Influence of experimental parameters on nanoscale mapping of the carriers in silicon, and consequences for the quantification of doping profiles

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The characterisation of the doping profiles in the very thin layers for the microelectronic devices is currently provided mainly by the SIMS (Secondary Ions Mass Spectrometry) analysis. The depth resolution and the sensitivity of the SIMS has always followed the shrinkage of the dimensions of the devices, and reach their ultimate performances. Nevertheless, SIMS analysis is basically a one-dimensional technique. The need for a two-dimensional, local characterisation of the dopants, in order to solve e.g. diffusion problems [1], makes it mandatory to develop other solutions that meet the needs of the microelectronic industry in terms of spatial resolution (down to 1 nm) and sensitivity (from $\simeq 10^{15} at.cm^{-3}$ to $\simeq 10^{20} at.cm^{-3}$).

Among others techniques the Scanning Capacitance Microscopy (SCM), since its introduction [2] has proved its capabilities for the qualitative mapping of both p-type or n-type dopants [3] in a range of concentrations compatible with the needs of the microelectronic industry, but it lacks quantitativity and reproducibility [4]. It has been established that this method is very sensitive, among other experimental parameters, to the quality of the oxide (native or regrown after a polishing step), the shape of the tip (see for exemple [5]) or the stray capacitance of the cantilever/tip/sample system [6]. The lack of reproducibility is the main drawback of this easy to use, fast, sensitive to both n-type or p-type dopants, and thus still promissing method even though its resolution, as it is the case for all near-field based methods, has to be improved.

In this communication, we aim to explore different experimental parameters that play a role in the final SCM signal and thus in the quantification of the doping profiles obtained through this method and in the spatial resolution of the technique. In particular, it is shown that the scan direction plays a non-negligible role in the final contrast, and also the tip coating (W_2C, $PtIr_5$ or diamond). Moreover, we confirm that it is possible to get images with a satisfying signal to noise ratio using the native oxide, i.e. without any polishing step nor UV and ozone oxide preparation, although the signal decreases with time and the oxide may need to be refreshed whenever measurements are to be made a long time after the sample has been cleaved.

The influence of the experimental parameters will be illustrated by the imaging of epitaxially grown, sub-micron boron-doped layers in silicon, previously caracterised by SIMS. Two types of samples will be studied : staircases and $\delta-$doped layers. Figure 1 and 2 shows the SIMS and SCM analysis of both kinds of samples. The first kind of samples might help to draw conclusions about the possible quantification of the samples, the second will be helpful to evaluate the spatial resolution (see the right image in Figure 2, where $\delta-$doped layers separated by 60 nm are detected).

In a second part, we use a simple simulation of the tip/sample system in order to quantify the SCM resulting images. This simple modeling of the system allows to draw conclusions about the influence of the shape of the tip, and its performances for the profiles quantification will be evaluated.

Using a more complex simulation (finite elements resolving Poisson-Schrödinger equation), we show that the tip pressure, i.e. the AFM setpoint should also play a role in the final signal. Experimental verification of this assumption will be provided.

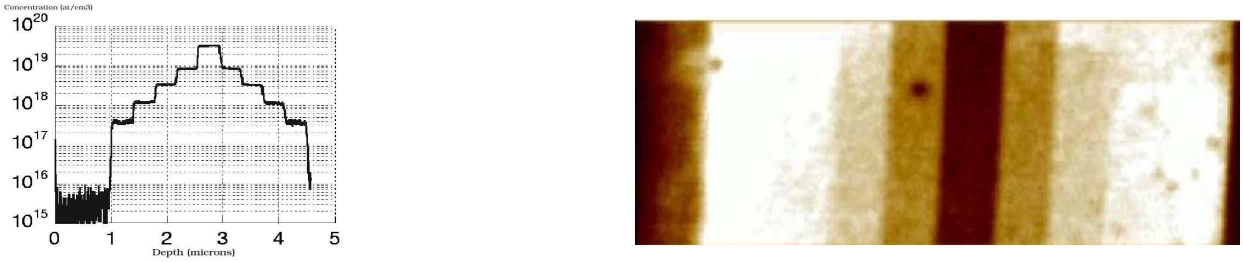

Figure 1 : Left : SIMS analysis of the test staircase sample used in this study. Right : SCM image of the corresponding sample. The darkest zones correspond to the highest doping levels.

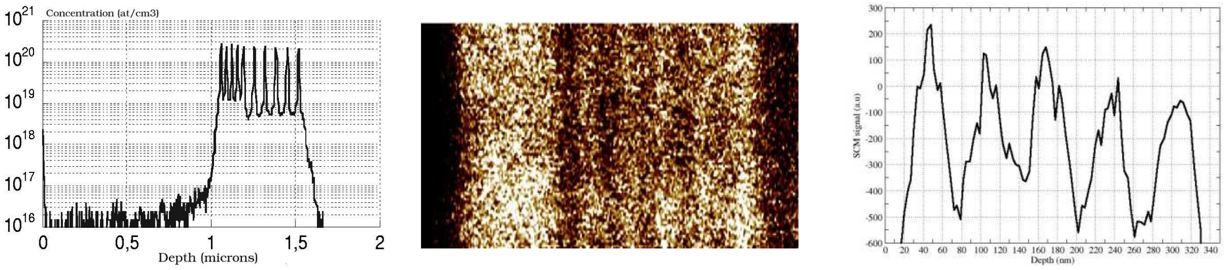

Figure 2 : Left : SIMS analysis of the test δ-doped sample used in this study (layers separated by 30 nm or 60nm). middle : SCM image of the corresponding sample. The $\delta-$doped layers separated by 30 nm are not visible, whereas the $\delta-$doped layers separated by 60 nm are resolved. Right : Cross section of four of the five δ-doped layers separated by 60 nm, analysed with a diamond coated tip

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