**Introduction**

SiP (System in a Package) is an indispensable packaging technology for achieving small sizing and high-functionality of mobile equipments. Packaging density of devices used for mobile equipment is ever increasing. For example, it is prospected that the minimum pitch of W/B (Wire Bonding) will be reduced to 20 µm from current 40 µm by 2008 and that the electrode pattern pitch of full grid type CSP (Chip Size Package) will also be reduced to 100 µm from current 150 µm by 2008 [1]. As the pattern pitch is narrowed, the sizes of bonding pad and the land on which a metal bump is placed are also reduced, thus, such failure modes as peeling of W/B, disconnection of metal bumps, imperfect plating and abnormal precipitation from plating have become a serious problem than ever before.

In this paper, we will introduce some examples of failure analysis relating to the defects in electrical connecting and plating that frequently occur in high density packaged electrical devices and also describe applications of various analysis equipments for such analytical use.

**Features of and Comparison Between the Cross Sectional Observation Methods**

The cross sectional observation is a base for analyzing the failure modes in packaged devices. Various methods such as mechanical polishing, Microtome, FIB (Focused Ion Beam) and ion beam processing are utilized depending on respective purposes. Mechanical polishing method is widely utilized because it is possible to observe wide areas and the equipment is not expensive in spite that it requires high-level polishing technique like workman. Especially, when observing the boundary state of intermetallic compound (IMC) and analyzing the composition of material, the mechanical polishing is the most convenient method and it is not technologically impossible to observe the cross-section of ultra-micro bump with a thickness less than 20 µm. Figure 1 shows an image of a cross-section of IMC formed at the boundary between a solder bump and an interposer. Regardless of the kind of Ni-plating, that is, regardless whether it is formed by electroless Ni-P plating or by electrolytic Ni plating, IMC with a composition of Ni$_3$Sn$_4$ at the boundary between eutectic solder is formed, but their forms are totally different. In case of electroless Ni-P plating, the IMC takes a pole-like or needle-like form, while in case of electrolytic Ni plating, it takes a layer-like form. In addition, it is known that in case of electroless Ni-P plating, a P-enriched layer is formed at the surface of Ni-P plating because only Ni element is consumed for diffusive reaction with Sn element. This status can also be clearly observed by the mechanical polishing method.

Since information obtained by mechanical polishing method depends greatly on the polished aspect state, it is impossible to observe and discuss the crystal structure or cracks on the polished aspect on which mechanical damages such as dents remain.

FIB has also been established as one of the cross-sectional observation methods for analyzing the packaged devices because it gives relatively small damages to samples and it is easy to handle. Especially when discussing the metallic crystal structure, channeling images obtained from FIB method gives us very effective information. But, since the area processed by this method is limited to 100 µm in width and 20 µm in depth, it is not appropriate to apply this FIB method to obtain information from wide area of sample. Figure 2 shows the channeling images obtained from various plating conditions. A method for developing the sample with a cross-section using an ion beam processing has been developed recently [2]. Since processing area of CP (Cross-section Polishing) is relatively wide, about 300 µm in width and 200 µm in depth, CP method enables the wider area to be processed flatter and smoother than FIB method, especially effective for pre-processing the sample to obtain a reflected electron image or EBSP (Electron Backscatter Diffraction Pattern).

Figures 3 and 4 show the reflected electron image and EBSP image of Au-ball, respective-ly. It can be observed that the crystal located at the center of the ball became enlarged by thermal stress of bonding process and that fine crystals were formed just under the capillary where a mechanical stress was applied. When processing a sample that simultaneously includes both the soft and hard materials and such metals as Sn and Ag of which etching rate is high with CP method, it should be noticed that beam damage may remain, making observation difficult.

**Identifying the Au-Al Compound**

W/B using a high-purity Au wire is a method for electrically connecting the semiconductor chip to the substrate that holds the chip, and the state of Au-Al compound formed at the boundary between Au-ball and Al-pad is an important measure of reliability of devices. Historically, EPMA (Electron Probe Micro Analysis) method has been utilized for identifying the Au-Al compound. However, since the thickness of compound layer just after bonding process is very thin, it has been very difficult to identify the compound in principle of EPMA measurement. FEAES (Field Emission type Auger Electron Spectroscopy) is good at analyzing a very small area with a diameter less than 1 µm. Accuracy of quantitative determination of AES method is inferior to EPMA method, and it is said that AES method is not adequate to identify the IMC. But, high reliability can be obtained by executing comparative analysis against the standard materials. Figure 5 shows a qualitative spectrum of Au-Al standard compound and Table 1 shows the results of semi quantitative determination that has corrected the relative sensi-

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tivity for Au and Al.

Since, although the relative atomic ratio of Au and Al does not completely coincide with the ideal composition calculated, errors fall in the range of ±few percents, we judged that it is possible to identify the Au-Al compound using this AES method. Figures 6 and 7 show the composition of the compound formed after mold curing and after storage at 200°C for 168 hours, respectively.

The dominated layer after mold curing is Au₅Al₃, and there exists Au₅Al in Au side, Au₁₇Al and Au₅Al in Al side. The dominated layer after storage at 200°C for 168 hours changed to Au₄Al and there exists Au₂Al and Au₅Al₂ remained around the ball. Change of the dominated layer is considered to result because a growing speed of compound by heating is limited to the diffusion speed of Au, and consequently, the Au₄Al as the most Au-rich layer was stabilized. On the other hand, defects are observed in the boundary between Au wire and Au₄Al layer, and since there exists strong Oxygen, it is considered that these defects are traces of compound’s erosion caused by moisture included in mold resin. TEM (Transmission Electron Microscope) observation image of the defect is shown in Fig. 8. Defects are composed of three types of modes, Phase-A, Phase-B and Phase-C. AS shown by EDS profile in Figs. 9 and 10, it became clear that the dominant layer of Phase-B has a composition consisting of only Al and Oxygen without Au, and Phase-C that distributively exists in Phase-B includes Au. Although it has been considered that the erosion of Au-Al compound is generally caused by Al-bromide as the result of a reaction between Br included in mold resin as a fire retarding material and Au₅Al [3].

But, in both of the above described FEAES and EDS methods, the energy positions of Br and Al overlap in the same location, it is impossible to detect the existence of Br. Therefore, we have confirmed the existence of Br in defects by EPMA analysis. Figure 11 shows a EPMA profile. Br was not detected in Fig. 11. Thus, it was suggested that there is a
possibility that erosion is not only accelerated by halogen element, but also promoted by just moisture as well.

**Analysis on peeling-off of electroless Au/Ni-P plating**

Electroless Au/Ni-P plating is utilized for surface finishing of printed wiring boards including interposers.

Since the flash Au plating is formed by a substitution reaction with Ni, when an excess substitution reaction occurs, underlying Ni-P plating layer is pitted by corrosion causing peeling-off ultra-sonic bonding and degradation of the adhesion strength of solder [4].

**Figures 12 to 5** show the AES depth profile and the surface state of Ni-P layer after removing the flash Au, in cases of normal plating and abnormal plating, respectively. In case of abnormal Au/Ni-P plating, P-enriched layer was observed at the boundary between Au and Ni-P, and it was also known that carbon and oxygen exist in Ni-P plating layer. On the other hand, pitting corrosion was observed along the grain boundary on Ni-P surface after removal of Au.

**Figures 16 and 17** show the FIB cross-sectional images of the part where Au plating was peeled off and remained normally, respectively. At the boundary between Au and Ni-P layers, an amorphous layer with 0.2 µm thickness including a micro-void was observed, and it was confirmed that peeling off occurred at the boundary between Au plating layer and the amorphous layer.

Taking account of the state of pitting corrosion on the surface of Ni-P plating layer, AES analysis result and FIB cross-sectional image, we concluded that the amorphous layer is a Au/Ni substitution layer formed by an excess reaction and that the pitting corrosion observed at the surface of Ni-P layer after removal of Au is a trace that an excess reaction took place significantly along the grain boundary. In addi-
tion, the excess reaction resulted from Ni-P layer including carbon. Figure 18 shows an estimated structure of the Au exfoliated part. In order to accurately analyze the concentration distribution of carbon (C), sulfur (S) and oxide (O) of which abnormal eutectoid into Ni-P layer is concerned, we used SIMS (Secondary Ionization Mass Spectrometer) analysis. Figures 19 and 20 show SIMS profiles of the normal and abnormal plating, respectively. The horizontal axis corresponds to concentration gradient in the depth direction. It is known that there is no difference in the concentration distribution of Au, Ni and P as the components of plating between normal and abnormal plating, while the concentration of C, S and O elements included in abnormal plating are higher than that of normal plating.

Then, in order to clear the origin of these impurities, we tried to analyze organic components included in Ni-P solution that was used for processing the abnormal plating taking a standard Ni-P solution as a reference. As for the organic components with high boiling point, we applied GC/MS (Gas Chromatograph/Mass Spectrometer) analysis after solid-phase micro extraction. While, as for the organic components with high boiling point, we applied $^{13}$C FT-NMR (Fourier Transform-Nuclear Magnetic Resonance) analysis after letting the residual material after heating and drying the plating solution dissolved into a heavy chloroform solution. Figures 21 and 22 show the results of GC/MS and FT-NMR analysis on the used solutions.

No volatile components included regardless of the used solutions after bath-plating, and citrate, succinate, EDTA and ureic compound, etc. were detected as non-volatile components. On the other hand, from only the used solution, kinds of polyethylene-glycol-diacrylate, kinds of amino-alkyl-phenon, azobisisobutyronitrile and its resolvent were detected.

It is considered that the organic component detected from the only used solution was...
brought into Ni-P solution and condensed within the bath. And it was estimated that the detected amino-alkyl-phenon, azobisisobutyronitrile and its resolvent originated from radical additive included in resin material. Actually we confirmed the status of Au/Ni-P with and without additive by FIB method and we also confirmed that the state of IMC formed at the boundary between solder and Ni-P plating after attaching the eutectic solder balls. **Figures 23 to 26** show the observed results. In case of Au/Ni-P plating with additive, an amorphous layer accompanied with voids at the surface layer of Ni-P plating was reproduced. And at the boundary between the solder and Ni-P plating, we could reproduce that no Ni3Sn4 compounds were formed.

As described above, it was estimated that the Ni-P plating layer becomes vulnerable and the bonding power of Ni element was weakened because the organic components get mixed in Ni-P solution bath was made eutectoid. Therefore, Ni-element becomes easily to diffuse under the presence of reacting species such as Au or Sn, and it generates an excess substitution reaction in succeeding Au plating process or soldering process, but the effect of kinds of aminophenon and organic components including sulfur element is significant. The result that SIMS analysis detected highly concentrated sulfur from abnormal plating layer corresponds to this idea.

**Conclusions**

We have introduced some examples relating to analysis on plating layer in packaged devices. As packaging technology advances, needs for analysis also becomes higher and more complicated. Today, analysis engineers are required not only to seek analysis technology but also to obtain an ability to give exact advices originated from empirical rules and to give so called “total solution”. Essential demand in the analysis market is moving to consultation from the excellence of operation skill.

**References**

[1] ITRRS2004 Update