

INTERFACIAL REACTION AND STRENGTH OF QFP JOINTS USING SN-ZN-BI SOLDER WITH VARYING LEAD PLATING MATERIALS

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ABSTRACT

We have investigated the effects of plating materials for Cu lead (Sn-10Pb, Au/Pd/Ni, Sn-3.5Ag, Sn-3Bi and Sn-0.7Cu) on properties of QFP joints using a Sn-8Zn-3Bi solder. The results were compared with the joints using Sn-3.5Ag-0.7Cu and Sn-37Pb solders. As a result, the joints with the Sn-3.5Ag, Sn-3Bi and Sn-0.7Cu plated Cu lead had the reliability comparable to those of the Sn-3.5Ag-0.7Cu and Sn-37Pb soldered joints with respect to the joint strength after the high temperature holding tests at 348K to 423K. In particular, the joint with the Sn-3.5Ag plated Cu lead had the best reliability. This is caused by the low growth rate of a Cu-Sn interfacial reaction layer that degrades the joint strength of the soldered joints. Consequently, the Sn-3.5Ag plating was found to be most feasible plating for the Sn-8Zn-3Bi soldered joint.

KEYWORDS

Sn-Zn-Bi solder, Lead plating, Interfacial reaction, QFP, Reliability

1. INTRODUCTION

At present, Sn-Ag-Cu solder has been regarded as a high reliability solder and has been prospected as a candidate of the lead free solder which takes place of the Sn-37Pb solder from the viewpoint of the global environment preservation^[1]. However, Sn-Ag-Cu solder has a problem to cause heat damage in LSI chips because the melting point is higher and thereby the soldering temperature is higher in comparison with the Sn-37Pb solder. Much attentions, therefore, have been paid to Sn-Zn solder of which melting point is close to that of the Sn-37Pb solder, and some applications have already been given to marketing products in recent years^[2]. However, the interfacial reactions in the joints and their reliability have not been insufficiently cleared compared to the joints with Sn-Ag system solders. Therefore, the fundamental examinations are needed for the Sn-Zn solders.

In this study, the QFPs (Quad Flat Package) generally being used as an LSI (Large Scale Integration) package were reflow-soldered using a Sn-8Zn-3Bi solder (when there is no mention, composition is described as a mass percent in the following) with varying plating materials for Cu lead, Sn-10Pb, Sn-3.5Ag, Sn-3Bi, Sn-0.7Cu and Au/Pd/Ni plating. We have considered the effects of lead plating materials on the growth of the interfacial reaction layers and the joint strength. Moreover, the high temperature holding tests were done below the solder melting point, and the evaluations of the solder joints were done in the same way as the as-soldered joints. Furthermore, the results were compared with those of the Sn-37Pb solder and the Sn-3.5Ag-0.75Cu solder

2. EXPERIMENTAL PROCEDURE

The Sn-8Zn-3Bi solder paste of which melting point is 470K was used as a solder material. Each plating material, Sn-10Pb (thickness; 10 μ m, melting point; 456K), Sn-3.5Ag (thickness; 10 μ m, melting point; 494K), Sn-3Bi (thickness; 10 μ m, melting point; 498K), Sn-0.7Cu (thickness; 10 μ m, melting point; 505K) or Au/Ni/Pd plating (thickness; 0.3/0.08/0.01 μ m)

was plated on Cu leads of the QFPs. The QFPs with 0.5mm pitch Cu leads were reflow-soldered on FR-4printed circuit boards under a nitrogenous atmosphere. A peak temperature of soldering was about 498K. The QFPs with Sn-10Pb plated Cu lead were also reflow-soldered using the Sn-3.5Ag-0.7Cu solder and the Sn-37Pb solders as reference samples. After the reflow, the soldered specimens were either examined or subjected to the high temperature holdings. The high temperature holding tests were performed at temperatures of 358K, 398K and 423K for 1.8Ms, 3.6Ms and 7.2Ms. After the reflow and the high temperature holding tests, the strength of the soldered joints was measured through a 45 degree pull tests with a tensile rate of 3.33 $\mu\text{m/s}$ as shown in Fig. 1. Microstructural characterizations of the soldered joints were also carried out. The solder joints were sectioned, metallographically polished and examined using a scanning electron microscope (SEM) equipped with an electron probe micro analyzer (EPMA).

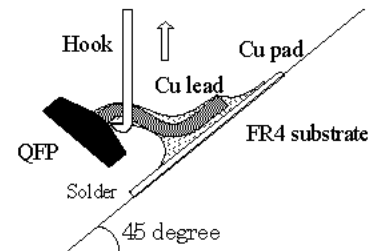


Fig. 1 Method of QFP pull test.

3 RESULTS AND DISCUSSION

3.1 MICROSTRUCTURES OF SOLDER JOINTS

Figure 2 shows the cross-sectional backscattered electron (BE) micrographs of the solder layers between the lead and the pad after soldering and 423K \times 7.2Ms holding tests and the results of EPMA area analyses of as-soldered QFP joint with the Sn-Ag plated Cu lead. The relationship between thickness of the reaction layers and holding times at 423K were shown in Fig. 3. The microstructural aspects of each solder joint will be described below.

(a) Sn-Pb plating

The γ (Cu_3Zn_8) reaction layers formed at the lead/solder and the solder/pad interfaces in as-soldered condition because Cu reacted with Zn more easily than Sn (Fig. 2 (a)-(i)). In the high temperature holding tests at 348K to 423K, the γ layers transformed to the β' (CuZn) reaction layers with the growth of the Cu-Zn layers. Afterward, the growth of the Cu-Zn reaction layers came to a standstill in the joints. Coincidentally, the Cu_6Sn_5 compound formed and grew as the holding time increased (Fig. 3 (a)). This is caused by the depletion of Zn in the vicinity of the interfaces due to the growth of the Cu-Zn reaction layers consuming free Zn. The Cu_6Sn_5 compound formed in the whole solder layer between the lead and the pad after the high temperature holding test at 423K \times 7.2Ms (Fig. 2 (a)-(ii)). Also, we observed a Bi and Pb rich phase at the solder/pad interface. From this result, the remarkable growth of the Cu_6Sn_5 layers is considered to be caused by a liquid formation due to the Sn-Bi-Pb ternary eutectic reaction. The phenomenon is similar to that in the QFP joint with the Sn-Pb plating using a Sn-Ag-Bi solder reported in the previous papers^{[3][4]}.

(b) Sn-Bi and Sn-Cu plating

The interfacial reactions in the joints with the Sn-Bi and the Sn-Cu plating were similar to those with the Sn-Pb plating (Fig. 2 (a)-(iii) and (iv)). However, the growth rates of the interfacial reaction layers in the joints with the Sn-Bi and the Sn-Cu plating were considerably lower than that in the joint with the Sn-Pb plating during the high temperature holding tests because no Bi and Pb rich phase to form the liquid phase existed in the solder layers (Fig. 3 (b) and (c)).

(c) Sn-Ag plating

The reaction layers of the soldered joints with the Sn-Ag plating consisted of the γ layers in as-solder condition, and they transformed to the β' layers during the high temperature holding test (Fig. 2 (a)-(v) and (vi)). However, the growth rates of the reaction layers in the joint with the Sn-Ag plating were much slower than those with the Sn-Pb, Sn-Bi and Sn-Cu plating (Fig. 3 (d)). Ag was found to dissolve into the Cu-Zn interfacial reaction layer as shown in Fig. 2 (b). Therefore, it

is considered that the diffusion of Cu and Sn across the Cu-Zn interfacial reaction layer may be inhibited by dissolving Ag into the reaction layer.

(d) Pd plating

The reaction layers of the soldered joints with the Pd plating consisted of γ layer at the solder/pad interface in as-soldered condition (Fig. 2 (a)-(vii)). Meanwhile, the reaction layer was hardly observed at the lead/solder interface because the Ni layer of the lead plating inhibited the diffusion of Cu into the solder. In the high temperature holding tests, the Cu-Zn reaction layer formed and grew at the lead/solder interface as holding time increased (Fig. 3 (e)). A thin Cu_6Sn_5 reaction layer formed at the Ni plating/Cu-Zn compound interface after the high temperature holding test at 423K \times 7.2Ms (Fig. 2 (a)-(viii)).

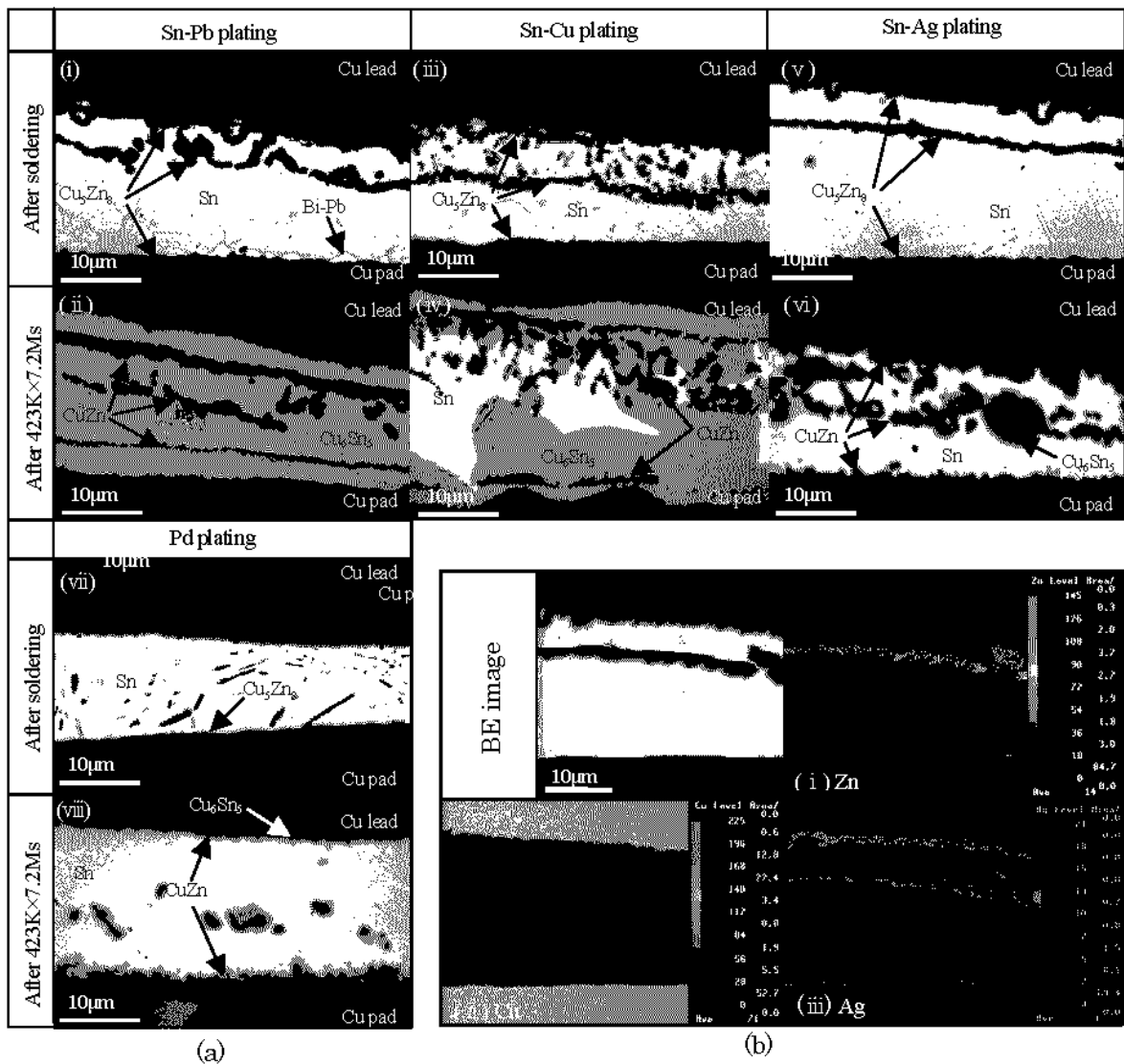


Fig. 2 (a) BE images of QFP joints using Sn-8Zn-3Bi solder and (b) results of EPMA area analyses of as-soldered QFP joint with Sn-Ag plating.

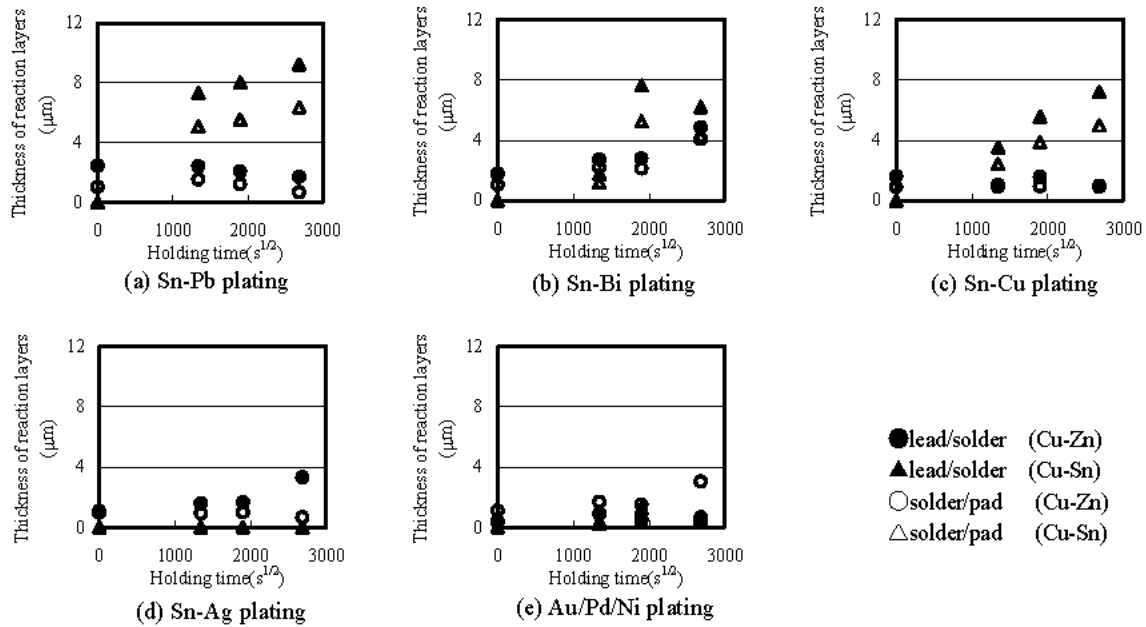


Fig. 3 Relationship between thickness of reaction layers and the holding times at 423K.

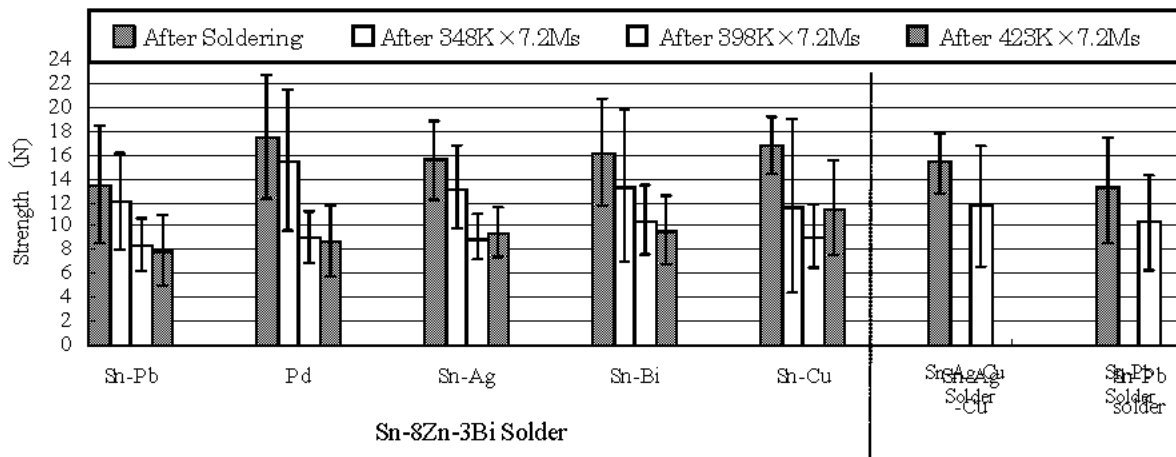


Fig. 4 Strengths of QFP joints.

3.2 EFFECTS OF LEAD PLATING MATERIALS ON THE STRENGTH OF THE SOLDER JOINTS

Figure 4 shows the results of the 45 degree pull tests of the soldered joints. The error bars exhibit the $\pm 3\sigma$ reliable ranges. The each potted value is average of 20 measurements. After the high temperature holding tests, the strength of every solder joint decreased as holding time increased. However, the joints with the Sn-Pb plating had lower strength than those with the other plating both in as-soldered condition and after the high temperature holding tests. Although the joint with the Pd plating had a high strength after the high temperature holding test at 358K, the strength showed significant decrease after the high temperature holding tests at 423K. The joints with the Sn-Ag, Sn-Bi and Sn-Cu plating had almost same average strengths both in as-soldered condition and after the high temperature holding tests. Among them, the lower limit value of the reliability range ($\mu-3\sigma$) in the joint with the Sn-Ag plating is highest. As a result, the joint with Sn-3.5Ag plating is considered to have the best reliability.

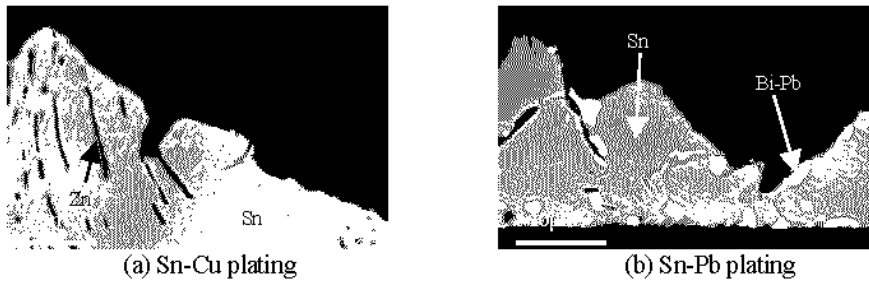


Fig. 5 BE images of crack path of 45 degree pull test specimens (as-soldered).

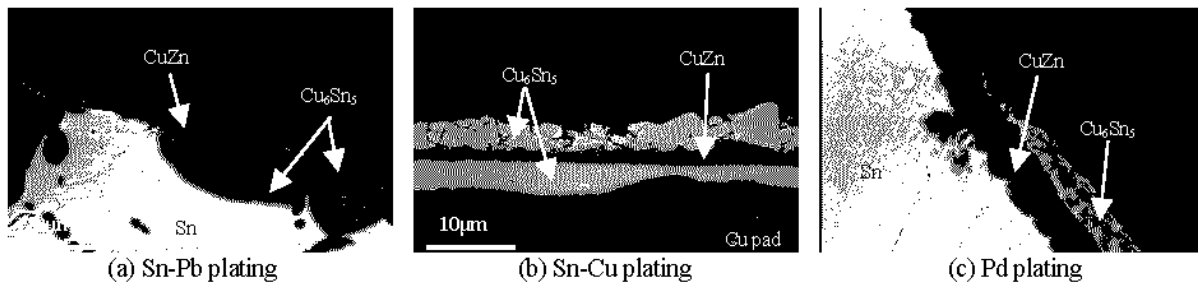


Fig. 6 BE images of crack path of 45 degree pull test specimens (after 423K \times 7.2Ms holding test).

Figure 5 and Figure 6 show backscattered electron micrographs of typical crack paths in the solder joints after the 45 degree pull test. In as-soldered condition in which only Cu-Zn reaction layers formed, the fractures occurred in the solder layer for all kinds of lead plating (Fig. 5). While the Cu-Zn layers formed at the lead/solder and solder/pad interfaces, they hardly caused the initiation and propagation of the fracture. In the joints with the Sn-Pb plating, segregated Bi and Pb rich phases were observed along the crack path (Fig. 5 (b)). This caused the lowest strength of the soldered joint with the Sn-Pb plating.

In the soldered joints after the holding tests at 423K \times 7.2Ms in which both the Cu-Zn layers and the Cu-Sn layer formed, the fractures occurred in the Cu-Sn reaction layers for the soldered joints with all kinds of plating (Fig. 6). The cracks propagated mainly in the Cu-Sn layer at the solder/pad interfaces in the joints with the Sn-Ag and the Sn-Bi plating, at the lead/solder interface in the joint with the Sn-Cu plating. It is found from these results that the growth of the Cu-Sn reaction layers has a more serious effect on the fractures of the soldered joints than the Cu-Zn reaction layers. In the joints with the Pd plating, the fracture occurred along the Ni plating/Cu-Sn compound interface (Fig. 6 (c)). The fracture morphology suggests that the strength of the Ni plating/Cu-Sn compound interface is relatively low. This may cause the abrupt degradation in the strength of the soldered joints with the Pd plating after the high temperature holding tests at 398K or higher. In the case of holding temperatures at 348K or lower, the soldered joint with the Pd plating had no Cu-Sn layers and thereby had the high strength. Therefore, if the soldered joint with the Pd plating using the Sn-Zn-Bi solder is exposed to a high temperature environment above 398K, attention should be paid to the joint reliability. In the joint with the Sn-Pb plating, the fracture occurred along the Cu-Sn compound/solder interface or in the Cu-Sn reaction layers that degrade the joint strength during the high temperature holding test as mentioned in 3.1. Thus, the Sn-Pb plating is not suitable for the plating of Cu lead with Sn-Zn-Bi solders.

Of all the soldered joints, the joints with the Sn-Ag plating had less Cu-Sn reaction layers both in as-soldered condition and after the high temperature holding tests. So, this joint had the least data scatter in strength, and had the highest lower limit of the strength in the reliability range ($\mu-3\sigma$) as shown in Fig. 4. Therefore, it is concluded that the Sn-Ag plating is the most feasible plating material for Cu lead among the five kinds of lead plating for the Sn-8Zn-3Bi solder.

3.3 COMPARING Sn-Zn-Bi SOLDER JOINTS WITH Sn-Ag-Cu AND Sn-Pb SOLDER JOINTS

In as-soldered condition, the joints using the Sn-Zn-Bi solder had higher or comparable strength compared to those using the Sn-3.5Ag-0.7Cu and the Sn-37Pb solders except for the joint with the Sn-Pb plating as shown in Fig.4. Figure 7 shows the relationships between the thickness of the interfacial reaction layers and the joint strengths. Although the joints with the Sn-Ag, Sn-Bi and Sn-Cu plating using the Sn-Zn-Bi solder had thicker

interfacial reaction layers than those using the Sn-3.5Ag-0.7Cu, the former had a higher strength than the latter. This is considered to be caused by the difference in the phases formed at the interfacial reaction layers. Thus, while the interfacial reaction layers of the former consisted of the Cu-Zn compounds, those of the latter consisted of the Cu-Sn layers that degrade the joint strength in as-soldered condition.

After the high temperature holding tests, the decreasing rates of the joint strengths using the

Sn-Zn-Bi solder were higher than those using the Sn-Ag-Cu solder, and the joints using the Sn-Zn-Bi had the same or lower average strengths as compared to that using the Sn-Pb solder after the holding test at $398\text{K} \times 7.2\text{Ms}$ (Fig. 4). With respect to the lower limit of the strength in the reliable range ($\mu-3\sigma$), the joints using the Sn-Zn-Bi except for the joint with the Sn-Pb plating had at least the same values as those of the joints using the Sn-Ag-Cu and Sn-Pb solders. In particular, the joints with the Sn-Ag plating using the Sn-Zn-Bi had a higher value than that using the Sn-Ag-Cu solder.

In conclusion, the Sn-3.5Ag plating was found to be most feasible plating for the Sn-8Zn-3Bi soldered QFP joint

5. CONCLUSION

In this study, QFPs with varying plating materials for Cu lead were reflow-soldered on FR-4 printed circuit boards using the Sn-Zn-Bi solder. The microstructural evaluation and the strength of them were examined. The following results were obtained.

In the soldered joints using the Sn-8Zn-3Bi, the γ (Cu_5Zn_3) reaction layers formed at the lead/solder and the solder/pad interfaces in as-soldered condition. The γ layers transformed to the β' (CuZn) reaction layers with the growth of the Cu-Zn layers during the high temperature holding tests. Afterward, the growth of the Cu-Zn reaction layers came to a standstill in the joints. As a result, the Cu_6Sn_5 compound formed and grew as the holding time increased.

Sn-Pb plating

The Cu-Sn interfacial reaction layer grew significantly. This may be caused by a Bi and Pb rich phase that has a possibility to form a liquid phase due to the Sn-Bi-Pb ternary eutectic reaction. Therefore the joint strength degraded after the high temperature holding tests.

Au/Pd/Ni plating

In as-soldered condition, the thinner reaction layer resulted in higher joint strength. After the high temperature holding tests at 398K or higher, the Cu-Sn interfacial reaction layer formed and grew at the Ni plating/Cu-Zn compound interface. Thereby, the joint strength was degraded after the high temperature holding tests.

Sn-3.5Ag plating

The joint exhibited the lower growth rate of the Cu-Sn interfacial reaction layer, which may be caused by dissolving Ag into reaction layer. Therefore, the joint had a higher strength after the high temperature holding tests than the other joints.

With respect to the joint strength, the joints with the Sn-3.5Ag, Sn-3Bi and Sn-0.7Cu plated Cu lead using the Sn-8Zn-3Bi solder had the comparable reliability to that of the Sn-3.5Ag-0.7Cu and Sn-37Pb soldered joints.

Of five plating materials for Cu lead, the Sn-3.5Ag plating was found to be most feasible plating for the Sn-8Zn-3Bi solder with respect to the reliability of the joints after the high temperature holding tests.

REFERENCE

- [1] T. Takemoto, The Fifth SANKEN International Symposium, (2002), p31
- [2] K. Sukanuma et al, J. Mater. Res. Vol.15, No. 4, (2000)
- [3] A. Hirose, T Fujii, T. Imamura and K. F. Kobayashi, Materials Transactions, Vol.42, No.5, (2001) p.794-802.
- [4] T. Imamura, T. Fujii, A. Hirose, K. F. Kobayashi, Proc. 7th Symposium on Microjoining and Assmby Technology in Electronics, (2001), p.481-486.

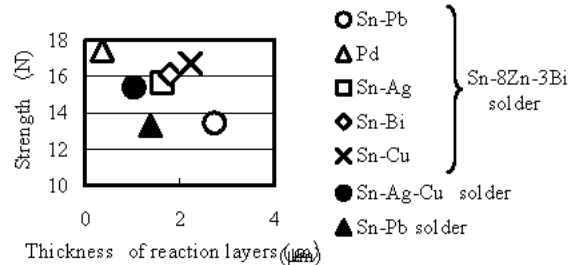


Fig. 7 Relationship between strength of as-soldered QFP joints