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Thermal approach of defects generation on copper/organic dielectric interface due to SEM inspections

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Abstract

Scanning electron microscopy (SEM) sometimes induce defects on samples during imaging. We study in this article the thermal effects of SEM views on the Cu/BCB interface, in focused ion beam (FIB) cross sections. Electrons can lead to local thermal power dissipation due to their deceleration and create delamination. A TEM lamella sample preparation method was also found to avoid this kind of delamination. In this case, the thermal dissipated power could be reduced due to the fact that a big part of the incoming electrons could go through the sample without interactions. Several thermal simulations (2D/3D) were carried out to estimate the field of temperatures under electron beam and to explain the Cu/BCB interface delamination.

1. Introduction

The scanning electron microscope (SEM) remains the most versatile instrument of the physical and failure analysis laboratory. When an electron beam runs into the surface of a sample, it generates many interactions: secondary/back scattered electrons, X-rays photons, etc. [1]. However, electrons flow is not easy to estimate: an important part of the incoming electron beam can go through the sample or accumulate in the volume. This accumulation leads to charging phenomena and local potential variations which are often associated to difficulties to image the sample (especially for non conductive materials). In the worst cases, they could generate "uncontrollable defects" like electrostatic discharges in thin oxide layers.

However, SEM induced defects sometimes appear progressively on samples during imaging, without any visible instability during scanning. In our failure analysis laboratory, we often observed such defects on cross sectioned samples made of electrolysis copper embedded in bisbenzo cyclo butene (BCB). BCB is a low k organic layer with good electrical properties for specific electronic applications. The main defect observed during SEM imaging is a progressive crack opening (delamination) at the Cu/BCB interface. Short experimentations showed that this delamination was not dependant on the cross section preparation. However, we observed a high dependence of the delamination dimensions to the SEM acceleration voltage (V_{acc}) and time of exposition to the electron beam. Figs. 1 and 2 show the delamination increase for high voltage acceleration and long exposition time to electron beam.

This kind of delamination always appears without charging phenomena and with relatively low V_{acc}. So electrostatic and irradiation phenomena were not considered. Thermal effects due to the incoming beam are suspected. Electrons indeed can lead to local thermal power dissipation due to their deceleration after collision with the surface and current flow. The aims of this publication are to estimate the thermal power effects due to electron beam on cross sectioned sample during SEM image and to propose a specific sample preparation to avoid this phenomena.

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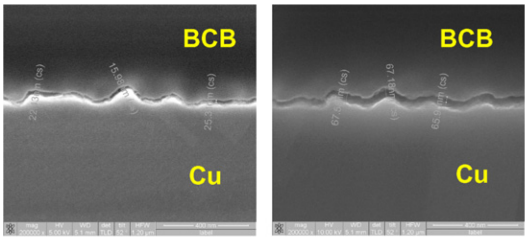

Fig. 1. Delamination @ 5 kV (left) and 10 kV (right) after 15′.

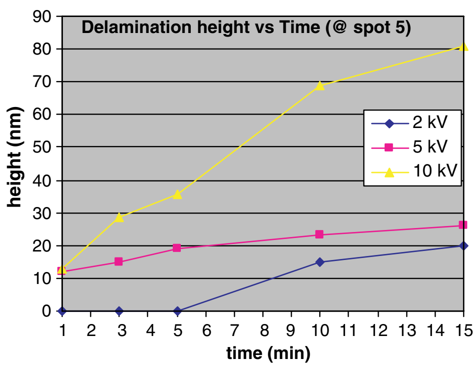

Fig. 2. Influence of V_{acc} on delamination height.

2. Materials and methods

2.1. Equipments

FEI Dual Beam NOVA 600 NANOLAB was used for the study of delamination (production + observation). This tool has an electron column with a cold emission source (FEG) and a gallium focus ion beam (FIB) column. For all FIB cross sections, a protective layer of tungsten was deposited before making a cross section to preserve the top layer.

In-situ thermal measurements were performed with SEM FEI XL 40, equipped with a thermo ionic source and in/out electrical connections.

These 2 tools allow V_{acc} from 1 kV to 30 kV with 7 spot sizes for each tension. The vacuum chamber is in a range of 10^{-6} mbar. They also enable in-situ sample current measurements (FEI options).

2.2. Sample preparation

We used a sample with a glass substrate made of electrolysis copper embedded in BCB organic layers. All samples were stuck on a stub with silver paint then coated with a PVD platinum metallization (10 nm). This procedure avoids charge effect on BCB surface and allows a good electrons flow.

Cu/BCB delamination was studied for different SEM parameters on several FIB cross sections. All FIB cross sections were always performed with the same parameters. They were performed in 2 steps with specific ion beam current (20 nA for the regular cross section and 1 nA for the cleaning step).

Two techniques were used for TEM lamella sample preparation [2]. The first one is based on the use of 2 FIB back-to-back cross sections cuts nearly abutted (see Fig. 3). In this case, final TEM lamella thickness is below 500 nm.

The second one is the H-Bar method which requires 2 steps (see Fig. 4). First, the region of interest is firstly sawed to reduce the sample thickness around 100 μm. Then, the sample is mounted on a TEM copper grid. Finally, this pre-lamella is introduced in the FIB for final thinning and polishing. This preparation removes all interaction behind the TEM lamella. Here, the final thickness is variable.

2.3. Thermal measurements and simulations

A type T thermocouple was used to measure temperature under the electron beam within the FEI XL 40 chamber. Thermocouple type T is made with two wires of 200 μm diameter (one in copper, the other in copper/nickel alloy). The two materials were welded at the extremity (the welding area has a diameter of 500 μm). A small hole was done with FIB in order to trap secondary/backscattered electrons generated during observation and to collect the full probe current like a Faraday cage.

Several thermal simulations (2D/3D) of electron beam spot interactions were carried out with SDEVICE software (SYNOPSYS). The thermal power (calculated from acceleration voltage and beam current) and the dissipating area (spot size) are the 2 mains parameters. Specific boundaries conditions were used to represent the real sample in the SEM environment. The room temperature is always 295 K.

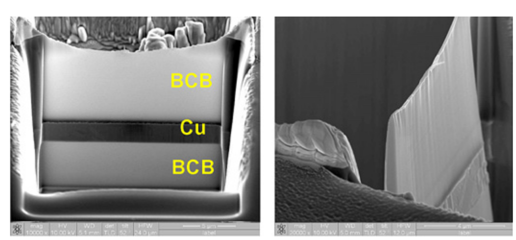

Fig. 3. SEM views of the TEM lamella.

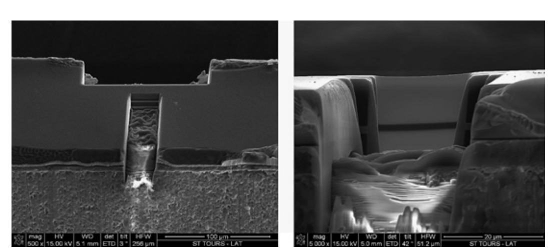

Fig. 4. H-Bar SEM views.