doi:10.1017/S1431927622008753
Microsc. Microanal. 28 (Suppl 1), 2022

Coupling Electronic Holography and Finite-Element Method Simulations to Measure Electric Fields in Nanocapacitors.

Kilian Gruel[1], Raphaël Serra[1], Leifeng Zhang[1], Aurélien Masseboeuf[1], Martin J. Hÿtch[1*] and Christophe Gatel[1,2]

[1.] CEMES-CNRS, Toulouse, France.
[2.] Université de Toulouse, Toulouse, France.
* Corresponding author: martin.hytch@cemes.fr

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 simulations that take into account factors such as specimen geometry, focus ion beam (FIB) damage, stray fields and charging [4]. Using finite element method (FEM) and automated fitting procedures, we will show how quantitative data can be determined from experiments on working nanocapacitors 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. To determine the effect of electrical biasing, the phase of holograms recorded with both electrodes grounded was subtracted from the biased hologram phases.

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*:

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

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 the trust-region reflective method [7, 8] to fit the experimentally measured phase shift. The automatic fitting 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 nacapactior and real devices will be presented and the errors analysed [9].

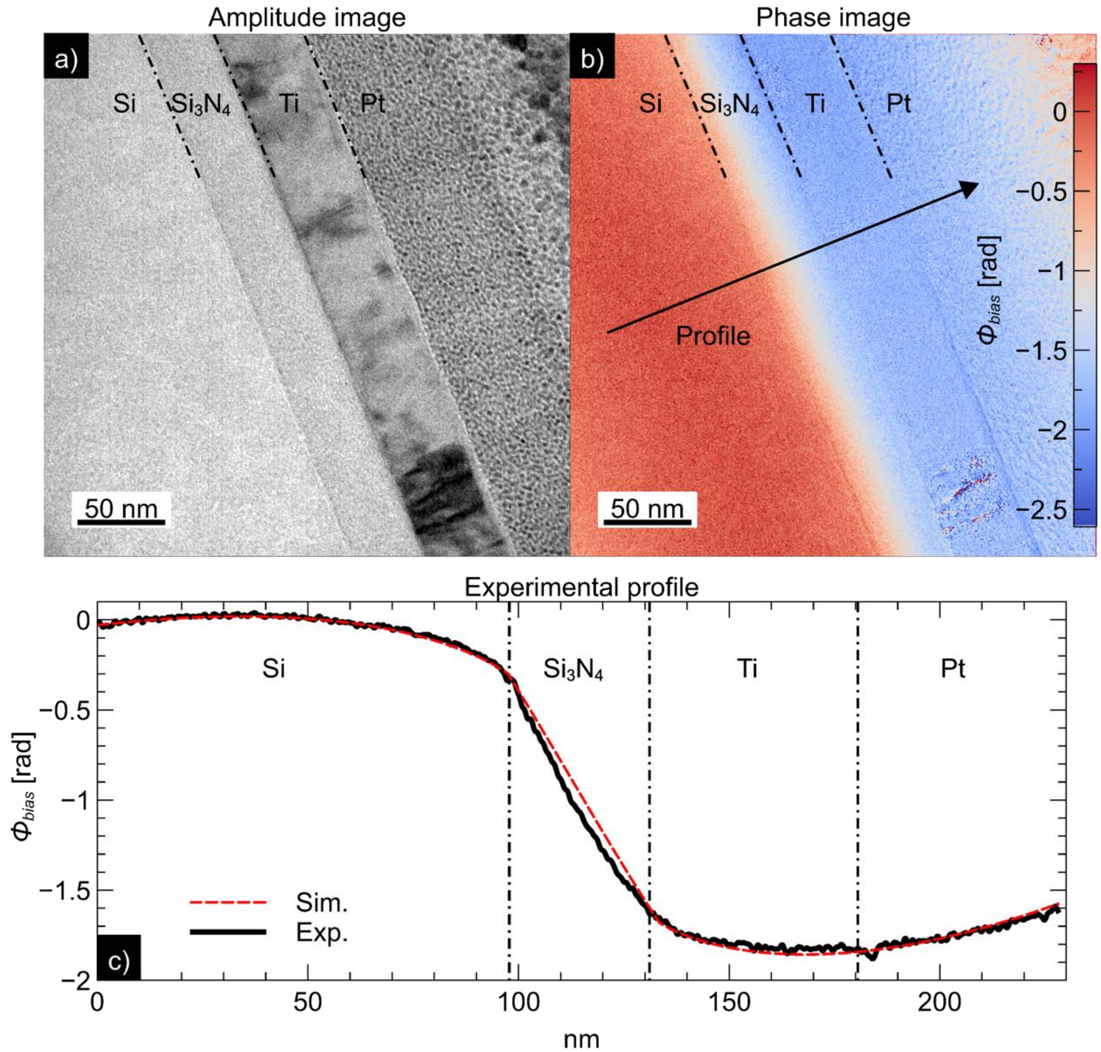

Figure 1. Operando electron holography of model nanocapacitor: a) FIB-prepared specimen device b) corresponding hologram phase due to biasing at -4V, corrected for 0V phase ; c) Profile across experimental phase image (full line) and best-fitting simulation (dotted line).

References:

[1] AC Twitchett, RE Dunin-Borkowski and PA Midgley, Phys. Rev. Lett. 88 (2002), p. 238302. doi: 10.1103/PhysRevLett.88.238302
[2] S Yazdi, T Kasama, M Beleggia, MS Yekta, DW McComb, AC Twitchett-Harrison and RE Dunin-Borkowski 152 (2015), p. 10. doi: 10.1016/j.ultramic.2016.07.016

https://doi.org/10.1017/S1431927622008753 Published online by Cambridge University Press

[3] C Gatel et al., Nano Lett. vol. 15 n° 10 (2015), p. 6952- 6957. doi: 10.1021/acs.nanolett.5b02892
[4] M Hÿtch, F Houdellier, F Hüe, et E Snoeck, Nature vol. 453 n° 7198 (2008), p. 1086- 1089. doi: 10.1038/nature07049
[5] M Duchamp et al., Resolut. Discov. vol. 1 n° 1 (2016), p. 27- 33. doi: 10.1556/2051.2016.00036
[6] C Gatel, J Dupuy, F Houdellier, et MJ Hÿtch, Appl. Phys. Lett. vol. 113 n° 13 (2018), p. 133102. doi: 10.1063/1.5050906
[7] P Virtanen et al., Nature Methods vol. 17 n° 3 (2020), p. 261-272. doi : 10.1038/s41592-019-0686-2
[8] MA Branch et al., SIAM J. Sci. Comput. Vol. 21 No. 1 (1999), pp. 1–23. doi: 10.1137/S1064827595289108
[9] This work was supported by the French national project IODA (ANR-17-CE24-0047). The research leading to these results has received funding from the European Union Horizon 2020 research and innovation programme under grant agreement No. 823717 – ESTEEM3.