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Coupling Electronic Holography and Finite-Element Based Simulation to Measure Electric Fields into Nanocapacitor.

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Electron holography is one of the few techniques capable of measuring electric, magnetic and strain fields at the nanoscale [1, 2, 3]. Therefore, coupled with in-situ biasing experiments, electron holography has the potential to become a powerful technique to measure electric fields in microelectronics devices during working operation. However, we first need to show that measurements can be performed quantitatively in *operando* conditions, beginning with model systems. Experimental results need to be compared with modeling that takes into account factors such as specimen geometry, focus ion beam (FIB) damage, stray fields and charging [4]. Using finite element method (FEM) correlated to experimental data, we will show how to extract quantitative data in model nanocapacitors, but also real devices, studied under *in situ* biasing.

Nanocapacitors were prepared for TEM observations with a gallium-source FIB (Helios ThermoFisher), placed on a chip and inserted in a dedicated biasing holder (Hummingbird). This method avoids the problems associated with contacting the sample with a nanotip [5]. Operando experiments were performed with the I2TEM microscope (Hitachi HF3300-C) operating at 300 kV whilst applying different bias to the samples. In order to improve the signal-to-noise ratio, extremely long exposure times were used (up to 30 mins) through dynamic automation for interferometric fringe and sample stabilization [6]. A dedicated electrical setup was developed, including wiring and software control, to avoid electrostatic discharges (ESD) that can destroy the tiny nanocapacitors. Holograms were processed on-line during experiments using HoloLive! (HREM Research Inc.) and post-processed with dedicated in-house software.

The link between the experimental data and the simulation is made by the phase shift ϕ^E acquired by an electron passing through an electrostatic potential V :

$$\phi^E = C_E \int V(\mathbf{r}) dz$$

where C_E an energy-related constant and z the direction of the electron beam. The electron acquires a phase shift not only when it traverses the sample, but also within the stray field that inevitably surrounds the biased sample. FEM was therefore used to model the electrostatic potential in and around the sample, using a commercial software (COMSOL Multiphysics). In addition, conducting layers were included into the model to take into account the effect of surface damage layers introduced during the FIB sample preparation.

Parameters were first adjusted manually and then algorithmically using Trust region reflective method in an iterative way to fit with the experimentally measured phase shift. The fit process allows us to estimate the real bias applied to the nanocapacitors and to obtain information on the presence of conductive layers on the surface. Results for the nacapactor and real devices will be presented and the errors analysed [7].

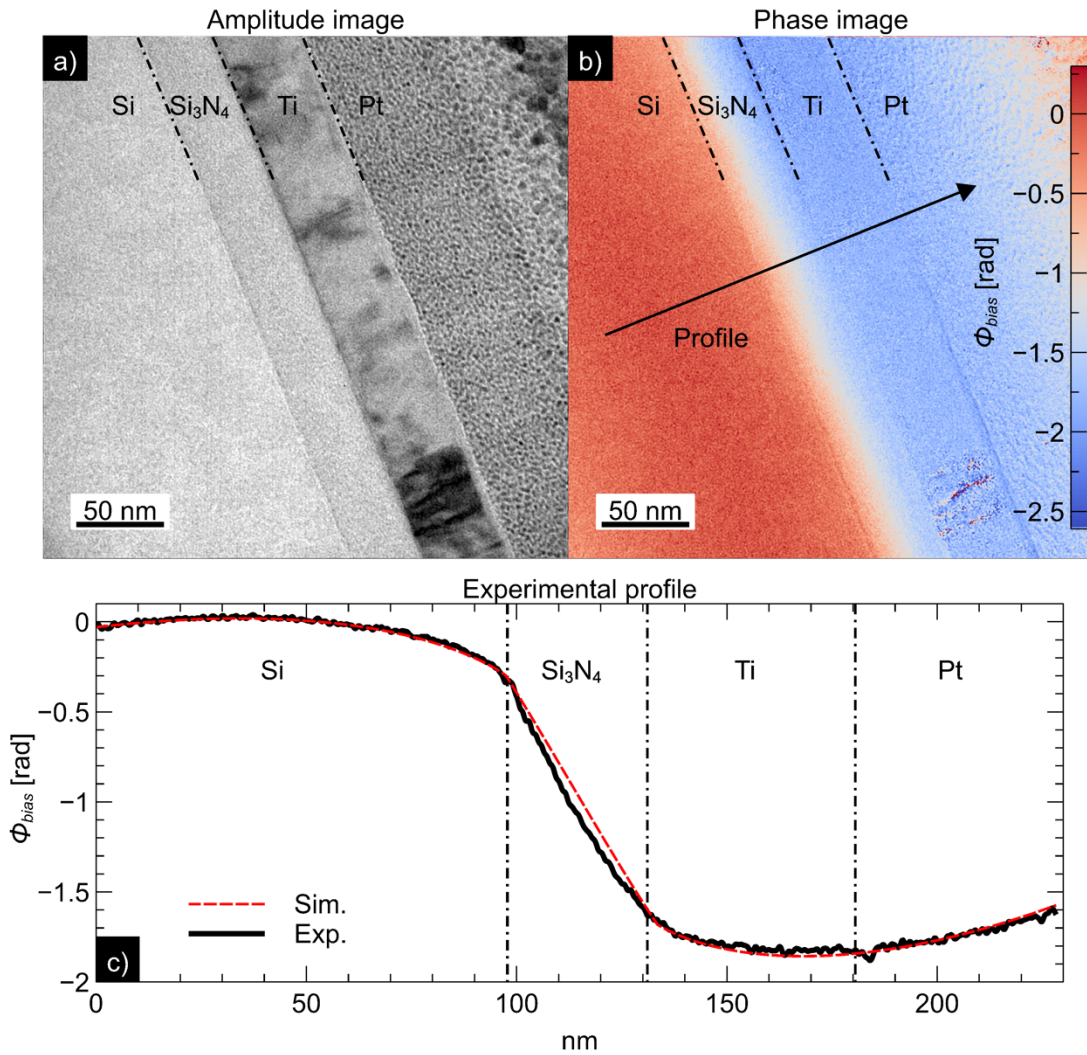


Figure 1. a) Nanocapacitor structure observed by TEM. b) In-situ hologram of the -4V biased nanocapacitor in the same location of the TEM image. c) Profile on the phase image and the simulation that fit with the best parameters.

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