Dopant imaging of Si and SiC structures using different SPM methods

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Motivation

Power semiconductor devices are key elements in power converters required for transportation of electrical power over long distances, e.g. from offshore wind parks to consumers ashore.
To enable an improved energy efficient design of the power semiconducting devices, a better understanding of the nano scaled implantation, activation and diffusion processes is indispensable. Therefore dopant concentrations of semiconducting devices made of silicon (Si) and silicon carbide (SiC) are imaged and analysed using different scanning probe microscope (SPM) methods.

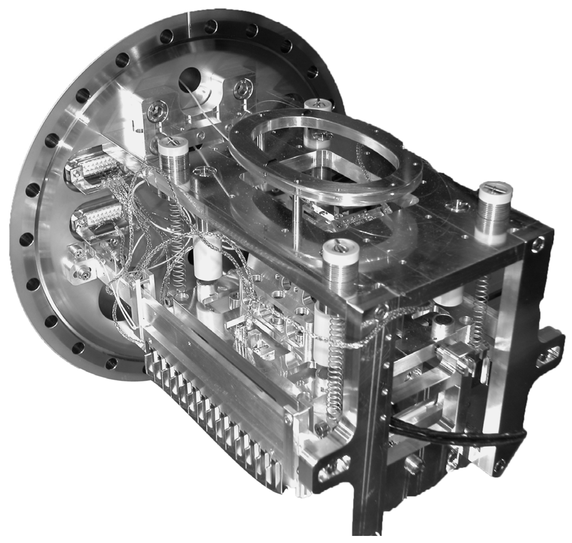
SPM Methods & Instrumental Setup

Several scanning probe microscopy techniques are adapted for dopant imaging.

Kelvin Probe Force Microscopy (KPFM). The contact potential difference V_{CPD} is obtained by nullifying the force acting on the 2nd eigenmode of the cantilever.

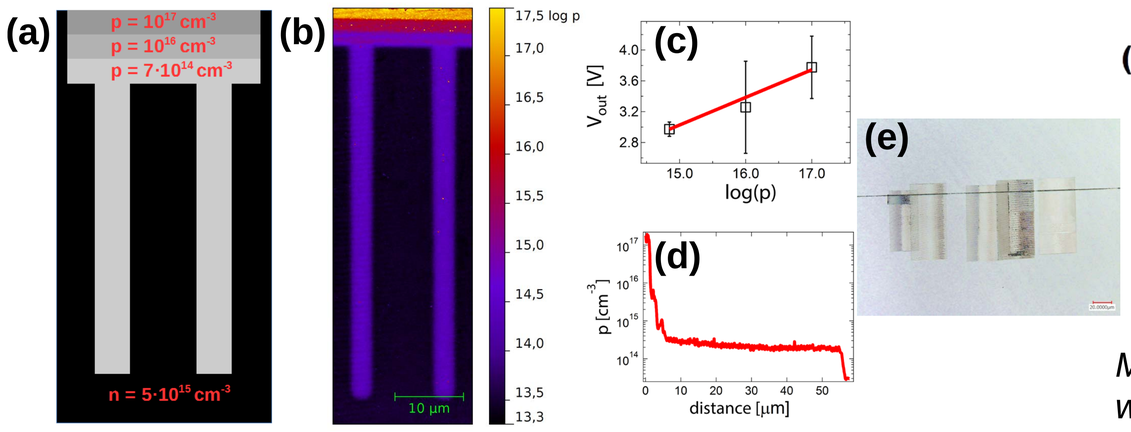
Scanning Capacitance Force Microscopy (SCFM). The derivative of the capacitance with respect to the voltage is measured as a force acting on the 2nd eigenmode of the cantilever.

Scanning Spreading Resistance Microscopy (SSRM). The resistance of the probe sample interface is measured with a logarithmic amplifier.

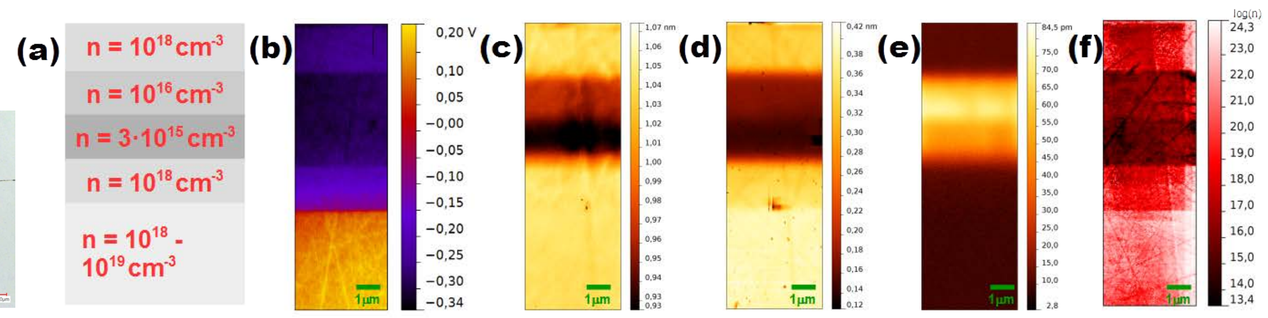


Home built Atomic Force Microscope operated in Ultra High Vacuum at ambient temperature.

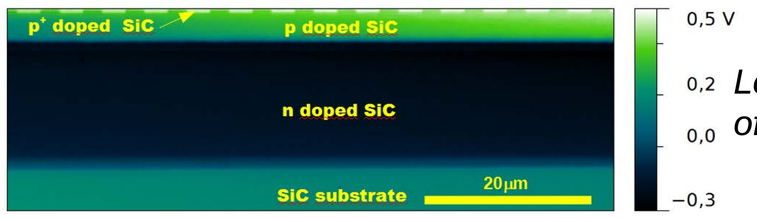
Measurements & Results



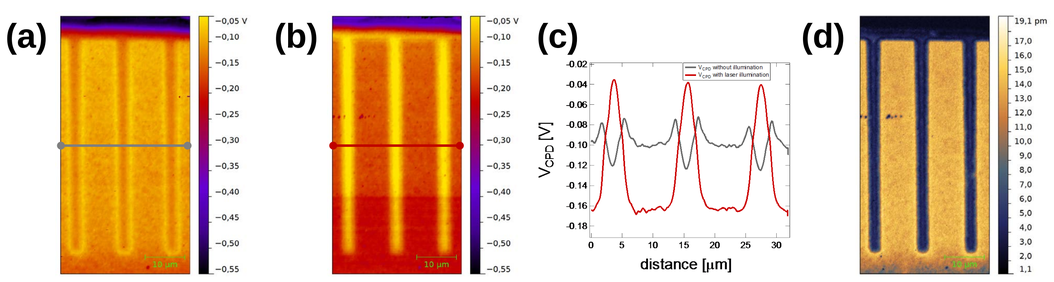
p-doped Si-trench structure embedded in n-doped Si substrate. (a) schematic drawing of the sample with calibration layers, (b) SSRM image, (c) SSRM calibration and (d) profile of a p-doped trench. (e) image of a sample after SSRM measurements.



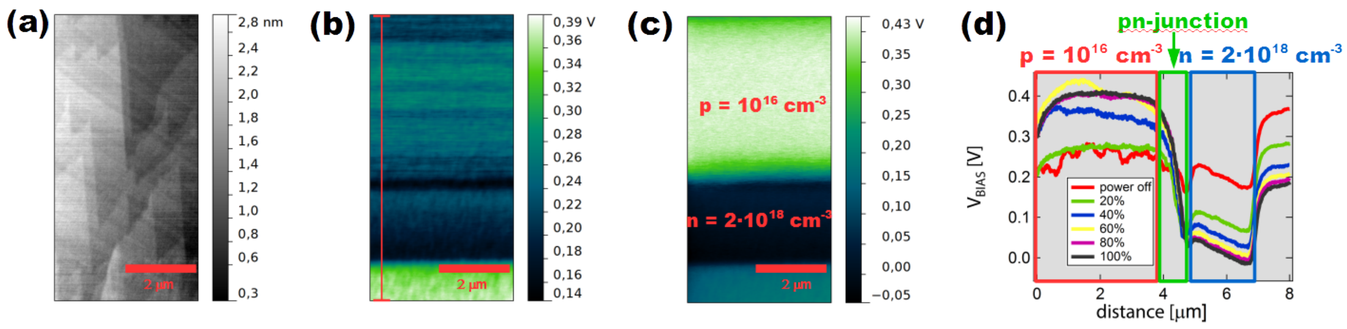
Measurements on n-doped SiC calibrations layers. (a) schematic view, (b) KPFM with laser illumination (λ=475-525 nm), (c) 1st (d) 2nd and (e) 3rd harmonic of the periodic force. (f) a SSRM image.



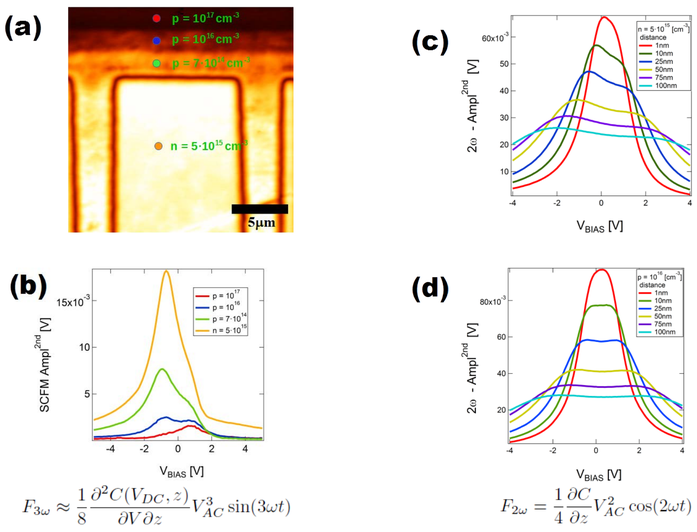
Left: KPFM image of a SiC test device.



KPFM images of the same Si structure. In (a) without and in (b) with laser illumination (λ=400-500 nm). In (c) profiles shown in the images. SCFM measurement of the same place in (d).



Surface photovoltage (SPV) effect shown on a SiC pn-junction. (a) topography, (b) dark KPFM, (c) laser illuminated KPFM (λ=470-480 nm) and (d) profiles for different laser power intensities.



$$F_{3\omega} \approx \frac{1}{8}\frac{\partial^2 C(V_{DC},z)}{\partial V \partial z} V_{AC}^3 \sin(3\omega t)$$

$$F_{2\omega} = \frac{1}{4}\frac{\partial C}{\partial z} V_{AC}^2 \cos(2\omega t)$$

SCFM and 2ω measurements on the Si sample. (a) the calibration layers. (b) spectroscopy on the calibration layers and substrate. (c) and (d) distance dependence of bias sweeps on p- and n-doped regions.

Conclusion & Outlook

Several scanning probe microscopy methods allow to image dopant profiles in a range from 10^{14} cm^{-3} to 10^{19} cm^{-3} in silicon (Si) and silicon carbide (SiC) structures. From SSRM analysis dopant concentration maps are calculated using calibration layers with known dopant concentration. SSRM is a rather stable method for dopant imaging and the calibration layers are easily visible. Unfortunately the samples are severely damaged after measurement as the diamond tip of the cantilever scratches them.
For the non contact SPM techniques like KPFM and SCFM sample preparation is crucial to visualize the calibration layers, but they have the advantage of being non-destructive. In future we will focus on spectroscopy measurements with different electrostatic force microscope methods.