Measurement against Whisker and Its Effect on Sn-Cu Plated Connector

In the transition movement of our lead-free products, it becomes an issue that whisker is generated on the contacting area of contacts when connectors are mated. In order to mitigate the whisker, various kinds of samples were made by using Sn-Cu plating and situations of whisker generation was verified. As a result, it was clear that the coating hardness was able to be deteriorated by controlling the crystal grain size of Sn-Cu plating and plating with less whisker generation was obtained in the end. The Sn-Cu plating is presently regarded as one of plating compositions on which whiskers apt to be generated. [1-2] The Sn-Cu plating of which grain size is appropriately controlled, however, has excellent characteristics in whisker resistance or solderability, so it is now a dominant as a lead-free plating for connectors.

Key words: Whisker, Sn-Cu, connector, lead-free

1. Introduction

Every connector manufacturer started to supply Sn base lead-free products from the year 2001 and 2002 in order to comply with RoHS regulation that is scheduled to be implemented since July 1, 2006. Since the Sn-Cu plating is considered as a dominant replacement of the Sn-Pb one in those days, many connector manufacturers adopted the Sn-Cu plating.

Since a series of accidents caused by short-circuit problem occurred around the year 2002 and 2003 on electric equipment in which lead-free plated connectors were used, the whisker problem cropped up. The scene of generation of this whisker differs from conventional ones, for it is known that the current whiskers are generated on around contacting areas in a short while by mating and unmating motion. It is also thought that the risk to cause short-circuit failure is higher on connectors used for connection with an FPC/FFC with narrower pitches, or the distance between leads is shorter.

Japan Electronics and Information Technology Industries Association (JEITA) has been studying in detail in order to perceive the situation and solve the problem. Accordingly it was cleared that whiskers generation on the Sn-Cu plating could be mitigated by heat-treat, though whiskers on the Sn-Cu plating are longer than those on other lead-free platings such as Sn-reflowed, Sn-Bi,Sn-Ag, and etc.) [3].

While the soldering materials used for mounting currently are standardized into Sn-Ag-Cu base, studying toward the practical use of low temperature solder is also being carried out at the same time. On the assumption of various mounting conditions that are expected in the future, a plating material that has stable and excellent whisker mitigation effect that is undisturbed by mounting temperatures is required. In order to meet this requirement, various kinds of Sn-Cu plated samples were prepared and the mitigation effect was verified. Various functional capability other than whisker resistance are required for plating on connectors, the solderability that is one of the most important functions is also verified.

2. Test method

2.1. Samples

2.1.1. Plating

Treatments of alkaline degreasing, electrolytic decreasing and acid activation was applied on the phosphor bronze (C5210-EH, t=0.2) that was stamped out in a form of contacts of a connector and sulfamic acid nickel was undercoated. Then electrolytic plating was applied in the order of matt Sn-Cu plating and semi-bright Sn-Cu. Matt Sn-Cu plating bath is the plating liquid that is a result of reducing the brightener component from the semi-bright Sn-Cu plating bath. The pattern diagram of cross section of the plating is shown in Figure 1.

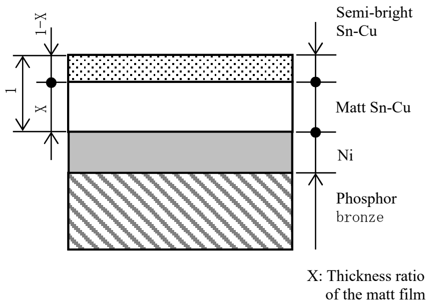


Figure 1. Pattern diagram of cross section of the plating

Samples are prepared for 6 variations in thickness ratio of matt plating and semi-bright one while certain thickness in total of the Sn-Cu film is retained. The film thickness of each sample were measured by using the X-ray fluorescence thickness meter (XRF) (See Table 1.) Oxidation inhibitor was applied to all samples as a post treatment.

Table 1. Measurement result of plating thickness

N=5

Sample No.	Thickness ratio of matt film X	Sn-Cu film thickness in total [μm]	Thickness of Ni film [μm]
1	0	4.78	2.10
2	0.2	4.92	2.14
3	0.4	5.02	1.79
4	0.6	5.35	2.26
5	0.8	5.48	2.03
6	1.0	5.21	1.88

It was proved that the Cu concentration inside the film met 2±1wt% by the EDX quantitative analysis. And the result of the DTA measurement proved that the melting point was 229℃.

2.1.2. Assembling

Contacts shown in Table 1 were pressed-in the insulator to which the slider was installed and thus connectors, sample products, were manufactured. These were ZIF type connectors used for connection with an FPC/FFC with 0.5mm-pitch. The cross sectional view of the connector is shown in Figure 2.

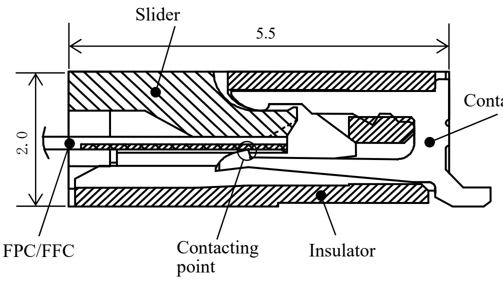


Figure 2. Cross sectional view

2.2. Tests

2.2.1. Whisker test with an FPC/FFC mated

Three types of connectors were prepared; subjected to no reflow (no pretreatment), reflow at the peak temperatures of 230[°C] and 250[°C] (Temperature on the printed circuit board, baking under the reflow conditions) respectively. Various FPC's/FFC's were connected to each type of connectors, which were exposed in the condition[3] at the room temperature (25±10[ºC]) that is regarded as the most suitable temperature for whisker to grow. The FPC's/FFC's were disconnected after the specific time elapsed, contacting areas were observed to be confirmed if whisker generates and the length of whiskers was measured by using the microscope (x300) In these circumstances, since this test meant a destruction test in elapse of the specified time, samples were prepared for each period of time respectively in advance.

2.2.2. Solderability test

Two types of connectors were measured; the initial one (no pretreated) and the one through the Pressure Cooker Test (PCT: 105[°C], 100[%RH], 1.22 x 10^5[Pa], 8[h]). Flux (Rosin 25[%] IPA solution) was applied to contact tails and measured the zero-crossing time through the meniscus method (Immersing speed: 2.5[mm/s], immersed depth: 0.5[mm], Sn-3.0Ag-0.5Cu: 245[°C]) .

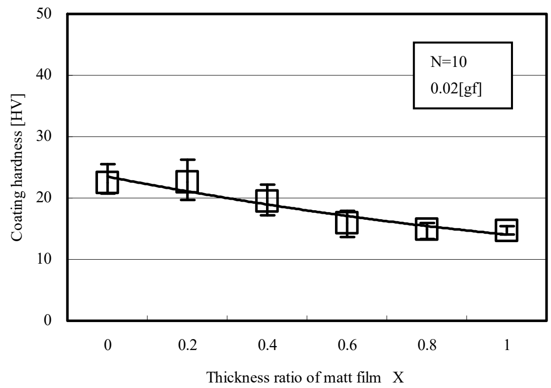


Figure 3. Measurement result of the coating hardness

3. Result and consideration

3.1. Samples with a variety of thickness ratios

3.1.1. Measuring the hardness of Sn-Cu plated film

The measurement result of micro Vickers hardness for samples is shown in Figure 3. The result said that the thicker the matt Sn-Cu plated layer is, the more the film hardness becomes degraded.

3.1.2. Whisker test under the connected condition

Figure 4 shows lengths of the longest whiskers formed on the connector and the dummy FPC (made of glass-epoxy, t=0.35) in connection after 72 hours. Since whisker performance can be observed most clearly on each sample, connectors were not reflowed here. From the test result, it is obvious that the thicker the Sn-Cu film is, the shorter the longest whisker becomes. Since the film hardness of the matt Sn-Cu plating is lower than the one of semi-bright Sn-Cu plating, it is presumed that the matt Sn-Cu plated layer absorbs the external stress.

The thickness ratio that shows the most excellent whisker resistance was matt film thickness ratio X=0.8. Whiskers little longer can be seen with X＝1.0 than with X＝0.8, the reason is not yet clarified.

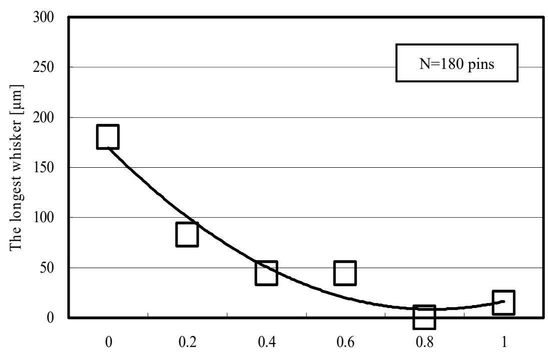


Figure 4. Result of whisker test under connected condition

3.1.3. Solderability test

The measurement result of zero-cross time is shown in Figure 5. While X=0.2 ~ 0.8 show the stable and good conditioned solderability, X=0 and 1 show the inferior one. An adverse effect of organic composition in the film can be a factor of inferior solderability with X=0. The solderability is inferior with X=1 because the surface is oxidized. It can be determined, however, that semi-bright Sn-Cu plated layer is a must as a protective coat since corrosion resistance is problematic only with a matt Sn-cu plated layer.

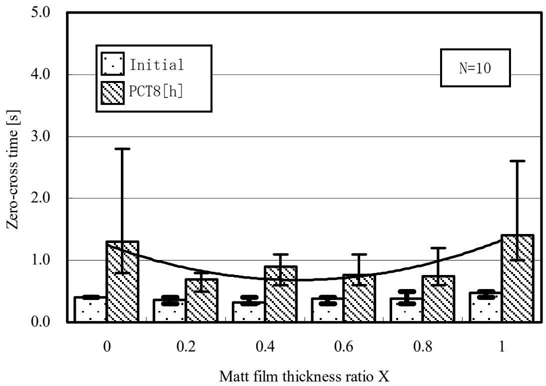


Figure 5. Measurement result of zero-cross time

3.2. Sample of X=0.8

3.2.1. Whisker test under the connected condition

By using the thickness ratio X=0.8 that showed the most excellent whisker resistance, the test was conducted with the Sn plated FFC (Sn plated thickness: 1μm or more, t=0.3) on the market connected. (See Figure 6.) The period while they were connected was 100 hours.

Whiskers were efficiently mitigated on every sample, for the length of whiskers generated on the contacting point of the contacts was 50[μm] or less regardless of reflow conditions. Compared the samples with no reflow with the ones subjected to reflow at 230[°C], whiskers were generated slightly less and formed slightly shorter on the ones at 230[°C]. This is presumed that the mitigation effect was obtained by the heat treatment (See to 3.4.). On the other hand, compared the samples subjected to reflow at 230[°C] with the ones at 250[°C], longer whisker was found on the one at 250[°C]. The cause of this result is still unknown. Currently, however, it can be pointed that growing of the intermetallic compound (See 3.4.) makes a difference on the whisker generation since it is possible to partly explain the mechanism of whisker generation in mated condition by using the atomic transition model[4].

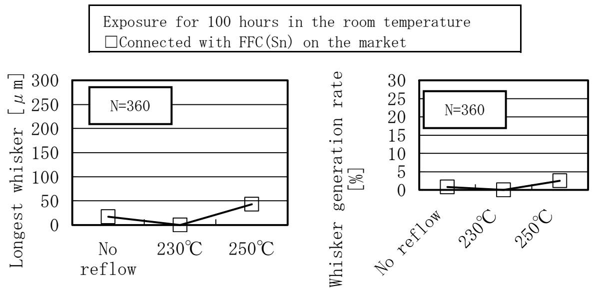


Figure 6.
Relation between the reflow temperature ad the longest whisker/generation rate

Figure 7 shows the result of the whisker test on the condition of connected for 5000 hours with no reflowed connectors and connectors reflowed at 250[°C].

It was observed that whiskers generated from the contacting points of contacts stopped growing when 100～500 hours passed in the connected condition. Compared no reflowed connectors with the ones reflowed at 250[°C], no significant difference was observed between them in the longest whiskers and generation rate.

The distance between leads of 0.5mm-pitch connectors is approximately 300[μm], and the one between conductors on FPC/FFC is approximately 100[μm]. It can be said, therefore, that whiskers generated on FPC/FFC conductors have a risk to cause short-circuit failure. Currently, measures against whisker are developed in FPC/FFC manufacturers as well.[4-5] Investigation with FPC/FFC's on which the measure is taken will be conducted as soon as possible after they were obtained.

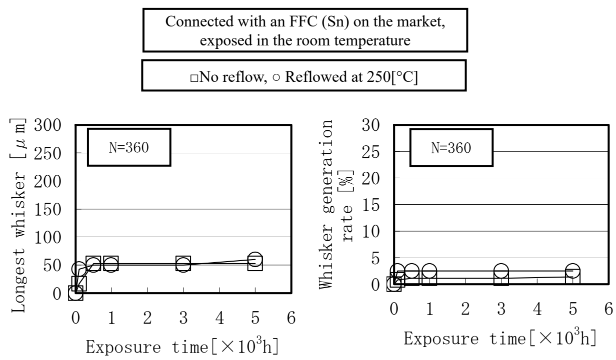


Figure 7. Relation between the exposure period and the longest whisker/rate of whisker generation

Table 2. Result of whisker test with nothing connected

○: No whisker generated, ×: Whisker generated N=10

No.	Test item	Test conditions	Result
1	Test under room temperature	Temperature: 25±2 [°C], Humidity: 50 [%RH] or less, Duration: 6 [months] (≒4300 [h])	○
2	Thermal cyclic test	The lowest storage temperature: -40±2 [°C], The highest storage temperature: 85±2[°C], Number of cycles: 1500 [times]	○
3	Test under high temperature and humidity	Temperature: 60±2 [°C], Humidity: 90~95 [%RH], Duration: 1000[hours]	○
4	Test under high temperature	Temperature: 50±2[°C], Duration: 1000[hours]	○

3.2.2. Whisker test with no connection

Table 2 shows the result of the investigation of whisker generation with nothing connected. Samples were not subjected to reflow process. No whisker was observed in every test.

Cu dispersion into Sn-Cu film could be a factor to cause whisker generation with nothing connected (exposed in a natural state). Cu_6Sn_5 is generated by Cu dispersion that caused cubical expansion, which increases compression stress that could be a driving force of the whisker generation [3]. It is conceivable, therefore, that Ni underplating could prevent Cu dispersion. For whiskers generated with exposure in the ambient situation, investigation only in this test is not enough since it has been presumed that verifications under various environments for about 4000 hours are required [3]. It will be confirmed in future that no whisker generates on further accelerated samples.

3.3. Relation between reflow temperature and hardness of coating film

Figure 8 shows the relation between reflow temperature and hardness of coating film. It is found that the coating hardness with samples subjected to reflow at 230[°C] decreased slightly from the initial state. With samples subjected to reflow at 250[°C], however, the coating hardness increased rapidly and measured values spread widely.

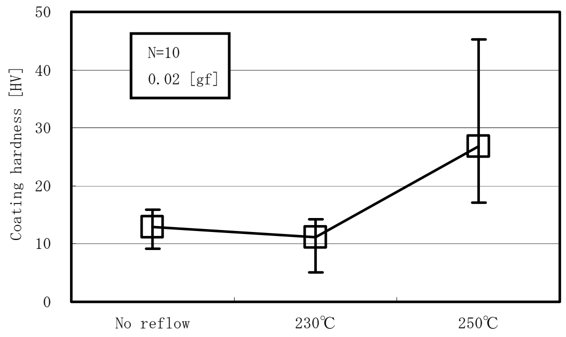


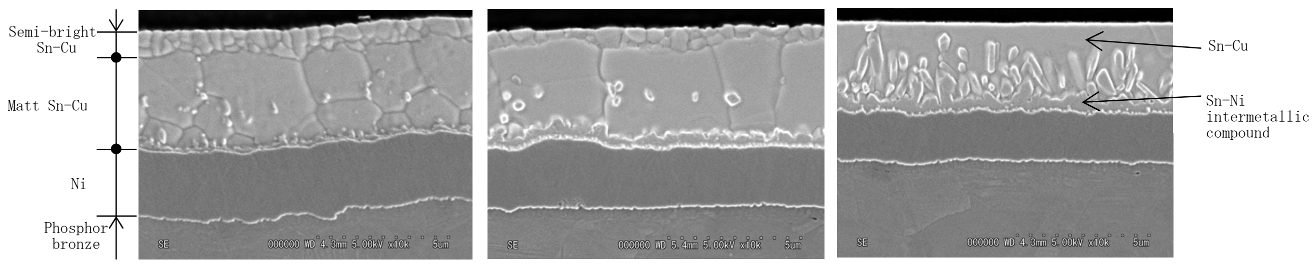
Figure8
Relation between reflow temperature and coating hardness

3.4. Observing plated cross section through SEM

In order to investigate the condition of particle of Sn-Cu plating in connection with reflow temperature, the plated cross section of samples subjected to each reflow condition was observed with SEM (Figure 9). It was found that the one with no reflow was consisted of semi-bright Sn-Cu layer with 0.5[μm] in diameter and matt Sn-Cu layer of 2[μm] in diameter.

Two kinds of Sn-Cu plating layer were found also in samples subjected to reflow at 230[°C]. Due to short period of peak temperature retention time, Sn-Cu plating did not start melting. Crystals in both layers grow bigger in grain size than those with no reflow. The effect of lowering in coating hardness shown by the growing of this Sn-Cu grain must be a reason to restrain whisker generation on samples reflowed at 230[°C] compared with no reflowed ones that were shown in Figure 6.

The Sn-Cu plating forms the biggest grain resulted from recrystallization after once completely melted in reflow at 250[°C], and it is conceivable that the Sn-Cu layer becomes the softest. It is also observed that needle-shaped intermetallic compound forms on the boarder of the matte Sn-Cu layer and Ni one. It was confirmed through XRD method that this layer was an alloy layer of which Ni_3Sn_2 or Ni_3Sn_4 is a major component. This is the cause that it was observed that the film hardness got increased in reflow at 250[°C] shown in Figure 8. It is presumed that this phenomenon facilitates whisker generation on the conductor of the FPC/FFC.



(a) No reflwo (b) Reflow at 230[℃] (c) Reflow at 250[℃]

Figure 9 Crystalline cross section of Sn-Cu plating in each reflow condition

4. Conclusion

It became clear that plating that has high whisker resistance and enough corrosion resistance could be realized by controlling the size of crystal grain by way of using two types of Sn-Cu plating, semi-bright type and matte one.

Semi-bright Sn-Cu plating is essential for solderability to be secured. Matt Sn-Cu plating attains film deterioration in hardness and inhibits whiskers generated when connected from growing longer than 50[μm]. The best resistance to whisker is obtained when the film thickness ratio is X=0.8. Whiskers generated in the mated condition become saturated after 100 hours to 500 hours elapse.

5. Afterword

It became clear that good mitigation effective against whisker (which can be regarded as a lead-free plating suitable for connectors) can be obtained by the relatively easy way of measurement taken even on Sn-Cu plating. Since the mechanism of whisker generation, however, is not yet fully understood still now, performances of whisker is required to be verified further in various conditions (bath composition, fabricating conditions, contact pressure, shape of contacting point, and etc.)

References

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