Shave-Off Profiling for TEM Specimens

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Abstract

This work aims to compare the results from the same specimens between shave-off profiling and TEM image. For the cross-check analysis, a specimen was picked up from a part was failed integrated chip (IC) package that may have suffered electrochemical migration. Critical disagreement between the results was found in the gradient curve of the shave-off profiling from the anode to the cathode. In each package, shave-off profiling revealed a faint gradient curve on migrated ions that could not be revealed from TEM image.

Keywords: shave-off profiling, cross-check with TEM, failure analysis

1. Introduction

In this study, we aimed to cross-check the same specimen, the same part and the same piece by using TEM imaging and shave-off profiling. The introduction of different analytical methods allows one specimen to be clarified from different and multiple angles. Agreement of the cross-check analysis provides reliability for each experimental result, whereas disagreement reveals the possibility that something has been overlooked in the other analytical results.

Cross-check analysis is usually carried out on the same specimen but at different points. For failure analysis, it is indispensable to cross-check the same specimen and the same point. We introduce two different analytical methods: TEM, which provides a projected image of the nanostructure with almost no damage, and shave-off profiling, which can reconstruct elemental distributions but the specimen completely disappeared. We have cross-checked the TEM specimens against the shave-off profiling specimens.

2. Shave-off profiling

2.1. Shave-off depth profiling

Shave-off depth profiling has basically originated from shaving process with a focused ion beam (FIB) and secondary ion mass spectrometry (SIMS). The volume of the specimen for shave-off depth profiling is almost the same as that prepared for TEM. Both specimens are micromachined and picked up with the FIB microsampling technique. The only difference is the thickness of the microsampled specimen. A thickness of the order of submicrometers is suitable for TEM specimens, while shave-off profiling specimens are typically several micrometers thick [1].

Figure 1 shows the shave-off depth profiling procedures. At first, a piece is picked up from the surface of the specimen by the FIB lift-up technique (1, 2). The piece is then placed on another substrate, and the substrate and specimen are tilted so that they are parallel to the axis of focused beams (3). The FIB then shaves off the specimen layer by layer (4), generating secondary ions that are mass-separated and monitored as a function of depth. Shave-off depth profiling is able to be applied to almost all solid state materials, even for rough structures and heterointerfaces.

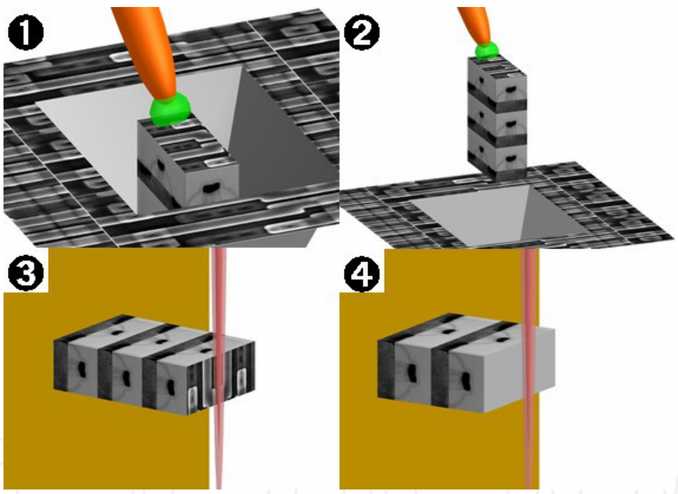

Figure 1. Schematic sequence of shave-off depth profiling

Detailed features of shave-off depth profiling have been noted in our previous paper [2]. The nanobeam SIMS system was significantly modified for shave-off depth profiling purposes [3].

2.2. Shave-off vector profiling

In respect to shave-off depth profiling, the "depth" only has meaning for the shave-off directions of specimen. The shave-off direction can be controlled by rotating the field of view, and the approach of "shave-off vector profiling" is a powerful technique for depth-profiled SIMS.

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This study is focused on the lateral distribution of electrochemically migrated elements within a semiconductor package. All semiconductor packages are consisted of fillers, carbon black particles and resin. When the semiconductor packages are exposed to high-temperature, high-moisture conditions, metal elements on chip electrochemically migrate into the resin or onto the semiconductor chip board [4]. For failure analysis, the distribution of the migrated ions provides important information. Ion diffusion phenomena to the resin have been studied by using time-of-flight SIMS [5]; however, such depth profiling over a wide area dilutes true local information about failure points. Shave-off depth profiling has been used successfully to visualize the migration of Cu ions from electrodes into the resin within a point of failure [6]; the profile projected a distribution of migrated Cu ions to the depth direction.

The distribution of the migrated ions between the anode and cathode also provides important information about how electrochemical migration occurs between the electrodes. In this study, the shave-off direction was vectored to be that in the direction from the anode to the cathode.

3. Experiment

In the test semiconductor packages, chips are packed with silica fillers, carbon black particles and resin. The surfaces of test chips are mounted on Cu electrodes (10 μm line and space each reputational width) and Ti thin films (40 nm). Pairs of electrodes were biased in high-temperature, high-moisture conditions (10 V, 400 K, 85% relative humidity). Some semiconductor packages began to display unusual conductivities within 400 h. Electrochemical migration may have occurred in failed semiconductor packages. A piece including the electrodes, fillers, carbon black particles and resin was picked up in the FIB microsampling chamber (FB-2000; Hitachi High-Tech. Co. Ltd.). The piece had a thickness of 1 μm, which is slightly thick for TEM samples but sufficient for shave-off profiling. Figure 2 shows a scanning ion (SI) image of the piece. Fillers appear as dark contrast in the SI image. Rectangular regions of bright contrast indicate the Cu electrodes (left: anode; right: cathode), which are seated on the Si oxide (band of dark contrast) grown on the Si wafer. The Ti film plays the role of binding material between the electrodes and Si oxide layer.

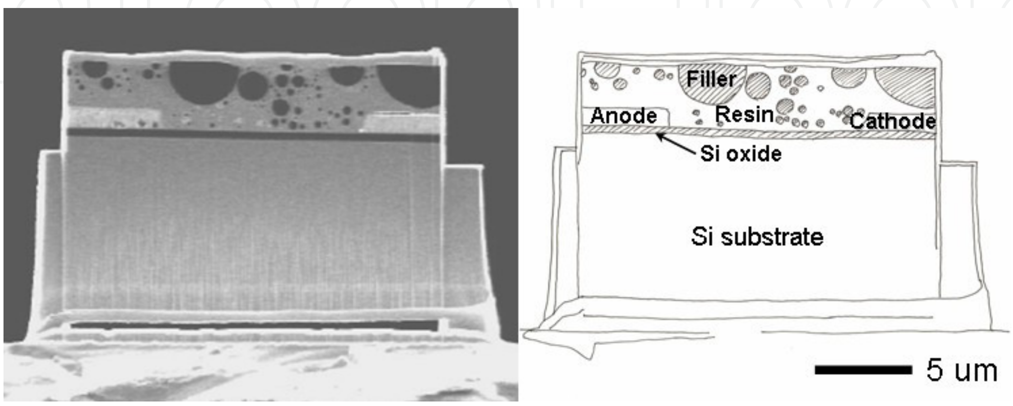

Figure 2. SI image (left) and sketch (right) of pick-up piece from failed semiconductor packages by FIB

The piece was manipulated in the TEM chamber (HD-2000 HITACHI High-Tech) and obtained secondary electron (SE) and TEM images. The specimen along with the substrate was then transferred to the nanobeam SIMS apparatus. The experimental conditions on shave-off profiling were as follows: an FIB potential and current of 24 kV and 35 pA, respectively, and total profiling time of 60 min for a 12 μm^2 area. Quick scanning started on the left (anodal region) and proceeded to the right (cathodal region) in the SI image.

4. Results and discussion

Figure 3 shows TEM bright-field image and SE image of the same piece picked up from a failed package. The TEM image reveals the whole volume of the piece. Comparing the SI and SE images reveals that the filler patterns are different. This difference arises from the different surfaces of the piece.

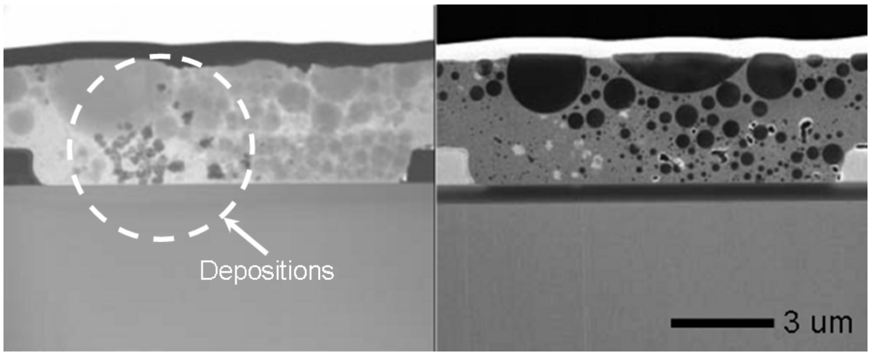

Figure 3. TEM bright-field image (left) and SE image (right) of the same specimen picked up from a failed package (both regions are the same)

In the STEM image, the rectangular regions indicating the anode (left) and cathode (right) appear in dark contrast, which is opposite to that in the SIM image. Small circular regions of dark contrast can also be observed in places between both electrodes. This dark contrast can indicate deposits from migrated material.

The spatial resolution of the shave-off profiling is estimated to be at most 40 nm for multilayers [7]. Electrochemical migration may occur in the field between the anode and cathode (10 μm width); the width of this field is wide compared to the spatial resolution. Figure 4 shows the shave-off vector profile of the as-prepared IC package. There are silent Cu^+ion signals between both electrodes. A faint tail, which could come from the memory effect, can also be observed; this point is discussed in another paper [8].

Figure 5 shows the shave-off vector profile and the corresponding TEM image of the same area. We see that the positions of the electrodes and depositions agree with the shape of the Cu^+profile and position of the dark contrast. Critical difference is found with the gradient curve of the shave-off vector profiling between the anodal region and cathodal region. The intensity of the gradient curve is high compared to the faint tail in Fig. 4 and may have its origin in

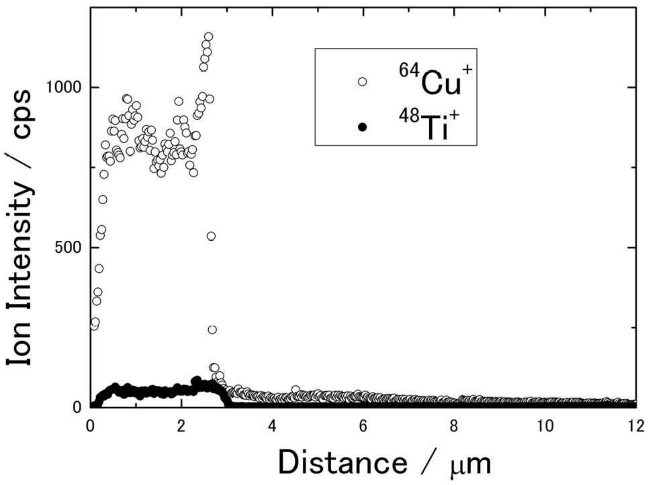

Figure 4. Shave-off profile of Cu electrode and Ti thin film in as-prepared IC package

electrochemical migration. Generally, the ionization probability of an oxide or complex is much higher than that of the elemental metal. It is possible that the high ionization probability of Cu^{+}ions amplifies the existence of electrochemical migration. In the same piece, shave-off profiling was able to visualize a migrated-ions distribution that could not be observed by TEM imaging. From these results, we emphasize that the advantage of shave-off profiling is the highly selective detection sensitivity especially for ions that have migrated into a package.

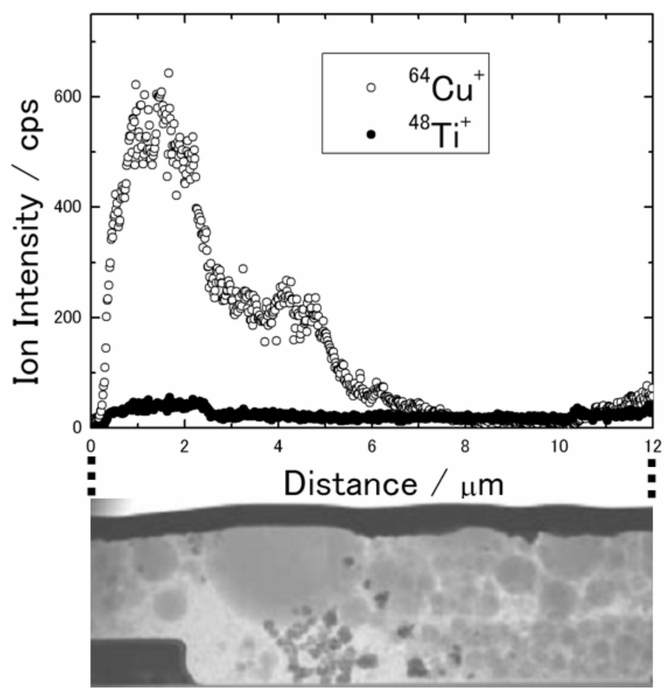

Figure 5. Cross-check analysis of semiconductor package that had undergone electrochemical migration (upper: shave-off profile; lower: TEM image)

5. Conclusions

We have cross-checked images of TEM specimens against shave-off profiling results and introduced a new approach to shave-off vector profiling. The results showed good agreement between the distribution of the electrodes and depositions. Critical difference was found with the gradient curve of the shave-off profiling from the anode to the cathode. In the same piece, shave-off profiling can be used to visualize a faint gradient of migrated-ions that could not be observed in TEM image.

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