Cross-sectional analysis of the interface between Sn-Ag-Cu solder alloy and Substrate by using angle lapping method

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The validity of the application of angle lapping method of investigation of the microstructure between the Sn-3.5wt%Ag-0.75wt%Cu Pb-free solder and substrate has been tried. Some of interface layers were too narrow to analyze the microstructure even using TEM of standard cross sectional analysis. But angle lapping method enabled showing elemental mapping by EPMA because of the apparent width was a few micrometer whose original width was less than 0.1 μ m. The reaction layer formed between Sn-3.5wt%Ag-0.75wt%Cu and Ni-electroless plate was divided two phases composed void rich layer of (Ag,Cu)-Sn phase and another one was Sn-Cu phase. The component analysis of both layer could not be detected by the standard cross sectional analysis. This results indicated that angle lapping method is powerful for the thin area analysis.

1. Introduction

BGA (ball grid assembly) technique has been applied for the high integration and reliability in the semiconductor device. The morphology of the BGA ball bonding have been researched actively since they have remarkable effects on mechanical and physical properties of the bonding. In the BGA process, IC chips are set on the print board and soldered by the heat treatment in the reflow furnace. The each ball structure, strength, electric property and so on are sometimes different even in the same chip and affect the yield rate and reliability.

On the other hand, various Pb free solder has been developed as alternative alloys due to the environmental pollution of Pb[1]. The microstructure analysis of the interface between substrate and solder are also actively investigated by various methods, scanning electron microscope(SEM) and electron probe micro analyzer(EPMA) and so on. But the scale of the interface layer frequently are less than the resolution of the surface analysis facilities. The focused ion beam(FIB) technique[2,3] developed and the transmission electron microscope(TEM) with higher resolution specimens for the cross sectional analysis of the interface layer such as soldering and semiconductor device packaging. But there still are some materials which have smaller structure than TEM performance.

Angle lapping method is one of the unique way of enlarging the small area. The purpose of this study is trying the validity of the application of angle lapping method for investigation of microstructure between the solder and Ni-P electroless plate on the substrate.

2. Experimental Procedure

The Sn-3.5Ag-0.75Cu solder balls with 0.75mm in diameter were used in this study. The Cu pads were covered with Ni-P electroless plating layer with about 4μm and Au vaporize layer with about 0.1μm. The solder ball and pads were bonded in the reflow furnace of BGA process. The Sn-3.5Ag solder balls prepared by BGA process are also used as reference materials.

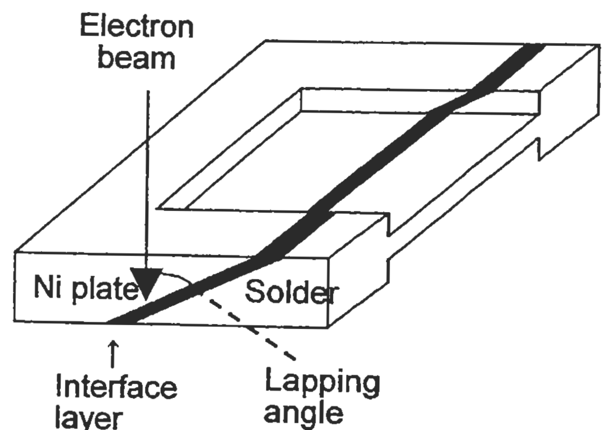

Figure 1. Schematic drawing of the FIB-TEM specimen of the joint of solder and Ni-plate using angle lapping method

Figure 1 shows the drawing of the TEM specimen of the interface layer between solder and Ni plate prepared by FIB utilizing angle lapping method. The "lapping angle " pointed in the figure means the lapping angle against the electron beam. For getting the apparent thickness of the interface layer of about 6 times of the original thickness, the "lapping angle" was set about 80 degree.
The TEM observation was performed by JEM-200CX and EPMA analysis was done by JXA-8900R.

Figure 2 shows TEM micrographs of the typical cross-section image of the interface between plate and solder of a)Sn-3.5Ag and b)Sn-3.5Ag-0.75Cu respectively. The solder parts can be seen only in b) since the interface layer is much thicker in a)

The thinning process has been done by mechanically. Both cutting process for the angle lapping specimen and the final thinning for TEM and EPMA observations were done by using FIB.

3. Experimental Results and Considerations

3.1 TEM observation the microstructure of the interface.

The "Ni_3Sn_4" and "$(Cu,Ni)_6Sn_5$" were deduced by EPMA analysis. There is void rich layer between "Ni_3Sn_4" layer and Ni-P plate as reported by Saka et al[4]. Voids can be seen as white dots in the figure. The origin of the generation of the void rich layer is thought as the Ni diffusion from the plate[4]. The similar layer pointed as the "void rich?" can be seen in b). But it is much thinner than that of a) and the EPMA analysis could not be applied. The analysis of the "void rich ?" layer is the focus of this study and that is the reason why the angle lapping method has been applied.

Figure 3 shows the TEM micrograph of the interface between the solder of Sn-Ag-Cu and Ni-P plate prepared by the angle lapping method. The apparent width of "void rich?" layer became more than 2 μ m and another layer of "$(Cu,Ni)_6Sn_5$" became too wide of the TEM scale. It is impossible to estimate the original width of the interface layer but approximately the "lapping angle" of the interface were more than 80 degree. There were many voids in the "void rich?" layer and they were circular due to the observation direction. The microstructure of "void rich?" layer seems single phase and simpler than that of Sn-Ag alloy.

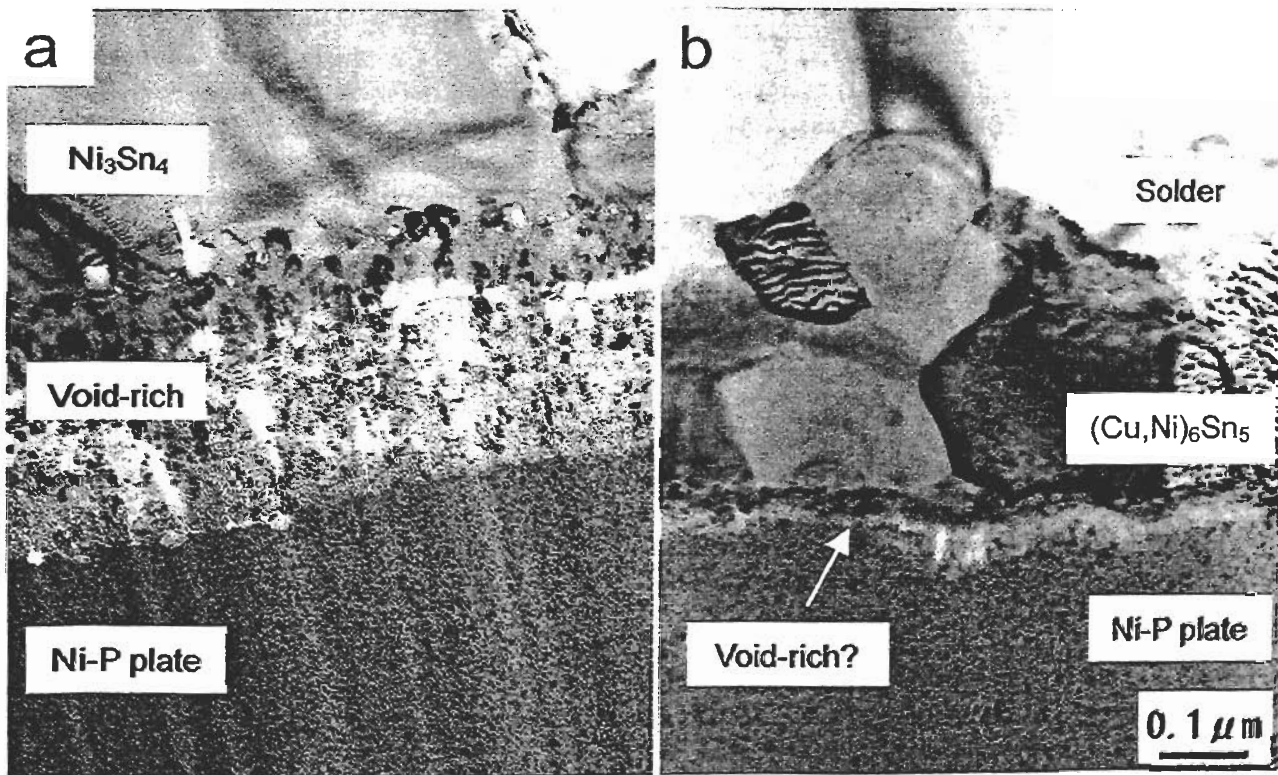

Figure 2. Cross sectional TEM micrograph at the interface between solder and Ni-P electroless plate. The solders are a)Sn-3.5Ag and b)Sn-3.5Ag-0.75Cu alloys and the component of was deduced by EPMA analysis.

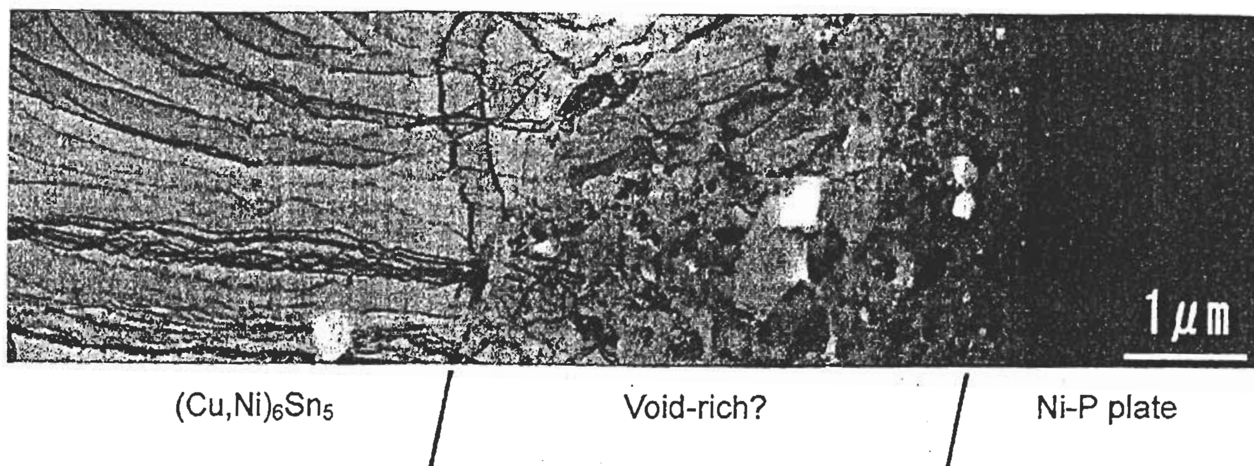

Figure 3. Cross sectional TEM micrograph at the interface between Sn-3.5Ag-0.75Cu solder and Ni-P electroless plate made by angle lapping method.

3.2 EPMA analysis

The interface layer was also analyzed by EPMA because the width of the interface was enough for EPMA analysis. Figure 4 shows the elemental mapping at the interface between solder around the "void-rich?" layer. The 10keV of electron energy was selected because the signals due to the overlapping of each layer were lowest. There were many interesting results. P rich layer was at the edge of the Ni-P plate and not correspond to the "void-rich?" layer. The "void-rich?" layer divided 3 phases, Ag, Cu and Sn rich layer respectively, $(Cu,Ni)_6Sn_5$ layer has low concentration of Cu and Ni. Ag was found in the "void-rich?" layer but not found $(Cu,Ni)_6Sn_5$ layer.

3.3 The interpretation of the results

The overlapping of thin layers has to be noticed in the case of angle lapping because the direction of observation is nearly vertical to the interface. And the "void-rich?" layer is composed by the small crystals which makes difficult to clarify the microstructure.

On the other hand, EPMA analysis gave clear information of the distribution of the components because the depth profile of X-ray emission can be controlled by changing the electron energy. In the case of figure.4, 10keV was best energy to avoid the mixture of the X-ray emission from each layer. These results of detailed information from the thin layers especially inside the "void-rich?" layer could not be taken by standard cross-section analysis. Angle lapping method is one of the powerful way to analyze thin layers.

4. Conclusions

The analysis of the detailed microstructure of the interface layer between the Sn-3.5Ag-0.75Cu solder ball bonded on the Ni-P electroless plate was performed by angle lapping method showed,

(1)The angle lapping method was interesting way to analyze the thin layer such as the interface between solder and substrate especially in EPMA analysis.

(2)The "void-rich?" layer was composed three phases and there were many voids inseide it. This result cannot be taken by standard cross-sectional analysis.

(3)Other layers in both side of "void-rich?" layer could be analyzed more precisely by using angle lapping method.

5.Reference

[1]for example, Mat. Trans, 42-5(2001) "Special Issue on Basic Science and advanced Technology of Lead-Free Electronics Packaging"

[2]Kirk ECG, et al.: Inst Phys Conf Ser,100,501(1989)

[3]Tarutani M, et al, Jpn J Appl Phys, 31, L1305(1992)

[4]Saka H, et al, Proc of spring meeting of Jpn Inst Metals, 141(2002)

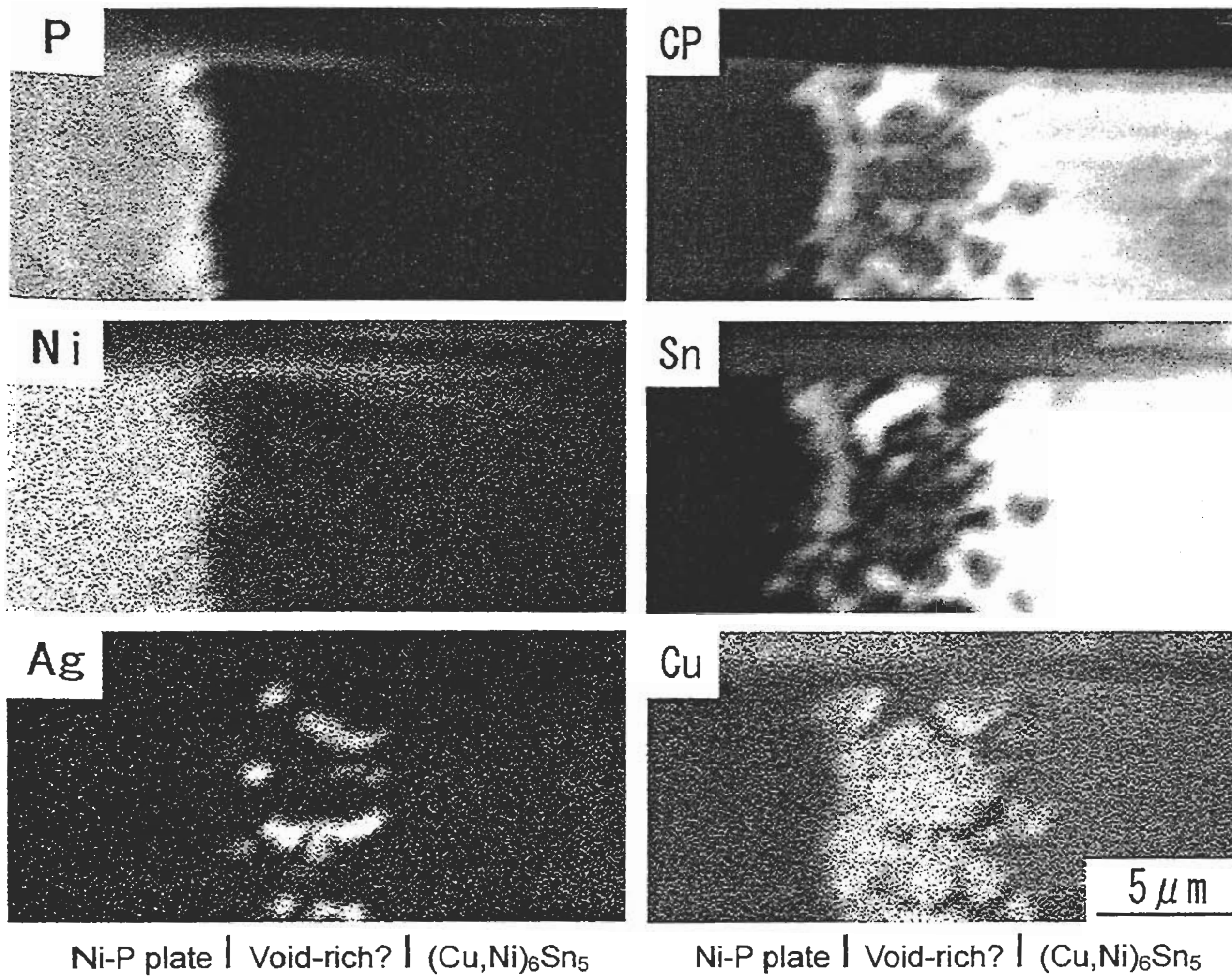

Figure 4. Elemental mapping of EPMA of P,Ni,Ag,Sn,Cu and CP(CP=SEM image) at the interface between Sn-3.5Ag-0.75Cu solder and Ni-P electroless plate. The energy of electron was 10keV.