Influence of Vacuum Environment in Conductive AFM measurements on advanced MOS Gate dielectrics

L. Aguilera[1], W.Polspoel[2], M.Porti[1], W. Vandervorst[2], M.Nafria[1] and X.Aymerich[1].
[1]Dept.Eng. Elect., Universidad Autónoma de Barcelona, 08193 Bellaterra, Spain.
[2]IMEC,Kapeldreef 75, B-3001 Leuven, Belgium.

Lidia.Aguilera@uab.es

In the recent years, the Conductive Atomic Force Microscopy (C-AFM) has become a very useful technique in the study of the electrical properties of CMOS gate dielectrics at the nanoscale [1-3]. When scanning with the C-AFM technique, the tip gets covered by contaminants (water and hydrocarbons) and loses its conductivity and resolution. This effect is even worse with high-k devices [4,5]. To avoid problems involving anodic oxidation and tip contamination, one possibility is to measure in a controlled ambient. In this work, a setup has been built and tested to study the effect of the environment ambient in the conductive AFM measurements on gate dielectrics.

The vacuum system consists of a commercial C-AFM mounted on a chamber which can reach a pressure of $3{\bullet}10^{-5}$ mbar. The set-up can measure a maximum current of 10pA. In this condition, bipolarity measurements with SiO_2 and high-k samples have been performed and evaluated. The samples consist on SiO_2 (2nm ISSG on top of n-type Si) and high-k stacks (HfSiO 80%Hf with 700˚C and 1000˚C of annealing) provided to test the system. Measurements with the same C-AFM but in air ambient have been also performed to compare the effect of the environment. Figure 1 shows the IV mean characteristics measured in a SiO_2 sample with the two environments. A shift in the onset gate voltage (voltage needed to measure current just above the noise level) is observed between the two IVs (5V in air and 4V in vacuum). In order to explore this behaviour, current maps have been done by scanning the sample's surface at a constant tip-substrate voltage. The first scans of each sample (fresh dielectric) can be compared to check the initial local conductivity. Here, the amount of current spots (spots of locally higher current), the average and total spot area, and the current magnitude provide insight about the initial local conductivity of the layers. As can be observed from figure 2 , for the same sample but a lower voltage, the amount of leaky spots is bigger in the current map measured in vacuum (figure 2a) than in air (figure 2b) , in agreement with the results presented in figure 1.A possible explanation of this behaviour is a reduction in the layer (water or contaminant) which forms on the tip during the scan. The same kind of experiments has been performed in high-k films to study the loss of conductivity that usually occurs when scanning the surface. To do that, consecutive current map scans on the same area have been done to study the electrical degradation of the layer due to electrical stress. The changes in the amount, area and current magnitude of the spots can be linked to charging and degradation of the layer. Figure 3 shows the consecutive current images obtained during 5V scans measured in vacuum on a high-k sample with 1000°C annealing. The number of leaky spots observed in the current map increases with every new scan and the conductivity in not lost as in figure 2. The same experiment has been performed in air and the conductivity of the tip has been lost after the first scan, so that leaky spots cannot be distinguished anymore. A loss of resolution can also be observed during the scan in air.

As a conclusion, the results show that vacuum environment for CAFM measurements allow for longer tip lifetime and lower onset voltage. This new set up can be used to study different parameters of the high-k materials with more accurate results.

References:

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Figures:

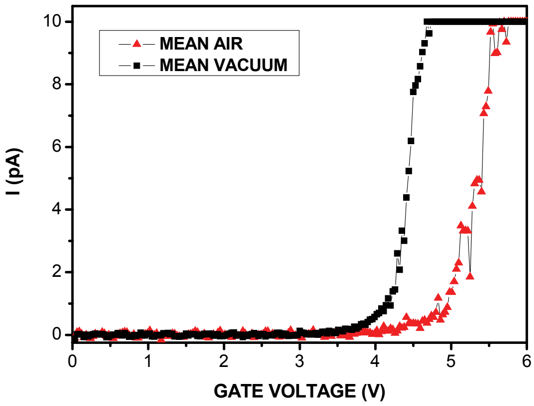
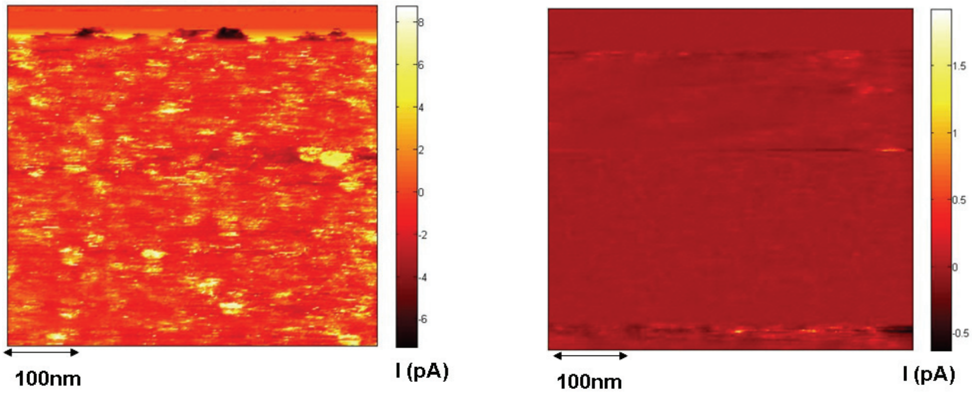


Figure 1.Average of several IV characteristics of a 2nm SiO2 sample measured in vacuum and air ambient.



(a) ***(b)***

Figure 2. Current maps measured at constant gate voltage of 4.5V in vacuum (a) and 5.8V in air (b) ambient in SiO_2 samples. Measurements in vacuum show better results.

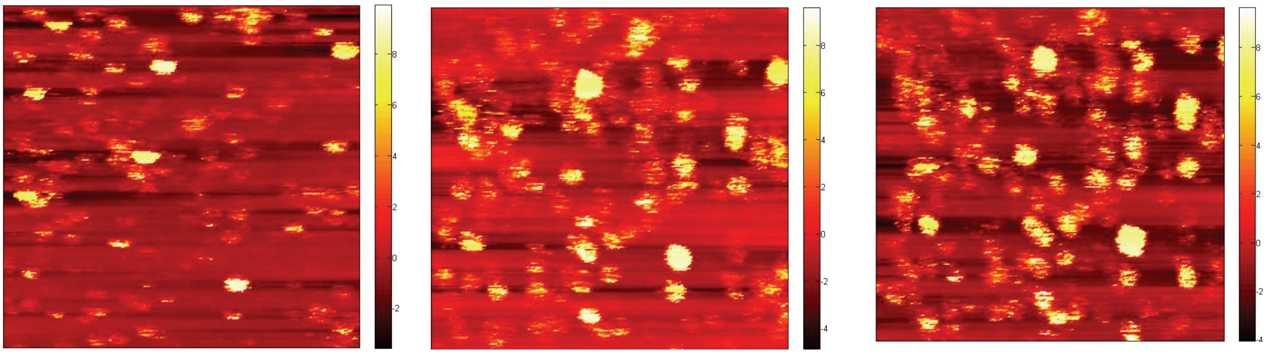


Figure 3. Consecutive current maps at 5V on the same area of a high- k sample. The measurements were performed in vacuum. The same experiments can not be reproduced in air without loss of tip conductivity.