

Assessing the sensitivity of 4D-STEM measurements for electric field mapping at the sub-micrometer scale

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Four-dimensional scanning transmission electron microscopy (4D-STEM) can provide quantitative information about electric fields in materials and it is currently a technique of choice for such measurements. However, mapping electric fields over large (micrometers) field of view with a very high sensitivity and a nanometer spatial resolution remains challenging [1]. Herein, we perform a systematic study to evaluate the expected achievable precision of 4D-STEM measurements for electric field mapping in vacuum.

All experiments were performed on a Thermo Fisher Scientific Titan Themis TEM operated at 300 kV in micro-probe configuration and equipped with a MerlinEM detector. First, the effect of microscope parameters was investigated by acquiring 4D-STEM maps in vacuum while varying one parameter at a time such as convergence semi-angle, electron beam current, dwell time or camera length. To assess the accuracy of the electric field mapping, a coplanar capacitor was fabricated by focused-ion beam (FIB) deposition of Pt on a MEMS biasing chip (DensSolutions). The center of mass (COM) method was used to analyze the shift of the transmitted beam, which was achieved by subtracting the COM map obtained at an applied voltage (object map) from a COM map in free field conditions (reference map) [2]. The reconstructed electric field was then compared with the results of finite element method (FEM) simulations using COMSOL [3].

The electric field sensitivity was evaluated in terms of measurement error. The results show that reducing the convergence semi-angle increases linearly the sensitivity but has a negative effect on the spatial resolution. Electron beam current and dwell time are also shown to have a direct effect on the field sensitivity, as directly controlling the electron dose. In practice, low electron dose values mean low sensitivity, which follow the root square behavior of the Poisson noise. Finally, the camera length study shows that this parameter has no influence on the sensitivity except for extremely small values when it strongly deteriorates. Overall, the experimental trends are in good agreement with previous theoretical studies [4]. The microscope parameters that optimize the measurement, including a convergence semi-angle of 370 μ rad, dwell time of 2 ms, electron beam current of 150 pA and

camera length of 1.45 m, were then used to quantify the stray electric field of the capacitor induced by an applied difference of potential between the plates. The integral of the in-plane component of the stray electric field over the electron path was directly compared with a FEM model where the simulated electric field was integrated along the z direction, assumed to be the direction of electron propagation. This comparison revealed good agreement for applied voltages in the range of 1 to 10 V, corresponding to a maximal projected field in the capacitor gap of 2 to 25 V, respectively. Finally, the electric field reconstruction was repeated using the template matching (TM) method and the results showed that proper choice of template is essential for comparable trends.

In conclusion, this study highlights the effects of microscope parameters on the sensitivity of large field of view electric field measurements using 4D-STEM and provides guidelines for optimized measurements. The full quantification of the electric stray field induced by an applied external potential is demonstrated as an example.

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Reference:

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