Determination of the 3D electrostatic field in situ at electron nano-emitters

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Revealing and quantifying the 3-dimensional (3D) electrostatic field of an electrically biased nano-emitter with nanometer resolution is of great interest and importance in the community of electron field emission (FE) and atom probe tomography (APT). In the case of FE, it is the key to answer the fundamental question of how the field interacts with the sharp tips, which has not yet been adequately addressed despite its long history [1]. For this purpose, the local electrostatic field around the apex of metal emitter tips must be accurately measured at the nanometer scale. Simultaneously, the emission current (density) needs to be logged at the corresponding condition(s). For APT, knowledge of the electrostatic field topography around the tip apex may form the basis of an aberration correction scheme [2]. The electrostatic field in both FE and APT is usually very strong (several V/nm) around the tip locally and extended to large distances, thus requiring techniques that can deliver the resolution and accuracy close to the tip which would not be influenced by the extended field, e.g. in the most common setup of electron holography.

In this work, we determine the 3D electrostatic field *in situ* at electron nano-emitters. The emitter is inserted in a Nanofactory STM/TEM holder with a gold counter electrode and electrically biased to electron field emission condition. Differential phase contrast (DPC) in the scanning transmission electron microscope (STEM), with an annual segmented detector, has been applied to image and quantify the local electron beam deflection by the projected electrostatic field of tungsten electron nano-emitter (cf. Fig. 1, ref. [3]). Assuming axial-symmetry of the nano-emitter, we derived a method based on the inverse Abel transform to quantitatively reconstruct the 3D electrostatic field (axial slice) from the single projection measurement. The highest field strength of 2.92 V/nm is measured at the nano-emitter apex, which is located about 650 nm apart from the counter-electrode, at -140 V bias voltage and an emission current around 2 A. The experimental results are compared with simulations based on a finite element numerical Maxwell equation solver. Quantitative agreement between experiment and simulation has been achieved (cf. Fig. 2). This study will find interest in the broad community of field emission and atom probe tomography research.

References:

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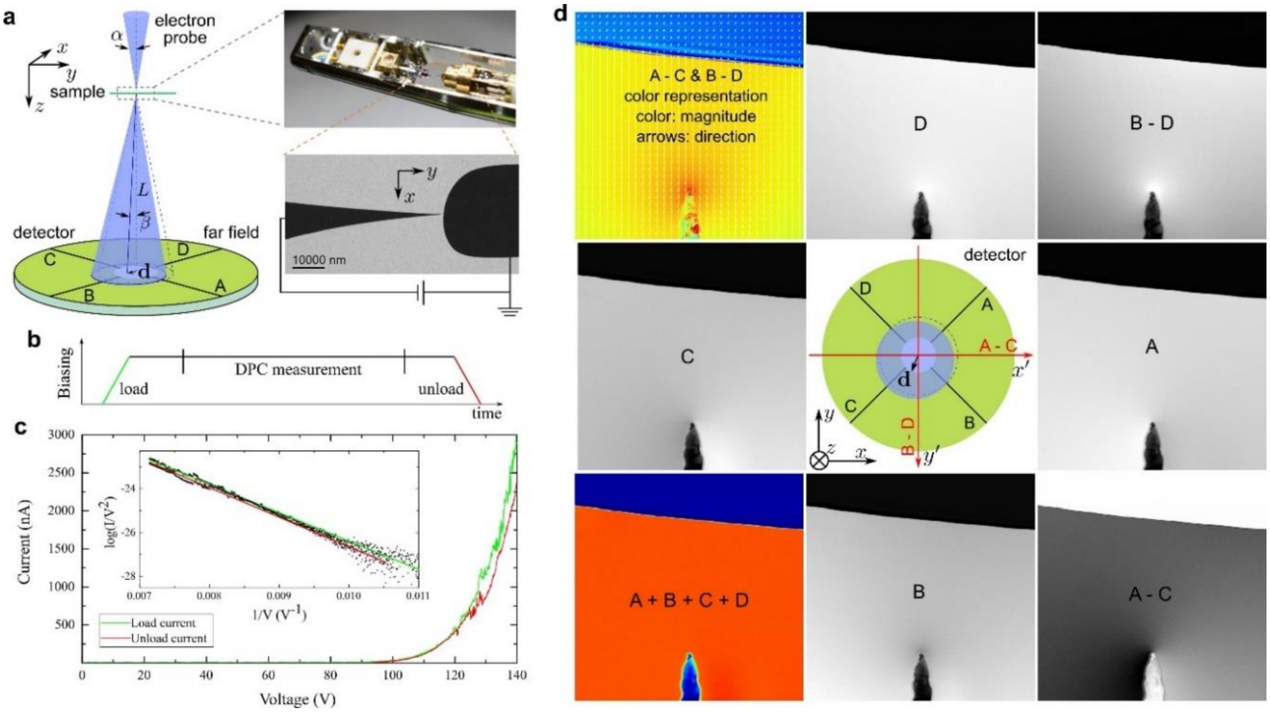

Figure 1. (a) Scheme of the DPC-STEM setup. (b) biasing and static DPC experiments. (c) I-V curve measured during load (green) and unload (red) period; and the Fowler-Nordheim plot (inset). (d) illustration of the DPC signal and color representation scheme.

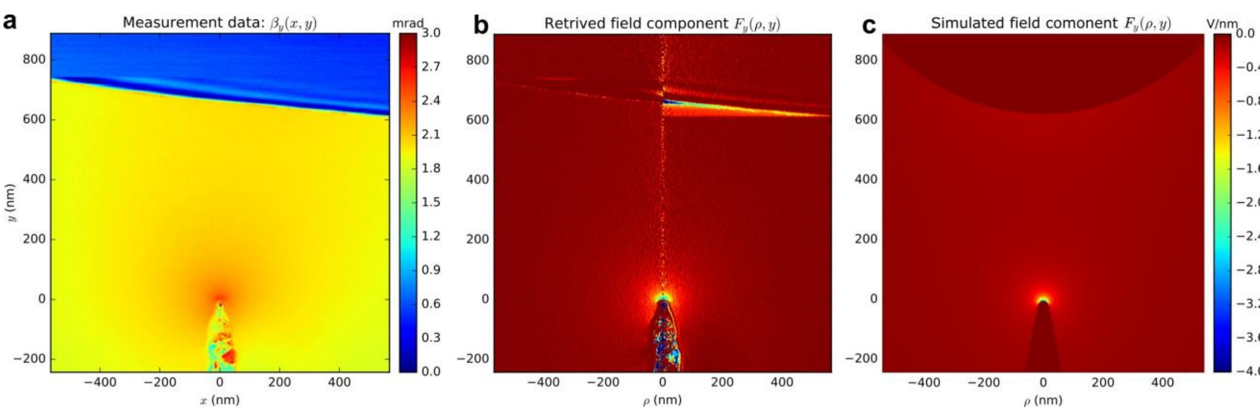

Figure 2. (a) experimental beam deflection component $\beta_y(x,y)$, i.e., along the axial direction. (b) reconstructed axial slice of the axial electrostatic field component $F_y(r,y)$ of the nano-tip at -140 V biasing, reconstructed from the deflection map (a). Simulated results of the field component $F_y(r,y)$. The center line in (b) is reconstruction artifacts due to noisiness of the raw data, and the reconstructed results close to and at the counter electrode is not direct interpretable due to the deviation of symmetry requirement of the applied reconstruction algorithm.