Type of presentation: Oral

IT-11-O-3089 Electrical charge quantification by electron holography

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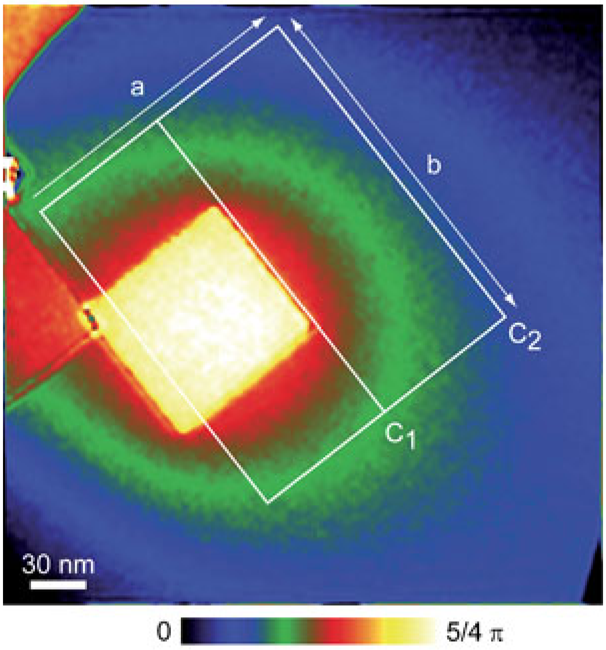
The distribution and movement of electrical charge are fundamental to many physical phenomena, particularly for applications involving nanoparticles, nanostructures and electronic devices. However, there are very few ways of quantifying charge at the necessary length scale. Beyond providing structural and chemical information at the atomic scale, TEM can also determine the electrostatic field at the nanometer scale with a dedicated technique known as electron holography (EH).

We recently developed a new quantitative method to count the elementary charges with a precision of one elementary unit of charge using aberration-corrected EH [1]. We achieve this by applying at the nanoscale the elegance and power of Gauss's Law to phase images extracted from holograms. This method provides direct access to the total charge enclosed by a given contour without assuming further details about neither the position of the charges within or outside the field of view nor the material investigated, contrary to a model-based approach where the whole electrostatic potential has to be computed. The extra sensitivity is achieved by the high signal-to-noise of aberration-corrected instruments and our new methodology. We performed a statistical analysis to reveal the relationship between the size of the contours and the precision of the charge measurement. A dedicated software has been developed for performing the charge evaluation based on line integration.

We will present different examples to illustrate the principle and the precision of this method. Among them, we will show the charge measurements on different MgO nanocubes where we determined a surface distribution of these charges with the corresponding value due to the surface states or adsorbates acting as charge traps (Figures 1 and 2). Another example will concern the in-situ field emission of a biased carbon cone nanotip (CCnT) [2]. The CCnT was placed to a defined distance from an Au-anode plate. We then ramped up the voltage between the nanotip and the anode from 0 to 95 V until the electric field around the tip was strong enough to allow the electrons to tunnel through the barrier and a field emission current could be acquired. During the voltage ramping and the field emission, holograms were recorded at each voltage step (Figure 3). After extracting the phase images, we applied this method to determine the numbers of accumulated charges and the charge density on different place of the tip as a function of the applied voltage (Figure 4). We will then discuss of these values, particularly the charge density at the beginning and during the field emission process.

[1] C. Gatel et al. Phys. Rev. Lett. 111, 025501 (2013)
[2] L. de Knoop et al. Micron (2014) - Accepted

Acknowledgement: The authors acknowledge the European Union under the Seventh Framework Programme under a contract for an Integrated Infrastructure Initiative Reference 312483-ESTEEM2



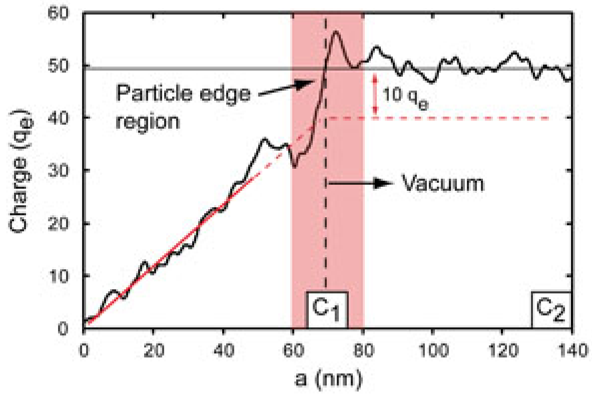
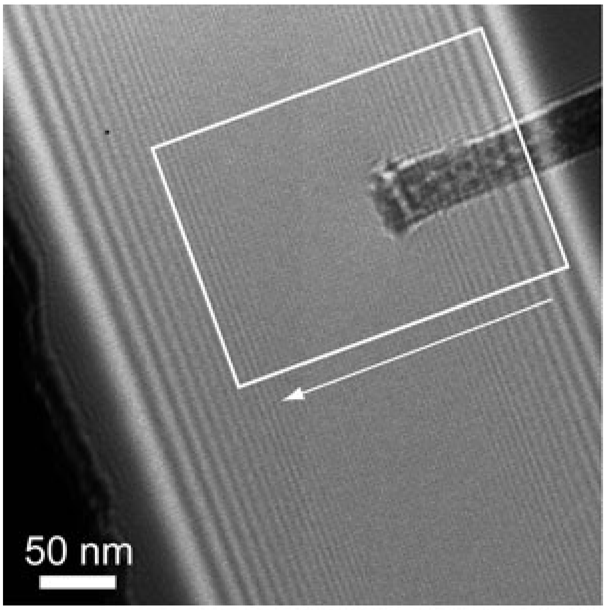


Fig. 1: Reconstructed phase image of a MgO nanoparticle.

Fig. 2: By contour enclosed charge as a function of the short side a as indicated on the Figure 1; the linear fit of contours within the particle and the constant fit outside of the particle are indicated by red and black lines respectively.



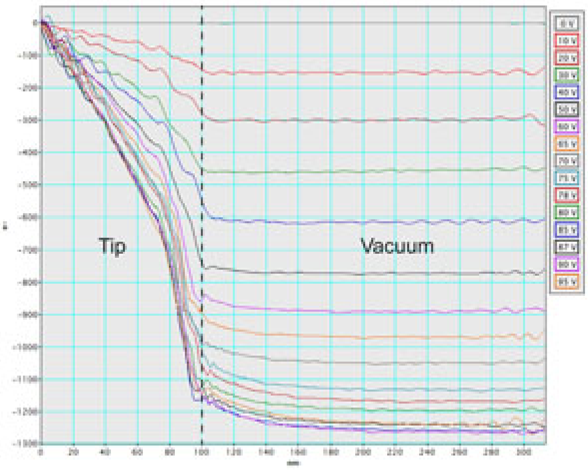


Fig. 3: Hologram of a biased CCnT for field emission. In white is represented the contour used to count the number of charges in the enclosed area.

Fig. 4: Enclosed charge as a function of the length of the enclosed area and the applied voltage between the CCnT and the Au-anode plate.