Static and Dynamic Electric and Magnetic Imaging

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Measurement of the electrostatic potential distribution in an in-situ biased p-type silicon field effect transistor using the combination of a Nanofactory-TEM-holder and Electron Holography

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Electron holography is an established analysis method for both qualitative and quantitative measurements of diffusion potentials, which appear due to locally varying dopant concentrations in the matrix of a semiconductor [1,2]. The phase φ *(x,y)* of a transmitted electron wave is modulated by variations of the electrostatic potential perpendicular to the electron beam, whereas variations in z-direction parallel to the electron beam are averaged in the projection process:

$$\varphi(x,y) = \sigma \cdot \int_{-\infty}^{\infty} V(x,y,z)\ dz = \sigma \cdot V_{proj}(x,y)$$

with σ the interaction constant depending solely on the accelerating voltage of the microscope.

Electrical biasing changes the potential distribution within such samples; in particular total potential differences across pn-junctions are either de- or increased. The ultimate goal of such experiments is to estimate the true concentration of electrically active dopants, as one often finds a difference between theoretically expected and measured potential drop over a pn-junction. This applies especially for FIB-prepared samples, where a significant number of dopants is obviously deactivated by the Ga^+-sputter process. Holographic in-situ biasing experiments at pn-junctions have been performed in the past [2,3]. Here, electrical biasing is applied directly on a FIB-prepared p-FET structure.

First step of a FIB-preparation is covering the area of interest with a relatively stable material, in this case platinum. The resulting platinum bar covers source, drain and gate of the p-FET and works as an electrical contact for the biasing of the sample. The tungsten probe of a Nanofactory TEM-holder connects the platinum with the voltage source (Figure 1). The bulk silicon of the sample is grounded, because it is mounted on a copper half disc that is electrically connected to the holder shaft. By applying voltages in the range between –8 V and +8 V, the potential distribution in the silicon beneath drain and source changes significantly (Figure 2).

For every biasing voltage, series of 50 holograms were recorded at an exposure time of 10 s each, which is limited by the stability of the used Philips CM 200 Lorentz TEM. All holograms with a fringe contrast larger than 2.5 % were reconstructed using Fourier Reconstruction methods. Subsequently, the resulting object waves were aligned using a semi-automated cross-correlation procedure [4]; their phases were adjusted in offset and tilt using a certain reference area. Finally, the phases were averaged to increase the signal-noise ratio as much as possible.

Unfortunately, electrical stray fields from the tungsten probe strongly influence the whole region around the p-FET, which renders the usual global phase correction impossible. Adding offset and phase wedge works here very localized as correction for only a small part of the image. Therefore, the interpretation of the phase images was performed for three different parts of the image using three different corrective phase wedges. The green dotted rectangles in Figure 2a, 2b and 2c frame the regions for which the corrective phase wedge was added in each image. The phase profiles illustrate the phase curvature under the different biasing voltages, whereas the images show the phase distribution only for the biasing voltage of –8 V. Further investigations of the results, for example calculating the Laplacian of the potential distribution, eventually intend to reveal evidence of an opening and, respectively, closing of the channel beneath the gate oxide.

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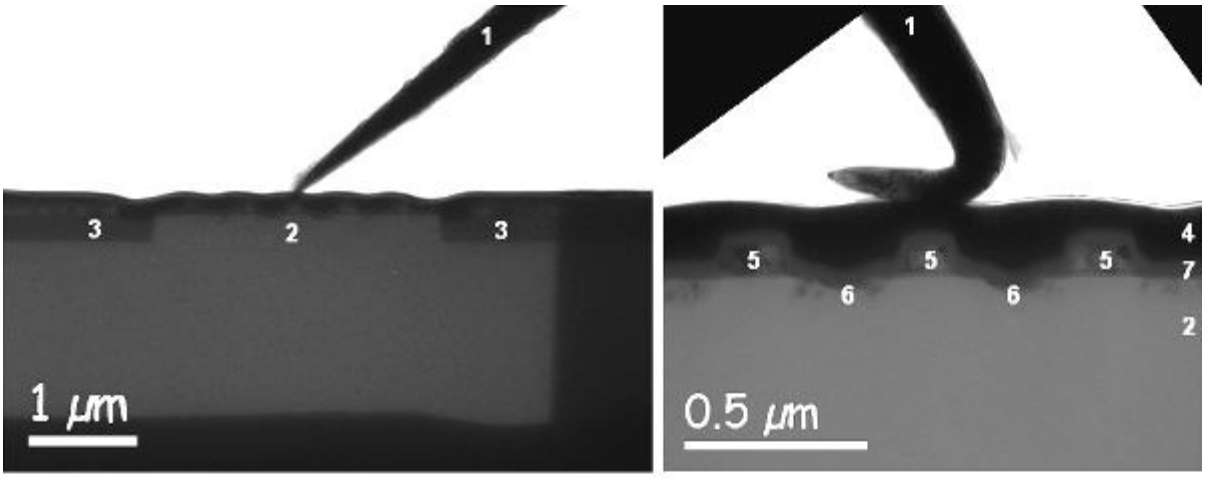

Figure 1. Contacting the FET: **Left:** The needle (1) is connected to the electron transparent FIB-lamella, which consists of a bulk-silicon pad (2) containing 5 FET structures surrounded by insulating oxide regions (3) **Right:** Bending of the needle enlarges the contact area with the platinum bar (4) and increases the elasticity of the whole connection. The gate contact (5) and the drain/source contact holes (6) were coated with amorphous silicon (7) before the FIB-cutting of the lamella was started

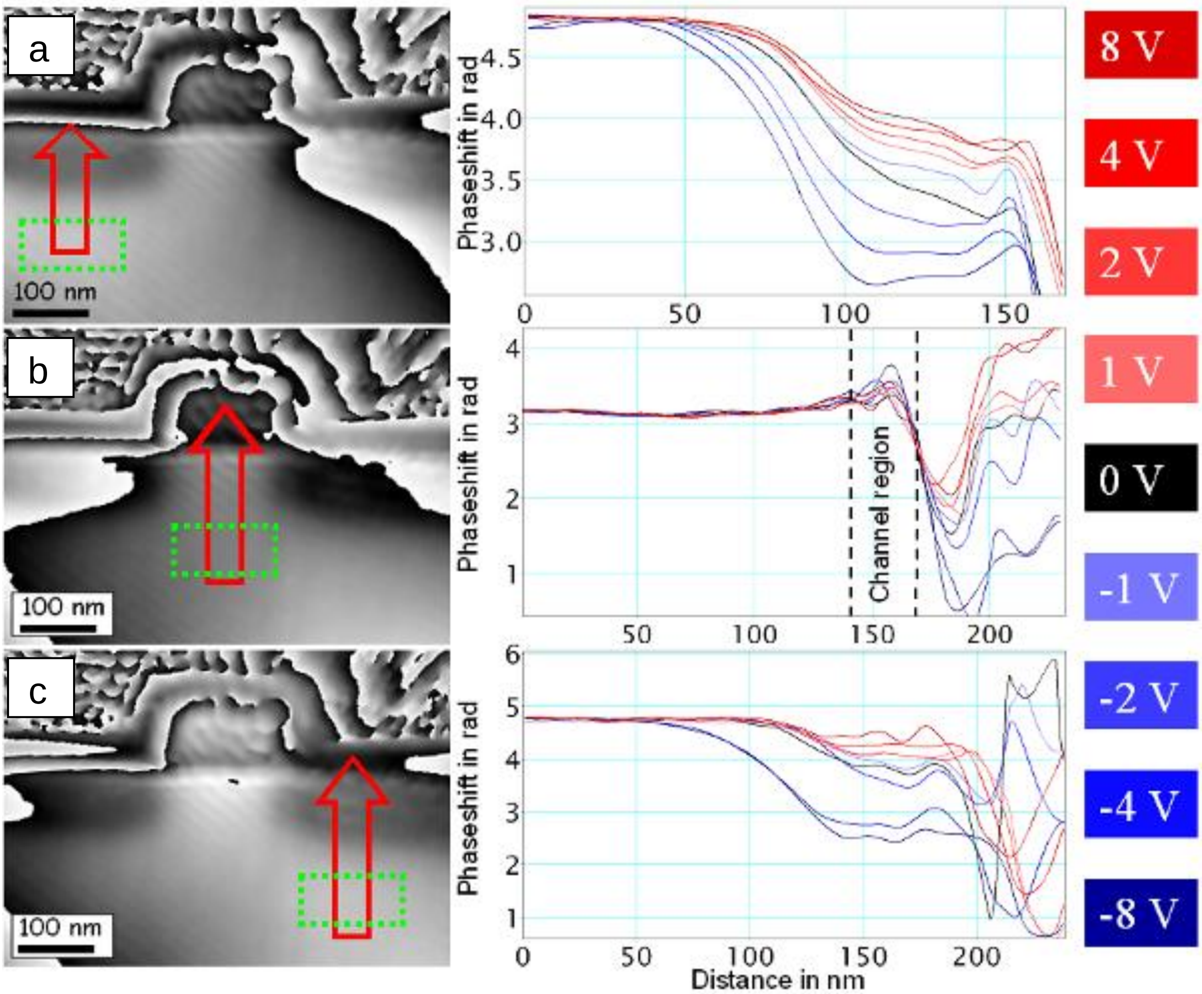

Figure 2. Measurement of phase shift beneath drain (a), gate (b) and source (c) under different biasing **Left:** Same phase image, three times differently corrected: The green dotted rectangle frames the region that was planished by adding a respective phase wedge. The red arrows indicate region and direction of the phase profiles shown next to the respective image. **Right:** Phase profiles for different voltages applied at the tungsten probe.