Poster

AFM and TEM analysis of after-BD changes on thin SiO_2 layers.

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Dielectric breakdown (BD) of ultrathin SiO_2 gate oxide layers of MOS devices is one of the major concerns for present and future microelectronic technologies. Therefore, many works have been devoted to study the BD phenomenon. Due to its extremely local nature (it occurs in areas of ~100nm^2 [1,2]), scanning probe microscopy based techniques (as Conductive Atomic Force Microscope, C-AFM [2,3]) can provide more detailed information of the breakdown process. As an example, in [3] it was observed that when a BD event is triggered at one oxide location, besides the increase of current (related to the loss of the oxide dielectric properties), in some occasions, changes in the surface morphology are also registered, whose characteristics depend on the measurement conditions (as the spring constant of the cantilever and the AFM operation mode). The topography features were analyzed with a KPFM (Kelvin Probe Force Microscope, which, simultaneously to the topography, measures the contact potential difference) to determine their origin [3]. The results indicated that the BD event induces some trapped negative charge in the affected area (called from now on BINC), which leads to an electrostatic interaction between the tip and the negative charge trapped in the oxide. This electrostatic force, only sensed at the BD region, provokes the modification of the tip position, leading to the measured features. Therefore, the results showed that the topography features are due, at least partially, to the presence of BINC at the BD spot. However, real modifications of the oxide morphology cannot be ruled out [4]. Any modification of the oxide surface could be masked by the features originated by the electrostatic interaction between the tip and BINC. In this work, we have combined AFM with TEM experiments to study the oxide morphology of the broken down region.

The experiments were performed on MOS structures (3.5nm thick oxides thermally grown on a n-doped Si substrate) with a polysilicon gate that has been removed with a wet etching to perform the experiments. The bare oxide has been electrically stressed with the tip of the C-AFM until BD is triggered. Afterwards, the BD spot has been scanned with the C-AFM (in contact mode) to measure the topography and current images. The BD spots have been also analysed with TEM using different modes of operation, to investigate the presence of morphological changes in the area affected by the BD event.

Fig. 1 shows (a) the topography and (b) the current image of an oxide region where a BD spot was induced with the tip of the C-AFM. Note that a large topographical feature (~2.4 10^5nm^2) is observed at the BD position (Fig. 1.a), in agreement with the results reported in [3]. Simultaneously, the current image (Fig. 1.b) shows larger currents (300pA, which corresponds to the saturation of the measurement electronics) than those obtained in fresh areas, as expected. To investigate if the topographical changes registered in Fig. 1.a can be partially due to the presence of real changes in the oxide morphology, the same BD spot studied with AFM has been analyzed with TEM. The results are shown in Fig. 1.c-e. Fig. 1.c. corresponds to the TEM image obtained using the Bright Field Mode, whereas Fig. 1.d. and e. correspond to the EFTEM (Energy filter TEM) images obtained at filtering energies of 36 and 55eV. The TEM image in Fig. 1.c. shows a change in the oxide morphology. However, it also reveals that the area morphologically affected by the BD event (with a size of ~2 10^4nm^2) is smaller than the features obtained during C-AFM experiments. The technique, when used in EFTEM mode, can provide details of the chemical nature of the morphological changes. Fig. 1.d. shows the EFTEM image obtained at an energy of 36eV, which corresponds to the energy loss of SiO_2. After subtracting the SiO_2 background, the image shows that, in the area affected by the BD event, the observed hillocks can be related to SiO_2. Fig. 1.e. shows an EFTEM image of the same spot when a filtering energy of 55eV is used. Again, changes in morphology are observed, but much smaller than those registered in Fig. 1.a. The filtering energy used corresponds to Pt, Ir or Co (the resolution is not high enough to discern between them) which indicates that one of these metals is present on the surface. Since Si tips coated with Co/Cr where used for the C-AFM experiments, the metal deposited on the sample can be Co. Therefore, the results demonstrate that the changes observed in the AFM topography images are a consequence of a combination of both, the electrostatic interaction between the tip and the sample and the real modifications of the surface morphology. However, the lasts are smaller, pointing out that the electrostatic interaction is the dominant effect controlling the C-AFM topography changes.

To sum up, although the presence of BINC can alter the C-AFM topography images due to the electrostatic interaction between the charge trapped in the oxide and the tip of the AFM, TEM images show the existence of real morphological changes of the oxide surface. The EFTEM analysis suggests that the chemical nature of these changes can be a combination of SiO_2 and some residual metal deposited from the tip on the sample. However, the TEM features are smaller than those measured with the C-AFM. This suggests that the C-AFM features are actually a combination of both, the real morphological changes and the BINC induced ones.

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Figures:

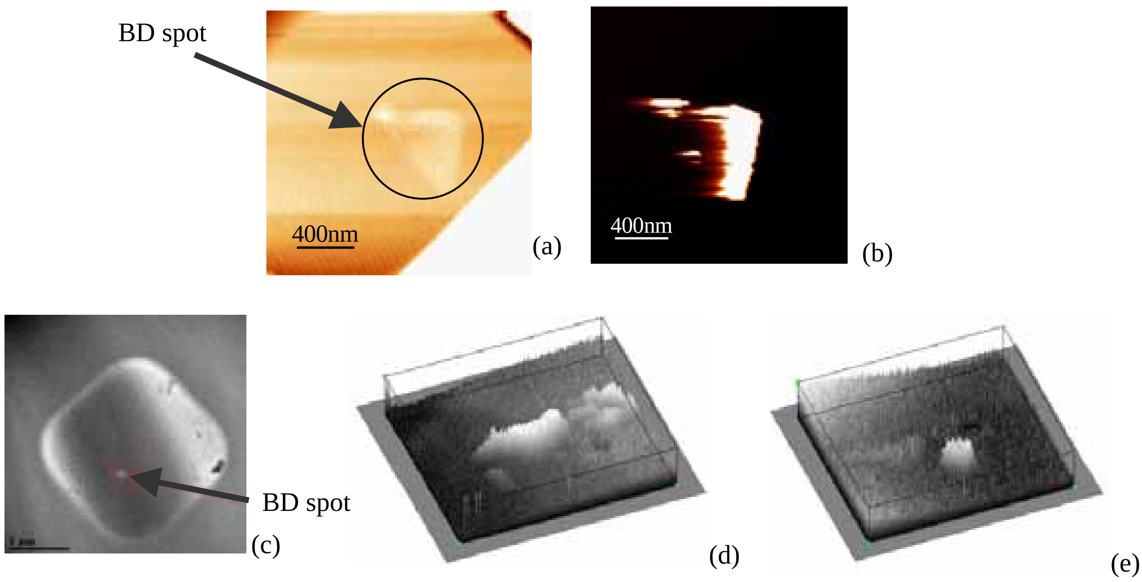

Fig. 1. (a) topography and (b) current image of a BD spot obtained with a C-AFM (contact mode). (c) The same spot has been characterized with TEM (Bright Field Mode) and the results demonstrate that real changes in the oxide morphology are present in the surface, although smaller than those measured with C-AFM. (d) and (e) correspond to EFTEM images of the same spot, which show that these morphological changes can be due to the presence of SiO_2 and residual materials of the tip of the C-AFM.