Electron tomography characterization of voids in a 30nm wide copper line after electromigration test

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One of the reliability issues encountered with copper interconnects is electromigration leading to the formation of voids and resulting in an increase of the resistance of the copper lines / vias [1]. Electromigration is a displacement of the copper induced by the electrical current. The aim of this paper is to characterize voids in a Cu line after electromigration test by electron tomography [2].

A group of nine 30nm wide and 150µm long copper lines with a pitch of 120nm are embedded in a low-k material. Only the central active line has been electrically stressed leading to the formation of voids. A 1.5 nm TaN/Ta barrier is present on the trench sidewalls and bottom as confirmed on images taken across similar metal lines. The TEM specimen is prepared by FIB (Strata, FEI) with the lift-out procedure in such a way that an electrically active and a dummy line are parallel with and in the TEM specimen. It is known that FIB milled Cu samples oxidize during air exposure and with time the copper moves out of the lines [3]. TEM specimens containing copper are therefore usually observed as soon as possible after the FIB preparation. In this case, the lines are narrower than the thickness of the TEM specimen and fully embedded in the low-k material preventing the oxidation of the copper. In order to minimize diffraction contrasts, the tomography image series is taken in HAADF-STEM mode. Au beads deposited on the TEM specimen are used as fiducial markers for the alignment of the image series. The specimen is mounted on a single tilt tomography holder (2020, Fischione) with the line length parallel with the tilt axis (fig. 1b). The acquisition of the image series from -73º to +73º (1º increment) is performed with the Xplore3D software (FEI); the alignment of the images and the simultaneous iterative reconstruction technique (SIRT, 20 iterations) with the Inspect3D software (FEI).

TEM and HAADF-STEM images of the voids are presented in the fig. 1a and b, respectively. Due to the presence of copper of both lines at the level of the voids in the thickness of the TEM specimen, it is not possible to deduce from these images the shape of the voids. The thin layer exhibiting a brighter contrast at the bottom of the Cu lines on the HAADF-STEM image (fig. 1b) is the TaN/Ta metallic barrier. This layer is also present on the sidewalls of the trenches but not distinguished for this TEM specimen orientation. The variation of contrast in the height of the lines observed on the TEM and HAADF-STEM images is due to the sloped sidewalls of the lines as can be observed on figure 3. Along the lines contrast changes on the HAADF-STEM image are due to the line width roughness that results in varying projected Cu thickness. Slices of the 3D reconstruction through the middle of both lines are presented in figure 2. Large voids and nano-voids are present in the electrically active line (fig. 2a, 3b and 4) whereas not in the dummy line (fig. 2b and others). The Ta/TaN barrier, exhibiting a bright contrast, is clearly observed at the bottom of the dummy lines (fig. 2b) and next to the voids area whereas not under the large voids (fig.2a). It might indicate that the formation of voids is related to the integrity of the barrier. The copper is rougher in the electrically active than in the dummy line. The metallic barrier is not observed on the sidewall of the Cu lines on the perpendicular slices (fig. 3). During the acquisition of the image series, the barrier at the sidewalls does not strongly contribute to the contrast due to its small projected thickness; it can therefore not be observed in the 3D reconstruction. Moreover the resolution of the reconstruction is poor on these sidewalls due to the missing wedge effect. The voids are present at both sides of the electrically active line (fig. 3b and 4b) with a narrow copper path in between. Several voids separated by copper walls are present in the electrically active line (fig. 2a, 3b and 4b).

Many information that were not obtained from the conventional TEM/STEM imaging modes, are retrieved from the tomographic analysis.

References

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[4] The authors acknowledge their imec colleagues involved in the processing of this sample.

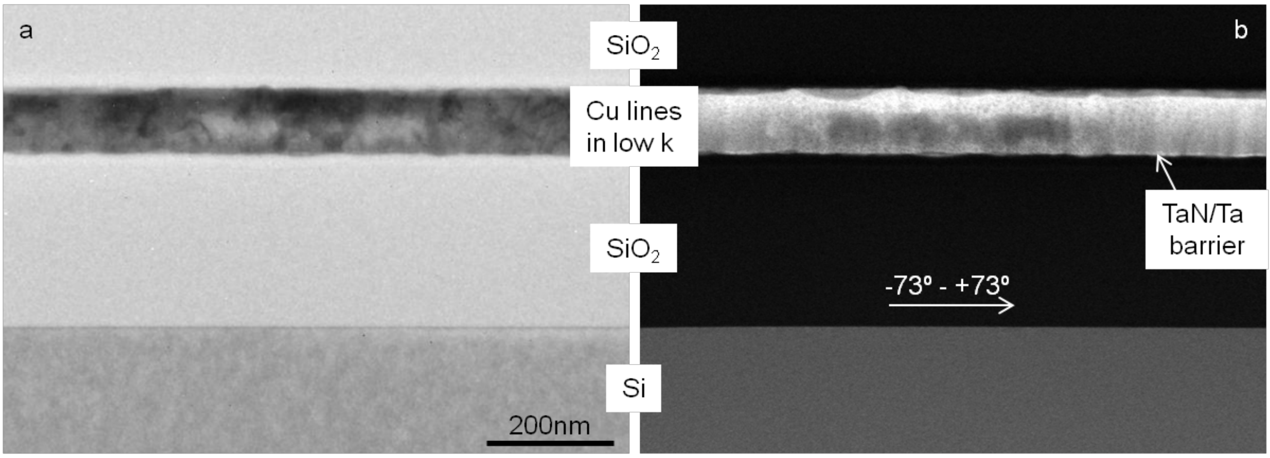

Figure 1. *Cross-section TEM (a) and HAADF-STEM (b) images of voids in copper lines.*

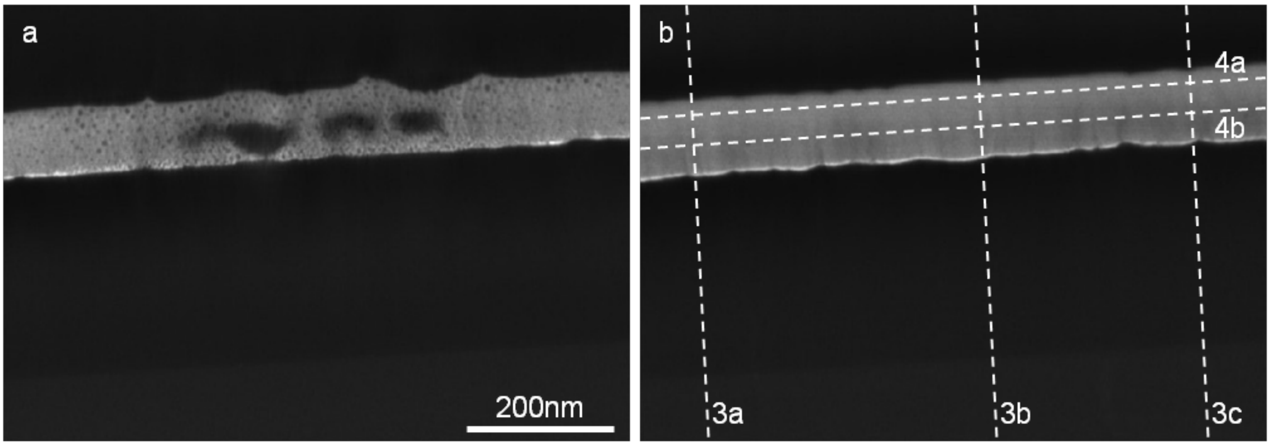

Figure 2. *Slices from the SIRT20 reconstruction coming from the centre of the electrically active line (a) and of the dummy line (b). See figure 3c for the localization of these slices.*

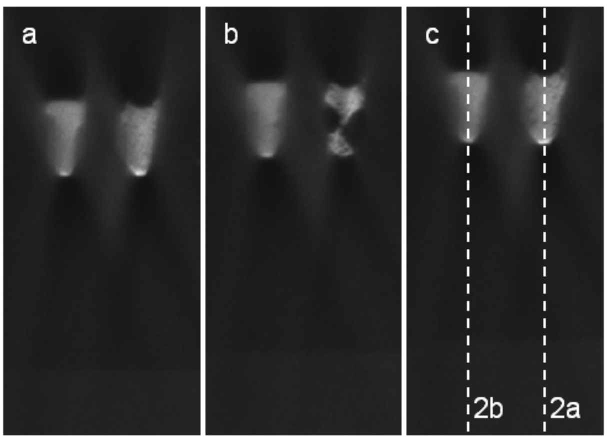

Figure 3. *Slices from the SIRT20 reconstruction showing the cross-section of the lines. The location of these slices is shown in figure 2b.*

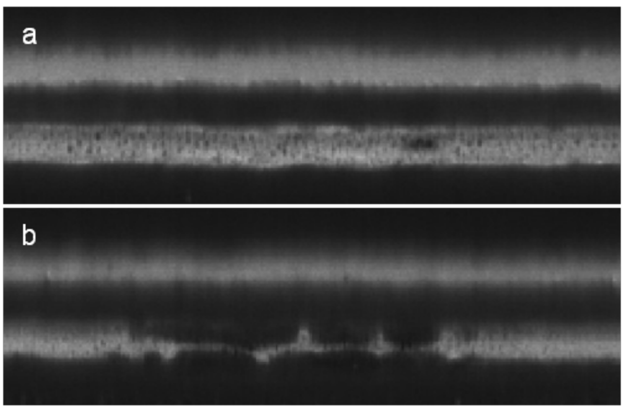

Figure 4. *Slices from the SIRT20 reconstruction taken across the lines as shown in figure 2b.*