Profiling of N-type dopants in silicon structures

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Among the dopant profiling techniques the scanning electron microscopy (SEM) reached position of a well established method which offers a high spatial resolution and good sensitivity to dopant concentration [1]. Differently doped areas exhibit a contrast depending on the dopant level and surface conditions. Photoemission electron microscopy (PEEM) is a surface-sensitive alternative providing a high sensitivity to the dopant density [2]. Both methods have already been successfully applied in imaging and characterization of the doped silicon structures [3, 4].

We have focused on variously doped n-type patterns, 10^{16} cm^{-3} (N16) to 10^{19} cm^{-3} (N19) on a lightly doped p-type substrate (10^{15} cm^{-3}, P15) because of the lack of detailed data for these structures. Combination of the UHV SEM and PEEM (with a high-pass energy filter) microscopes should provide more information about possible quantifying of the doping levels in n-type areas and about origin of the contrast between the n-type patterns and p-type substrate. Planar structures of this kind, prepared in the clean room laboratory at Masaryk University in Brno [6], were observed in SEM with native oxide on their surfaces, and in PEEM after etching in 5% HF, which should remove the oxide layer and passivate the surface.

Laterally resolved threshold and X-ray spectroscopies provided information about the edge of the valence band and the Si 2p core level [6]. Threshold micrographs for various retarding voltages applied on the sample are shown in Fig. 1. Distinct contrast appears between differently doped n-type areas and it is possible to quantify the doping levels in n-type structures via contrast dependence on the dopant concentration. Energy spectra also exhibit clear dependency on the n-type dopant concentration (see Fig. 2). The height of the spectra and corresponding total photoemission from the n-type structures decrease with the increasing doping level, nevertheless the shift between p- and n-type spectra remains around 30 meV.

Fig. 3 shows direct comparison of variously doped n-type areas covered with native oxide layer, imaged in SEM with the impact energy tuned from keV to the units of eV. There is a contrast evolution between doped n-type structures and p-type substrate as a function of the primary beam energy. The behavior at very low energies is connected with presence of a graphitic layer on the surface created by the decomposition of hydrocarbons under primary beam impact. When removing the oxide layer with ion treatment, contrast inversion takes place indicating an important role of oxide in the contrast generation (see Fig. 3).

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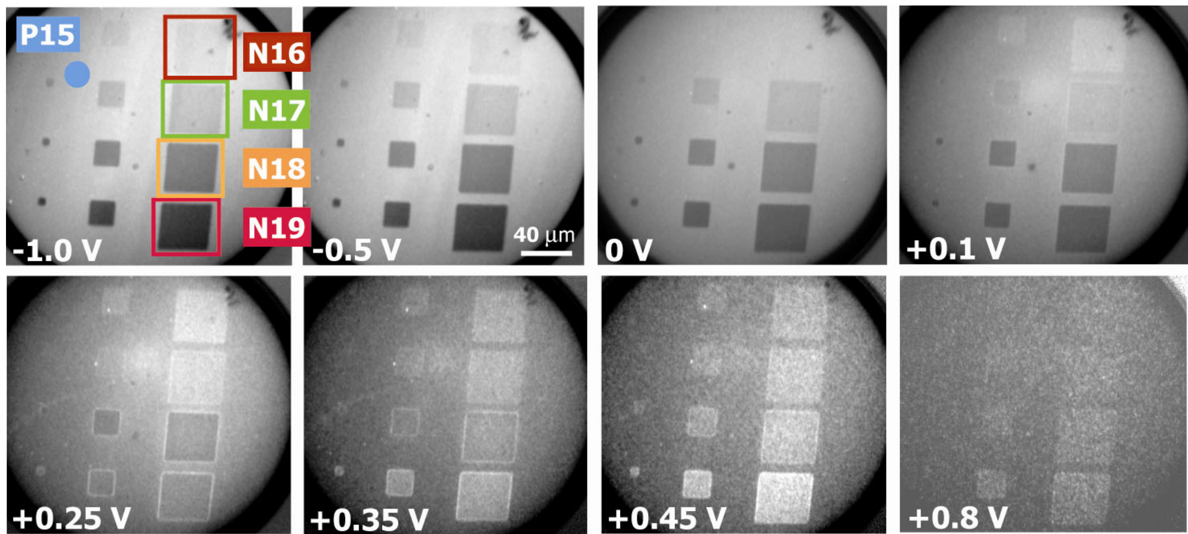

Figure 1. PEEM micrographs of the chemically etched sample with differently doped n-type structures on a lightly doped p-type substrate for various retarding voltages.

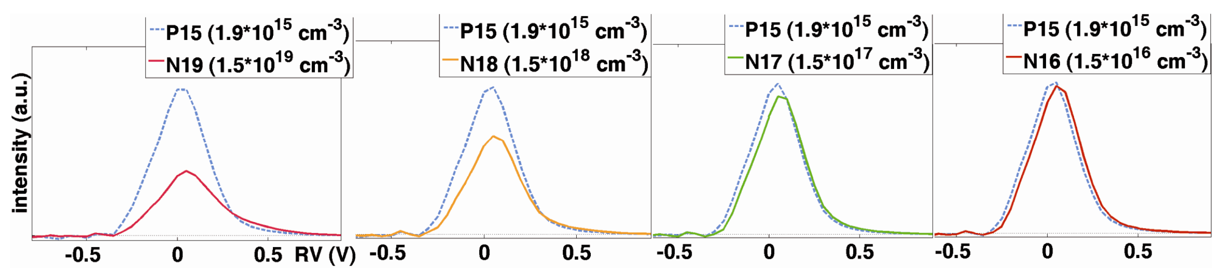

Figure 2. Energy spectra taken from differently doped n-type structures and p-type substrate.

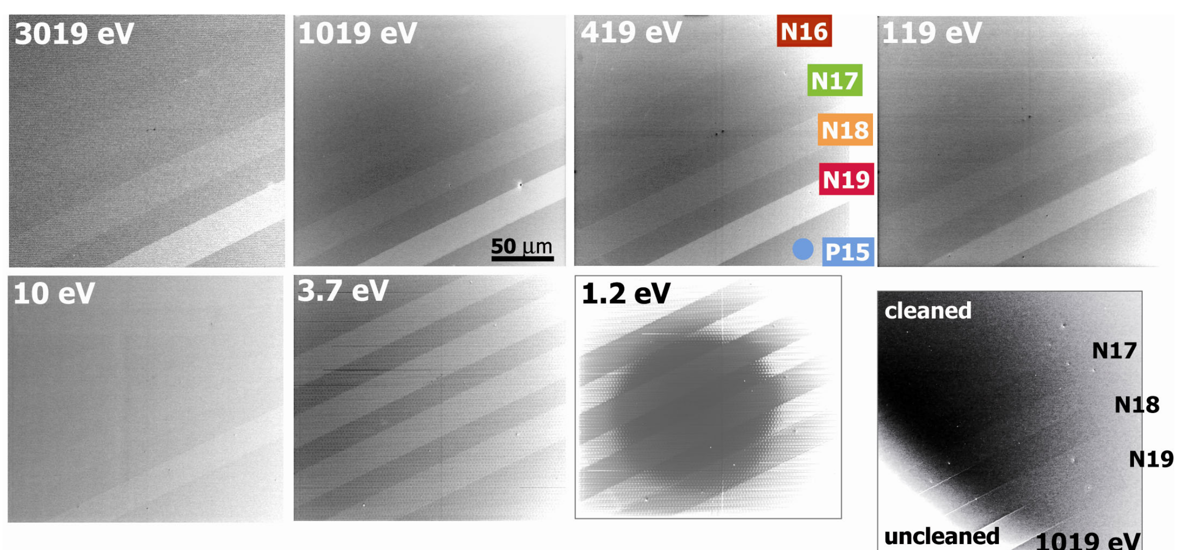

Figure 3. Sample covered with native oxide layer, imaged by electron beam in the SEM. The micrograph in the right bottom corner shows the contrast inversion after the ion treatment.

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