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Citation	2026 International Conference on Electronics Packaging and Hybrid Bonding Symposium (ICEP-HBS 2026). 2026, p. 150-151
Version Type	AM
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Characterization for the Bottom Joint of Stacked Micro-Via Integrated in the Substrate by ToF-SIMS and STEM

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Abstract— We investigated the electroless Cu interface layer of stacked micro-via in the substrate. The ToF-SIMS shows the 2D elemental distribution for the main elements, and the 3D distribution for Cl- and S- views, and show their distribution of trace elements can be found inside the Cu electroless plated layer, clearly. The results of STEM characterization also show the main elemental distribution of the bottom of micro-vias, but could not show the trace elements like Cl and S effectively.

Keywords—micro-via, electroless Cu, characterization

I. INTRODUCTION

Integrated circuit substrate technology enables the attachment of semiconductor chips to high-density interconnect printed circuit boards (HDI-PCBs). These boards are built with multilayered interconnects, connected by through-holes and micro-vias. Especially, micro-vias are crucial, and their quality is important for the miniaturization of electronic devices. An electroless Cu-plated layer is formed through chemical reactions with additives and stabilizers, creating a Cu-Cu bonding interface that contains impurities. During the via-filling process, residual organics and other substances remain before the electrolytic Cu plating following the desmear process. Consequently, nanovoids, cracks, or delamination occur, which is known as a reliability issue, “Weak Interface Micro-via [1-2]”. Concerns about micro-via reliability have increased as the diameter of micro-vias continues to shrink, reaching several micrometers, and the risk of failure increases. Therefore, it is important to understand the elemental composition and the nanovoids formed in the electroless layer of the micro-vias embedded in the substrate. We carried out their characterization using time of flight secondary ion mass spectrometry (ToF-SIMS) and scanning transmission electron microscope (STEM).

II. METHOD

We prepared a stacked micro-via structure in a prototype substrate as shown in Fig. 1 (a). using the traditionally used Ni-containing electroless plating process. The specimen for ToF-SIMS characterization was cut into a 15 × 15 mm plate and chemino-mechanically polished first, and then the Xe⁺ Plasma focused ion beam (PFIB) system (TESCAN; Amber-X) was applied to make the polishing surface parallel. Three-dimensionally (3D) ToF-SIMS spectra for ions and clusters were acquired from the area of the above polished surface of the 1st micro-via, as shown by the white rectangle in Fig. 1 (a). ToF-SIMS (M6; ION-TOF) was equipped with a Bi₃²⁺

pulsed ion gun (1st ion gun: 30 keV) as the probe and a Cs⁺ ion gun (2nd ion gun: 2 keV) as sputtering for negative polarity was used to acquire the ion/cluster depth profile.

The specimens for STEM observations were prepared from the cross-sectional specimen and prepared using a FIB with a scanning electron microscope (FIB-SEM; JIB-PS500, JEOL Ltd.). Micro-vias were characterized using a spherical aberration corrected analytical STEM (JEM-ARM200F, JEOL Ltd) equipped with X-ray energy dispersive spectrometry (X-EDS) and electron energy loss spectrometer (EELS) operated at 200 kV.

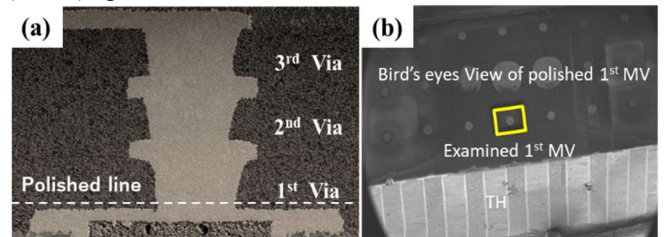


Fig. 1. Secondary electron microscope (SE) images of (a) stacked micro-via and (b) plain polished top surface of the 1st micro-via.

III. RESULTS AND DISCUSSIONS

Fig. 2 shows (a) SE image and 2-dimensional secondary mass spectrometry (2D-SMS) image of (b) total, (c) Cu⁺, (d) C⁺, (e) Ni⁺, (f) O⁺, (g) Pd⁺, and (h) Si⁺ ion, respectively. The bright contrast indicates that the signal intensity for each ion or cluster is high, meaning their abundance is also high. The Cu⁺ ions in (c) appear bright in the micro-via region, while the C⁺ ions in (d), O⁺ ions in (f), and Si⁺ ions in (h) appear bright in the resin region, respectively, because they are the primary constituent elements. A similar tendency can be observed for Cl⁺ ion, though this element is an impurity element and its content remains quite low (less than 0.1%) even within the resin portion. Ni⁺ ion in Fig. 2 (e) and Pd⁺ ion in Fig. 2 (g) exhibit brighter near the micro-via-resin interface, which is the electroless Cu plated layer. Although the electroless Cu plated layer is processed roughly 300 nm, it is distributed widely compared to its intrinsic thickness, due to the roughness of the resin surface. It should be noted that a similar tendency is observed for Cl⁺ ion and S⁺ ion. Nevertheless, they are trace elements or impurities. ToF-SIMS measurement can show the distribution of S⁺ ion, Cl⁺ ion, and any other ions.

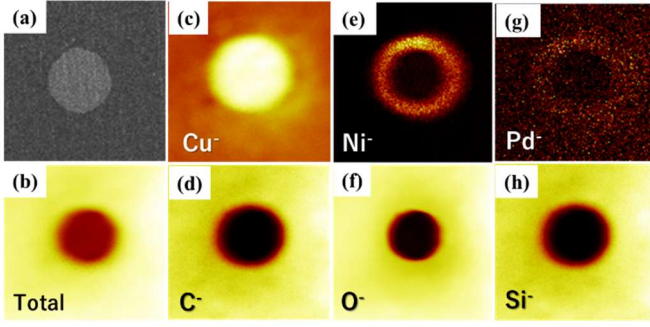


Fig. 2 (a) SE image and 2D secondary mass spectrometry image of (b) total, (c) Cu^+ , (d) C^- , (e) Ni^- , (f) O^- , (g) Pd^- , and (h) Si^- , respectively

Fig. 3 shows Bird's eyes view SMS images of (a) Cu^+ , (b) Cl^- , and (c) S^- ions. These 3D images allow the spatial distribution of each ion to be visually captured. (a) shows Cu^+ , clearly illustrating the micro-vias in 3D. The trace element Cl^- is distributed within the resin, but its concentration is slightly higher near the interface. S^- exhibits a similar pattern, though its concentration within the resin is lower than that of Cl^- . It should be noted that its concentration is particularly high near the interface between the electroless copper layer of the micro-via and the resin. At the micro-via bottom, it shows a distribution corresponding to the etching profile during via processing, exhibiting high concentration in this region.

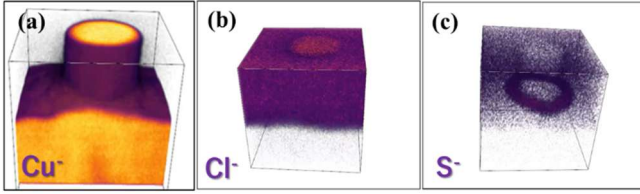


Fig. 3. 3D SMS images of (a) Cu^+ , (b) Cl^- , and (c) S^- ions.

Fig. 4 shows STEM-EDS mapping of the interface layers of the micro-via. in the electroless Cu layer. Fig. 4 shows a HAADF-STEM image of (a), the elemental maps of (b) the Cu-K line, (c) the Ni-K line, (d) the Pd-L line, (e) the C-K line, (f) the O-K line, along the interface of the electroless Cu layer. The electroless Cu layer is clearly distinguished in the Ni-K line map in (c) because the Ni element is usually added only to the electroless Cu layer. A very small amount of Ni was added to the plating process to reduce the internal stress of the electroless Cu layer and to enhance its reaction speed. The distribution of Pd L-line in Fig. 4 (d) shows the bottom interface because the electrolytic Cu plated pad was covered with Pd catalyst ions. This indicates that at least the nanovoids are formed at the early stage of the electroless Cu plating along with the surface of the electrolytic inner Cu plating layer, and the Pd is related to forming the nanovoids. However, it should be noted that we can see the Pd concentration in the map in the low magnification map. This means that the Pd catalyst is not necessarily uniformly dispersed in uniform sizes on the inner Cu surface. Elemental maps of (e) the C-K line, (d) the O-K line exhibit low intensity. This can be considered that the signals and background are comparable, considering they are almost background signals. From previous TOF-SIMS measurements, the electroless Cu plating layer contains more C, O, S, Cl, and some trace elements than the electrolytic Cu

plating layer, but their concentrations are quite low.

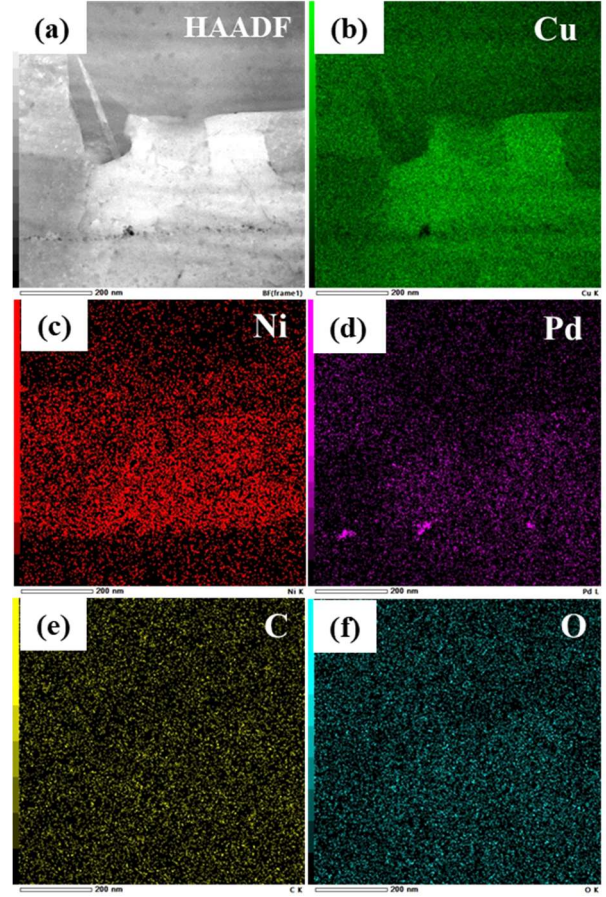


Fig. 4. (a) HAADF-STEM images, and the elemental mapping image of (b) Cu-K line, (c) Ni-K line, (d) Pd-L line, (e) C-K line, (f) O-K line, of the bottom interface of micro-vias.

IV. CONCLUSION

The 2D SMS images of ToF-SIMS for stacked 1st micro-via embedded in the prototype substrate show the elemental distribution for the main element and the 3D SMS images for Cl^- and S^- views also show their 3D distribution, inside the Cu electroless plated layer, clearly. The results of STEM characterization also show the main elemental distribution of the bottom of micro-vias, but could not show the distribution of the trace elements effectively.

V. ACKNOWLEDGMENT

A part of this work was supported by the Comprehensive Analysis Center of SANKEN, and "ARIM Project of the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT), Grant No. JPMXP1222OS0038" at the Research Centre for Ultra-High Voltage Electron Microscopy in Osaka University.

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