of the existing packaging process. Prior to investigation of the whisker propensity, four conditions were applied separately; 1000 cycles of TC -35 ~ 125 ˚C, 1000 hours of soak at 85 % relative humidity(RH) & 85 ˚C, 1000 hours of high temperature storage(HTS) at 65 ˚C or 12 months of room temperature storage(RT). The reliability tests of packages were performed under lead-free conditions; Pre-conditioning level 3 at 30 ˚C and 60 % RH for 192 hours, 240 hours of pressure cooker test(PCT) at 121 ˚C & 2 atm, 1000 cycles of TC from -35 to 125 ˚C and 500 hours of HTS at 150 ˚C. 1000 cycles TC test for module level was carried out also.

2. Results and Discussion

2.1. Selection of Plating Solution

As shown in figure 1, the plating thickness corresponded to the target, 9 to 11 μm, and was constant regardless of current density. These data show that the cathode efficiency was nearly

100 % in the range of 15 and 35 ASD. But the appearance with current density was different with plating solutions(Figure. 2). The leadframe plated with vendor A's electrolyte didn't show burnt surface across all leadframe area up to 25 ASD. Even though the corner or edge side of leadframe burned, the functional area had a good appearance through all current ranges. The limiting current density is very important to secure mass productivity and dependent on the diffusion coefficient, metal ion concentration and diffusion layer thickness. To improve line speed, jet plating system is being considered now.

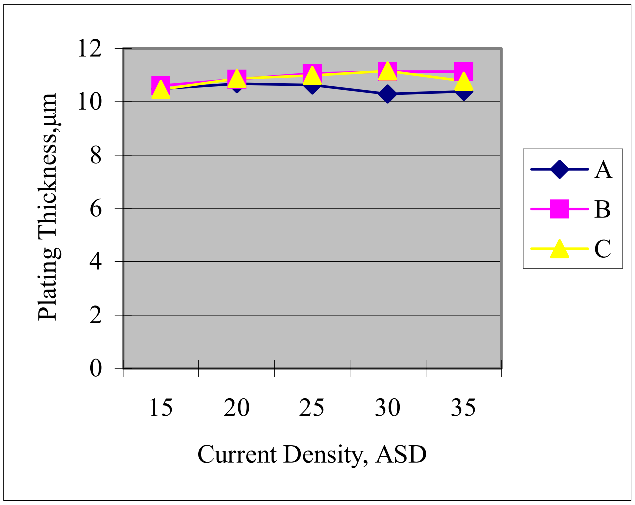


Figure 1. The plating thickness as a function of current density

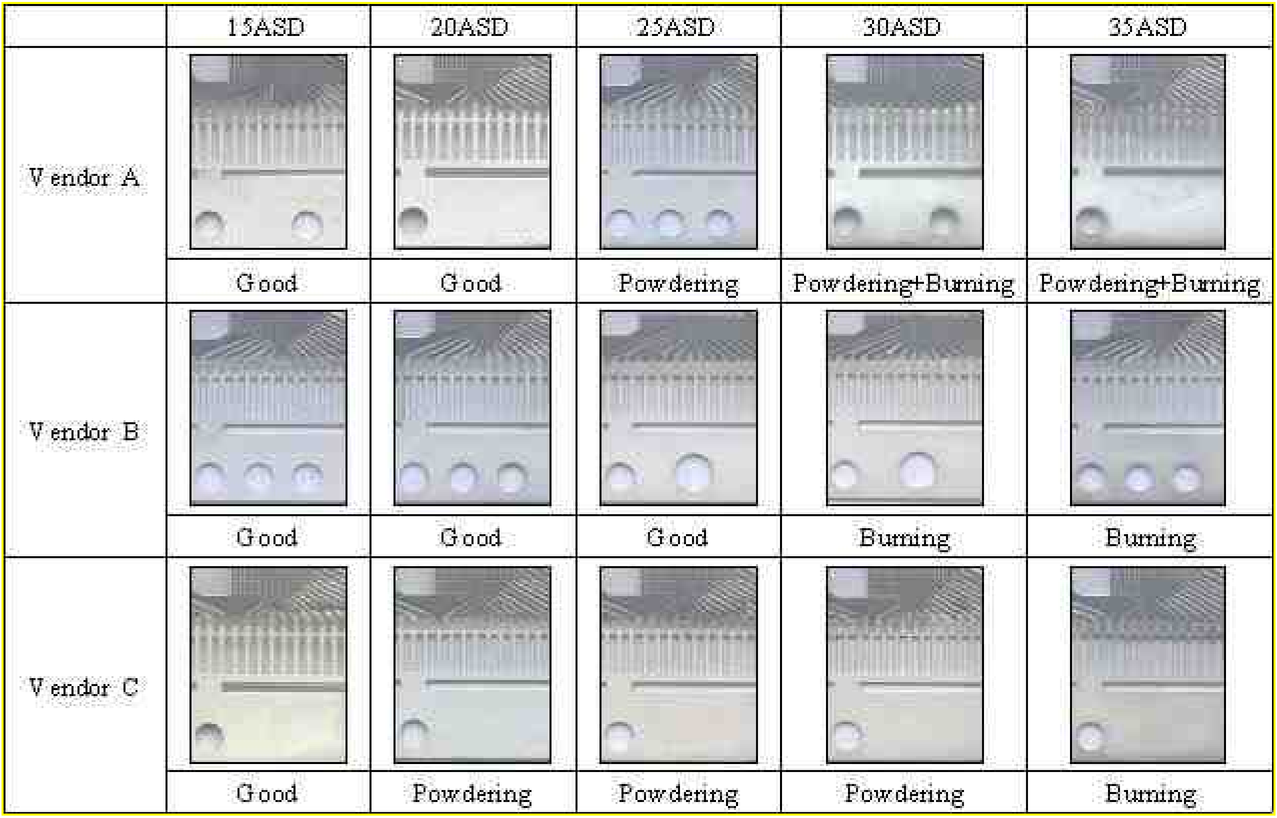


Figure 2. The optical microscope images of appearance of edge area

2 to 3 weight percent(wt%) of Bi content in electrodeposit was chosen to take a trade-off between whisker performance and bending crack. Too low Bi content means higher possibility of whisker growth and lower bending crack and vice versa. In Sn-Bi phase diagram, the maximum solid solubility of Bi in Sn at room temperature is about 1 wt%, but the Sn-Bi electrodeposit has higher solid solubility of Bi in Sn. In this experiment Bi content in plating layer decreases as current density increases(Figure 3). This result corresponds with the existing experimental result[9]. This behavior can be explained that noble metal is deposited preferably in the low current density range. Especially samples made from vendor C's chemical showed a steep drop under 2 wt% at near 15 to 20 ASD. The alloy stability with current is essential due to the following reasons. Even though the average current is constant for one leadframe strip, the apparent current density can be variable with position because leadframe has a complicated shape and current is distributed unevenly. Besides more Bi metal ion should be added in the plating solution in order to achieve a specific Bi content in electrodeposit at higher current density.

The more amounts of Bi in solution, the higher precipitation of Bi on the anode, stainless jig, pipe and tank. This results in the difficulty of process control and cost increase.

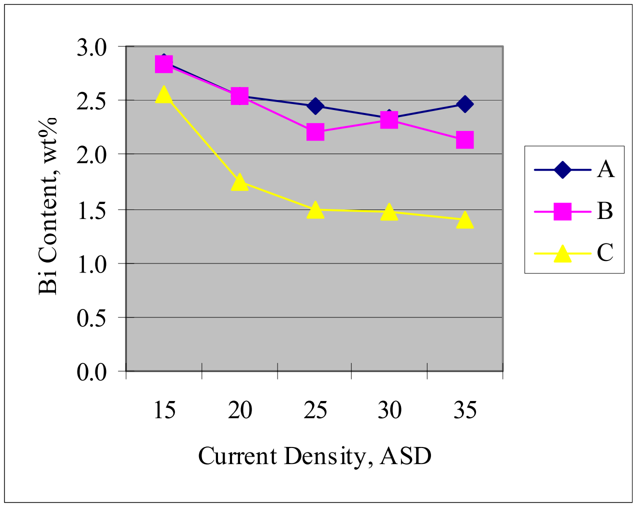
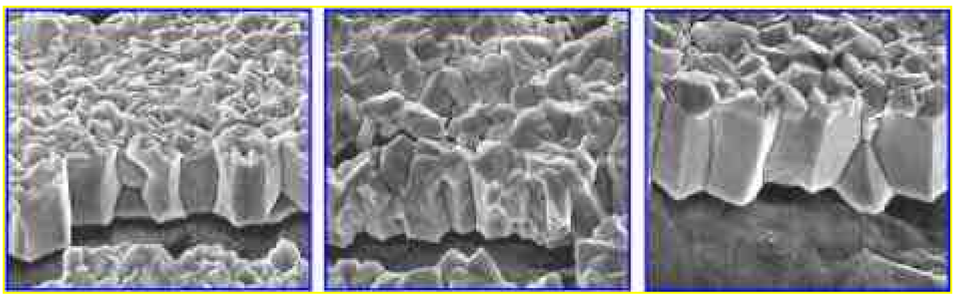


Figure 3. The Bi content as a function of current density

The grain shape of flat view showed polygonized structure and each sample for 20 ASD demonstrated the following grain size; 2.36 µm for vendor B, 2.20 µm for vendor C and 1.89 µm for vendor A respectively(Figure 4). At cross-sectional view, the grain structures were columnar and the sizes were 3.67 µm for vendor C, 3.14 µm vendor A and 2.20 µm vendor B respectively(Figure 5). Namely the order of grain size between as-plated and fractured surface was different. This results from the fact that borders of each grains of flat view don't coincide with those of cross-sectional view. The vendor B samples had the smallest real grain size. The grain size is strongly dependent on the relative rates of formation of crystal nuclei and the growth of existing crystals[10]. As the current density becomes high, the nucleation rate gets relatively higher than the growth rate. Therefore grain size decreases with current density as shown in Figure 6.

a) Vendor A (1.89 μm) b) Vendor B (2.36 μm) c) Vendor C (2.20 μm)

Figure 4. The SEM images of grain structure for each supplier's solution



a) Vendor A (3.14 μm) b) Vendor B (2.20 μm) c) Vendor C (3.67 μm)

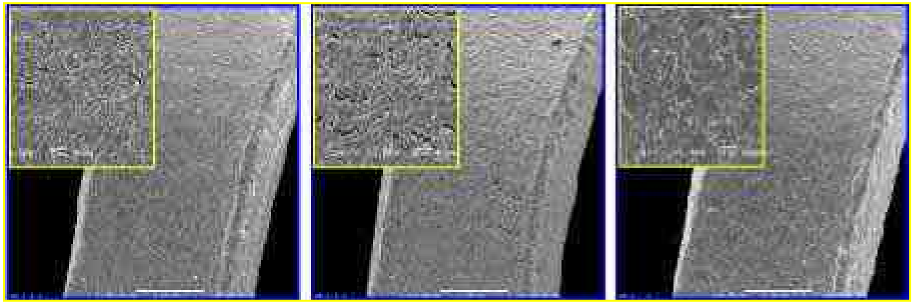
Figure 5. The SEM fractography images for each supplier's solution

a) 15ASD b) 20ASD c) 30ASD

Figure 6. The SEM images of grain size of Vendor B with current density

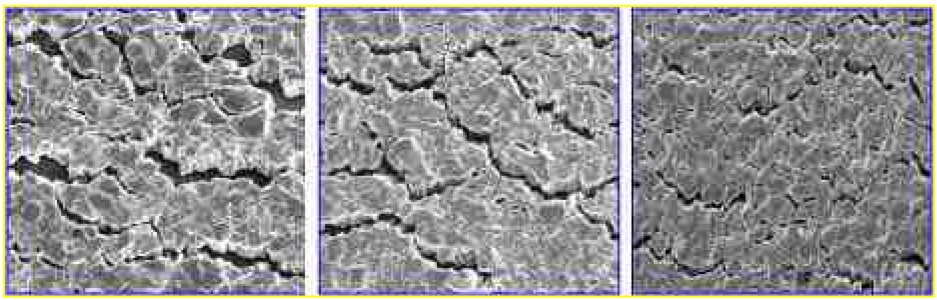
When bent and observed with optical microscope of 50 x magnification, the Fe-Ni base materials were not exposed to pass the specification. Figure 7 shows bending crack was the severest for Vendor B and no crack for vendor C with SEM. And the higher the current density, the lower the bending crack for vendor B(Figure 8). Two factors have effects on bending crack; the smaller the grain size and/or the higher Bi content, the more bending crack. In this experiment decrease of Bi content was dominant in determining the bending crack property.

The solder coverage of A & C solutions was very good but that of B solution showed poor wetting(Figure 9). Figure 10 shows the wetting speed tendency. The zero cross time was under 0.3 seconds which meant excellent wetting speed for all samples.



a) Vendor A b) Vendor B c) Vendor C

Figure 7. The bending crack for each supplier's solution at 20 ASD



a) 15ASD b) 20ASD c) 30ASD

Figure 8. The bending crack of Vendor B with current density

a) Vendor A b) Vendor B c) Vendor C

Figure 9. The solder coverage of each supplier's solution

Whisker growths were detected on all samples after TC. The change in current density did not affect maximum whisker length except for vendor B as shown in Figure 11. Wider temperature range was chosen compared with customer's specification to maximize whisker growth. Part of samples didn't pass the criteria of 50 μm in length. Due to the difference of coefficient of thermal expansion (CTE) between alloy42, 4.6 ppm/°C, and Sn-Bi, about 23.8 ppm/°C, whisker is formed and grown. At low temperature section, the compressive stress is exerted on the Sn-Bi electrodeposit so whisker growth is promoted. The typical whisker morphology can be seen in Figure 12.

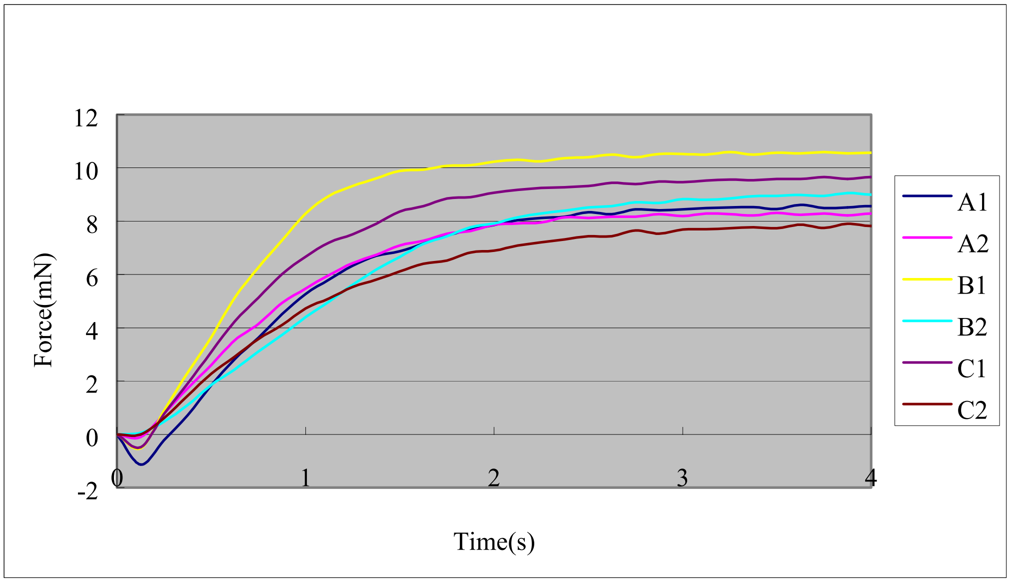


Figure 10. The zero cross time of each supplier's solution

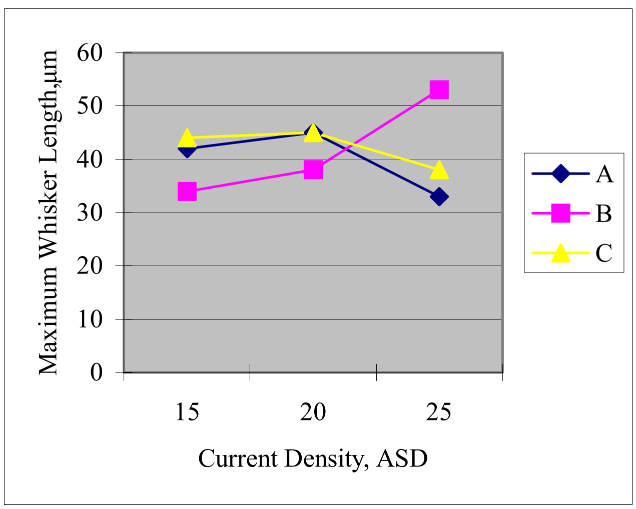
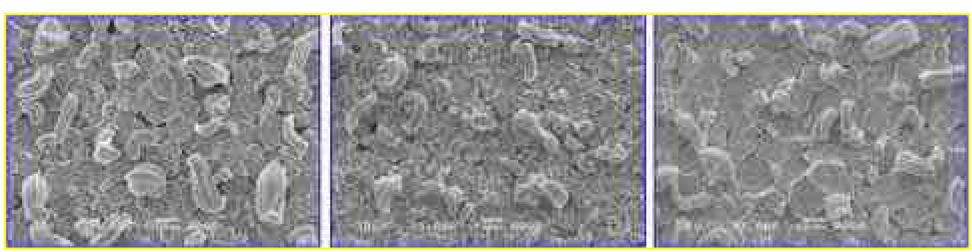


Figure 11. The maximum whisker length after 500 cycles TC as a function of current density



a) Vendor A b) Vendor B c) Vendor C

Figure 12. The whisker morphology of each sample at 20 ASD after 500 cycles TC

Table 1 summarized the results of comparison according to the preliminary test. In case of C supplier's electrolyte, the qualities of coating were excellent but performances of plating solution were not so good. A solution secured balanced capabilities in all aspects. Therefore vendor A's chemical was chosen for fabricating samples for assembly test.

Table 1. The comparison of each electrolyte's performance

Items	Vendor A	Vendor B	Vendor C
Limiting current density	+++	++	+
Alloy stability of chemical	+++	++	+
grain morphology & size	++	+	+++
Bending crack	++	+	+++
Solderability	+++	+/-	+++
whisker length	++	+/-	++

+++: excellent, ++: good, +: marginal, -: poor

2.2 Assembly test

The plating thickness of Sn-Bi was 10.20 µm in average and 0.69 in standard deviation and the Bi content was 2.74 wt % in average and 0.13 in standard deviation. The Sn-Bi plating area of outer lead is critical to moldability at assembly process. The difference between maximum and minimum plated position was 0.078 mm and process capability for plating area was excellent, 4.27.

The grain morphology, solderability and bending crack were excellent. The maximum whisker length after 500 cycles of TC from -35 to 125 ˚C was 26 µm. This improved datum results from narrower temperature range of TC. Consequently the performance of vendor A solution turned out to be reproducible.

The melting point of Sn-Bi was about 229 ˚C according to DSC results in Figure 13. The die attach temperature exceeded 400 ˚C but Sn-Bi electrodeposit was not affected by thermal attack because the process time was very short, under one second. The process temperature of a few processes exceeded the recrystallization temperature of Sn-Bi for more than one hour. After packaging, the plating layer was unchanged. The solderability test was done by lead-free condition and showed good results.

The maximum whisker length was 30.9 µm after TC 1000 cycles. The whisker growth had a tendency to be saturated under 500 cycles as shown in Figure 14. There were no whisker growths on all samples after PCT 1000 hours, HTS 1000 hours or RT 12 months. Test yields of Sn-Bi PPF runs were equal level to those of Sn-Pb runs. The reliability of component level by customer's specification passed. All modules passed the module TC & lead pull test.

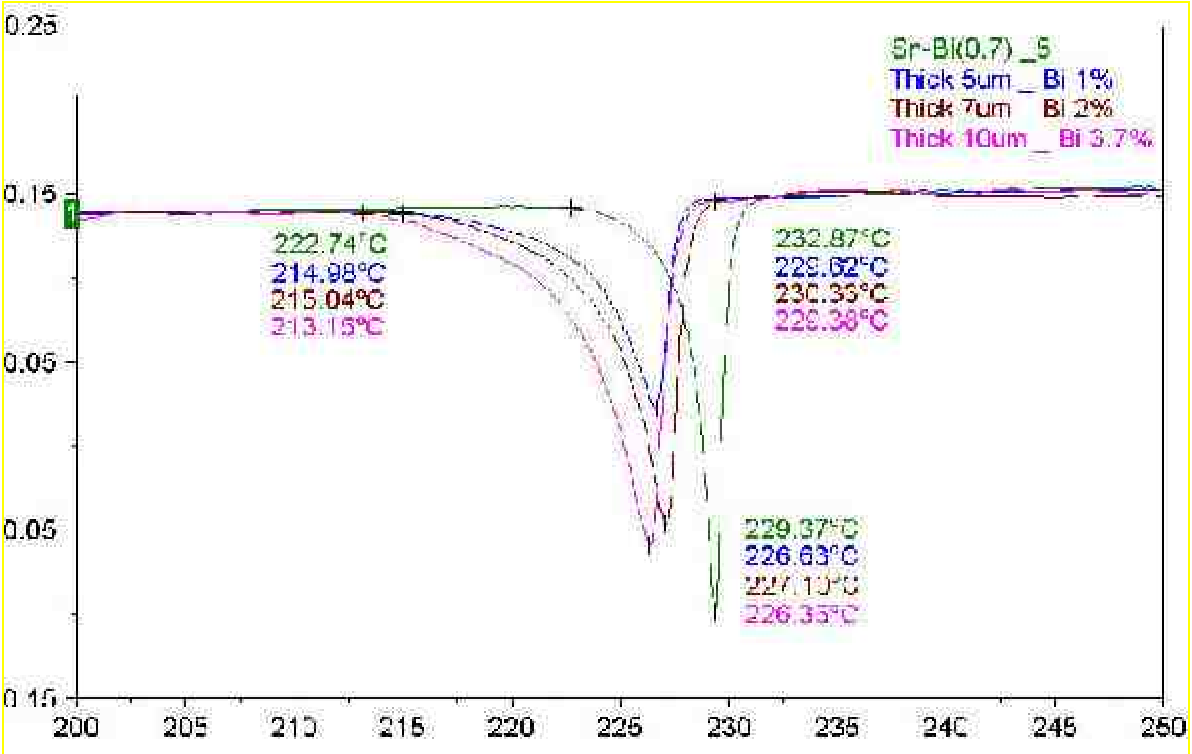


Figure 13. DSC results of Sn-Bi electrodeposit

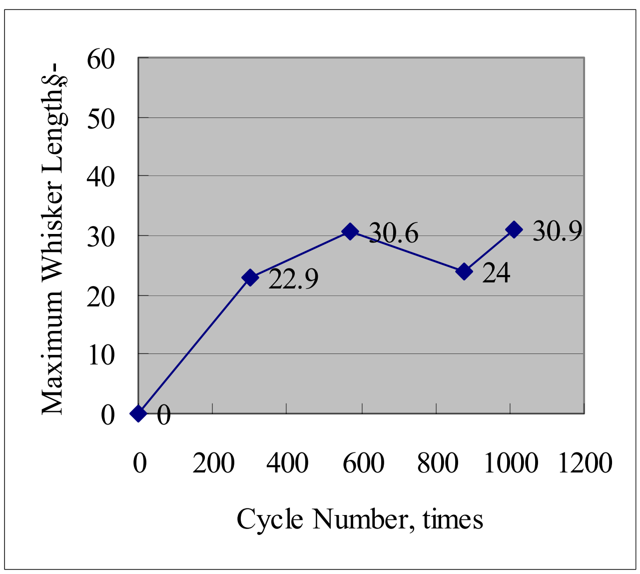


Figure 14. The maximum whisker length with cycle number of TC

Conclusion
As a potential candidate to replace Sn-Pb component finish, Sn-Bi PPF was investigated. In this study, the following conclusions were obtained.

1. The functional area of leadframe had a good appearance without burning up to 35 ASD.

2. Bi content and grain size in Sn-Bi electrodeposit decreased as current density increases. The data indicated that Bi contents of A & B plating solution were in the range of 2 & 3 wt %. The smaller grains at higher current density results from higher nucleation rate compared with growth rate.

3. The bending crack decreased with increasing current density. The decrease of Bi content had an important role to reduce crack.

4. The solderability and whisker criteria were satisfactory.

5. The feasibility of Sn-Bi PPF with package assembly process proved to be acceptable.

6. The reliability tests of component level and module level showed good results.

Acknowledgements
The authors would like to thank IPT team of Samsung Electronics for package assembly tests.

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