The Influence of Surface Preparation and Probe Configuration on the Reliability of Work Function Measurement using Kelvin Probe Microscopy

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The electrode Work Function (WF) is a key parameter which defines the electrical characteristics of major devices such as the MOSFET threshold voltage (Vth) and the optimization of Metal/Insulator/Metal capacitors. For the 45 nm gate-width and below, the standard polysilicon electrodes of MOSFETs are expected to be replaced by metals in order to suppress high resistance and double depletion phenomena. To solve those issues, new metals deposition processes such as Atomic Layer Deposition (ALD) technique as well as metal WF engineering are under investigation [1,2]. Thus, the understanding of the impact of deposition processes on both metal WF value and its variations within the layer becomes an important issue in the development of advanced devices [3].
Based on charge-transfer cancellation between a metal coated AFM tip and the sample connected as a capacitor, Kelvin Force Microscopy (KFM) is a spatially resolved technique (50 nm) well suited to characterize local WF variations on metal layers with a sensitivity of about 5 meV. We have reported elsewhere, WF mappings at the decananometer scale using KFM on various metal layers to study the impact of the deposition process on the electrical properties of the devices [4]. This approach, which is a variation of the well known Kelvin Probe technique [5], can be operated at both normal pressure or in UHV. However KFM is sensitive to environmental artefacts when operated in air [6].
In this paper, we report on the influence of the environmental conditions to the image contrast using KFM to image the WF of polycrystalline metals. We demonstrate that the WF is related to the grain orientation as observed on Cu layers (figure 1) [4]. However, the measurement contrast decreases as the relative humidity (RH) increases, as confirmed by successive KFM measurements performed on the same area at different RH values. This behaviour is associated with the contribution of the surface to the bulk WF [7]. Therefore, to obtain a reliable WF value, it is important to maintain the RH value as low as possible while scanning.

Secondly we investigate the effect of the surface oxidation on the WF measurement. It has been demonstrated using X-ray Photoelectron Spectroscopy that $WSi_{2.58}$ layers fabricated using ALD show the presence of only a Si oxide after annealing. The WF change with the surface oxidation of the sample is analysed. KFM measurements are performed on 15-nm-thick $WSi_{2.58}$ layers both before and after annealing. In addition, measurements are performed both with and without HF cleaning. The WF of the tip is determined using a reference sample (Pt layer). Figure 2 shows the WF obtained from $WSi_{2.58}$ samples both with and without the presence of a surface oxide. The reliability of the measurements is confirmed by the low dispersion in the values of an AlCu test sample. For the $WSi_{2.58}$ layers, the WF value is higher for annealed layers than for the as deposited ones. After HF cleaning to remove the surface oxide, the WF values are lower, as expected from an oxide-free material. These results show that the extracted WF value depends on the chemical composition of the sample surface, therefore careful specimen preparation is required to avoid surface artefacts.
It is well known that the tip aspect-ratio limits dramatically the spatial resolution of the KFM. To solve this issue, we have deposited on a commercially available tip a high-aspect-ratio tungsten needle, using an electron beam induced deposition process. First results obtained from the measurement of copper lines show a contrast enhancement of about 70% using these new tips.

References:

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Figures:

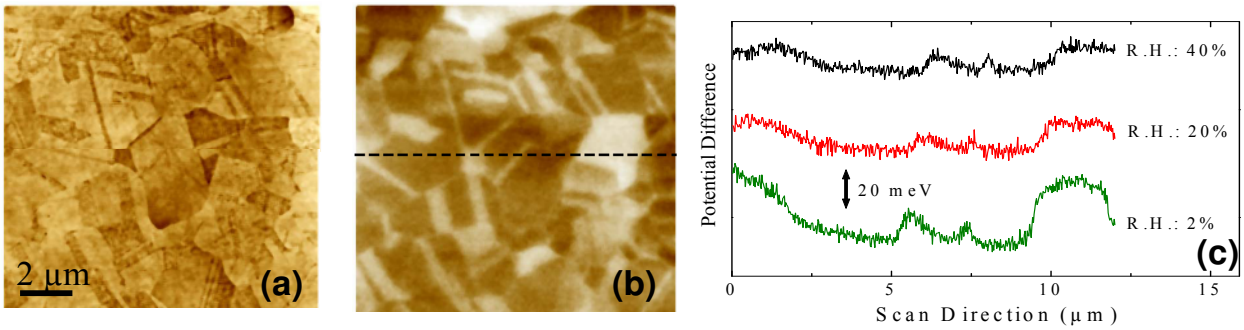

Figure 1 – (a) Surface topography of the copper layer (Zscale= 10 nm), (b) measured potential on the same area and (c) potential profile along the dashed line for three RH values.

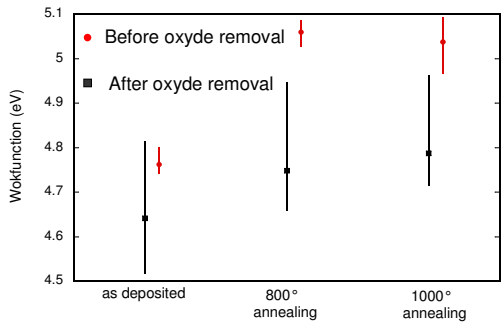

Figure 2 – Evolution of Work function measure by KFM (reference set on a platinum layer at 5.3eV) for three different samples of $WSi_{2.58}$ material (thickness = 15 nm) deposited onto silicon dioxide (thickness = 200 nm). For each sample, analysis has been done both before and after oxide (top surface) removal (dip FH 1%, 15 s). Error bars are reported for a set of 10 measurements with two tips (same tips used before and after oxide removal)

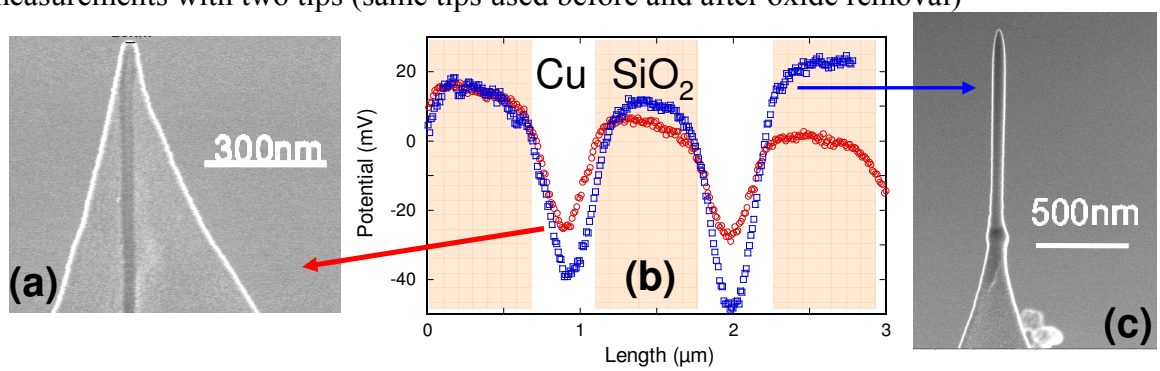

Figure 3 - (a) Conventional PtIr tip, (b) Potential measurements with tip shown on and 3-a (red circles) ad figure 3-c (blue squares), (c) W EBID needle deposited on a conventional tip.