ESRF	**Experiment title:** **Grazing incidence diffuse x-ray scattering from defects in ion implanted Silicon at ultra-low energy for future generation devices.**	**Experiment number**: Si765
Beamline: ID-01	**Date of experiment**: from: 17/04/2002 to: 22/04/2002	**Date of report**: 28/08/2002
Shifts: 18	**Local contact(s)**: T.H. Metzger	*Received at ESRF:*

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Report:

This report is on the **first** beam time of proposal SI-765, which has been approved by the review committee as a mid term project (1 year, 2 beamtimes of 18 shifts each). The **second** beam time will take place in December 2002.

The next generation of devices fabrication has to challenge the production of ultra-shallow junctions with a depth of less than some tens of nm [1]. One possible approach to meet this goal is to make thin conducting layers in Si by ion-implantation at ultra-low energies (1 keV for B and some keV for As). The unavoidable defects present after implantation and annealing need to be characterised both with respect to their nature and depth distribution.

We have recently shown that the defect induced diffuse scattering in grazing incidence geometry is very well suited to study the defect evolution in a destruction-free manner in silicon implanted by boron at 35 keV [2,3]. In this report the same method was applied to study the defects in Si implanted by BF_2 at 3 keV and As at 3 and 5 keV. A series of low-energy implanted Silicon wafers (about 10 samples), annealed with different thermal budgets, has been investigated using the GI-DXS (Grazing Incidence Diffuse X-Ray Scattering) technique. The samples were supplied partly by AMD, our industrial IMPULSE partner and partly by Istituto IMM Bologna.

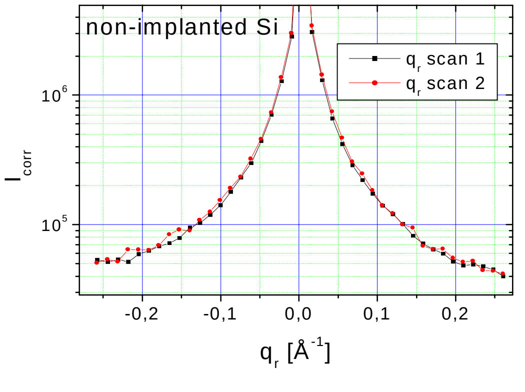

Fig.1: reproducibility test in two radial scans through the (220) reflection at an incident angle $\alpha = \alpha$ -0.05^{o}.

Here, the main difference to the previous work [2,3] consists in the very shallow location of the defects that are distributed mainly in the first 20 nm below the surface. Thus the defect induced diffuse scattering contribution should be strongest close to the critical angle of total external reflection, where the penetration depth of the x-rays, and thus the intensity, changes dramatically from some tens to some hundreds of nm. This means that the accurate control of the grazing angles is of crucial importance.

We have thus first checked the reproducibility of the sample alignment procedure and diffractometer movements. The accuracy in the setting of the incident angle α_i was found to be 0.02 degrees (see fig.1), which proves that the beam line is well suited for reproducible intensity measurements. Second we avoided the "miscut" problem by preparing the samples in one piece with one side implanted and the other one virgin. The sample needed only to be translated in the beam and thus the measurements could be done under identical conditions. Figure 1 shows the reliability of repeated intensity measurements after a new sample alignment.

On the other hand it was found that the diffuse scattering of virgin Si differs unexpectedly from sample to sample, most probably due to the varying oxygen content (Czochralsky grown substrates!) and also with different annealing steps (see figure 2). It is therefore indispensable to measure the virgin part of each sample rather than relying on the virgin Si to be always the same. This feature has doubled the needed beamtime for each sample (about 12 hours after sample alignment). In the future we will ask for floating-zone grown Si to see the effect of oxygen contamination in the samples used so far.

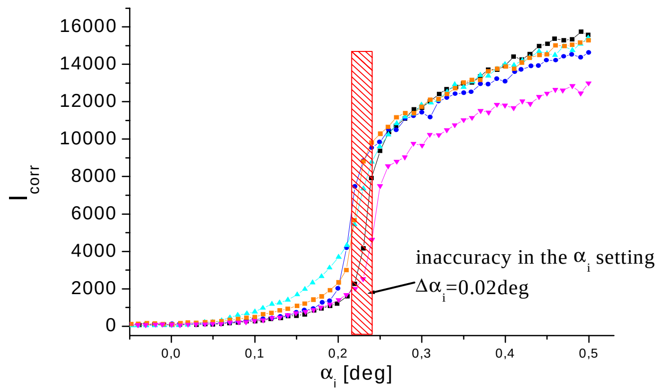

Figure 2: Diffuse scattering intensity close to 220 silicon surface peak as a function of the incident angle α_i for different non-implanted virgin Silicon wafers.

The measurements were performed at 8 keV and consist in radial and angular scan in about 10% of the Brioullin zone close to the (220) surface Bragg reflection at different incidence angles. The data evaluation will enable us to follow the defect structure and evolution during annealing. In addition we recorded the diffuse intensity as a function of the incident angle to probe the defect depth distribution. Examples are shown in figure 3 and 4, respectively.

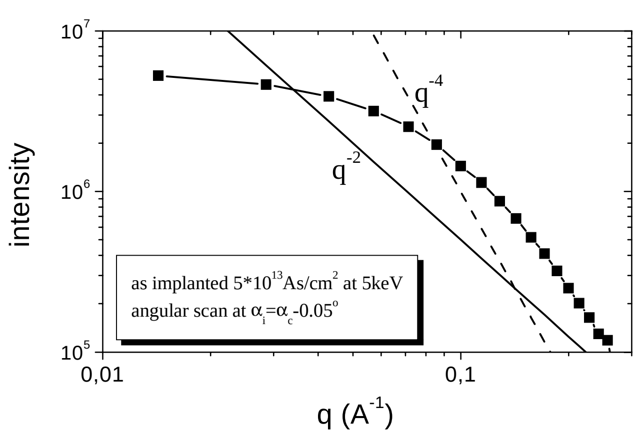

Fig.3: Defect induced diffuse intensity in $q_{angular}$ <1-10> direction close to the (220) surface reflection

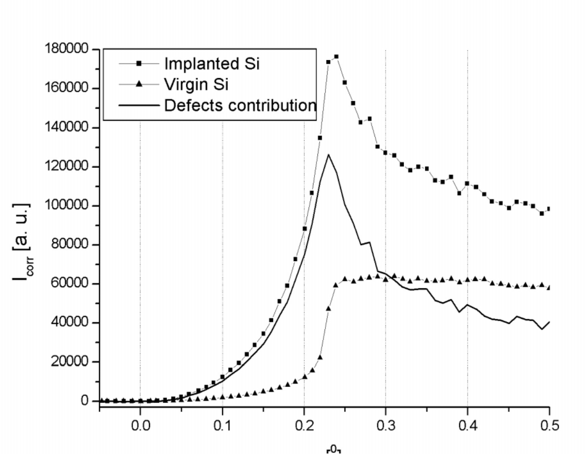

Figure 4: Defect induced diffuse scattering intensity close to 220 silicon surface peak as a function of the incident angle α for As implantation at a dose of

Fig.3 shows that the q-dependence of the diffuse intensity is influenced by the relaxation of the displacement field around the defects close to the sample surface. As expected for defects close to the surface, we do not find the q^{-2}, q^{-4} dependence typical for point defects in the bulk [2]. In fig.4 the intensity difference of the implanted and virgin Si (called defect contribution) will be modeled by a convolution of the electric field and the defect distribution as a function of the depth. The quantitative analysis of the experimental data is now in progress and it will allow for the determination of the presence of surface amorphous layers, the defect type, size and depth distribution, and the thermally assisted transition from point-like defects to extended defects or to the complete defect recovery.

References

[1] - International Technology Roadmap for Semiconductors, 2001 update.

[2] - U.Beck, T.H.Metzger, J. Peisl and J.R.Patel, Appl. Phys. Lett. **76**, 2698, (2000).

[3] - K. Nordlund, U. Beck, T. H. Metzger and J. Patel Appl. Phys. Lett. **76**, 846 (2000).