ESRF	**Experiment title:** Depth resolved strain analysis at lateral nanostrutures defined by ion implantation	**Experiment number:** SI-944
Beamline: ID 10B	**Date of experiment:** from: 18/02/2004 to: 26/02/2004	**Date of report:** 22.02.2005
Shifts: 18	**Local contact(s):** Sean O'FLAHERTY	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

J. Grenzer*, P. Mirzoyan* and U.Pietsch
Institut of Physics, University of Potsdam, Am Neuen Palais 10, 14415 Potsdam, Germany
U. Zeimer*
Ferdinand-Braun-Institut fuer Hoechstfrequenztechnik, Albert-Einstein-Str. 11, 12489 Berlin, Germany
L. Bischoff
Forschungszentrum Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, P.O.Box 510119, D-01314 Dresden, Germany

Report:

We report on the strain analysis of a Si-structure which was laterally patterned by focused ion-beam implantation using either a Au or a Ge ion beam source. The samples were investigated by X-ray grazing-incidence diffraction using synchrotron radiation. Samples were prepared by either 35 keV Au$^+$ ions (dose: 0.3, $2 \cdot 10^{14} cm^{-2}$) or 70 keV Ge^{++} ions (dose: $8 \cdot 10^{14} cm^{-2}$) using an ion source of liquid AuGeSi alloy with an ion beam diameter of about $250 nm$. We produced stripes with a width of almost $300 nm$ building up a lateral grating with a period of $550 nm$ along the [100] direction. The implanted area on the Si-structure amounts to a size of $0.6 \times 0.6 mm^2$.

Before X-ray measurement the sample surfaces were inspected by atomic force microscopy (AFM). The root mean square roughness for all samples was found to be less than 1 nm both in the implanted and non-implanted regions. The GID measurements have been carried out at the multi-purpose eight-circle diffractometer at ID10B of the ESRF [1]. The incident beam was monochromized ($\lambda = 0.155$nm) and collimated using a horizontal (111) diamond double-crystal monochromator. High-resolution in reciprocal space was achieved by mounting a germanium (111) analyzer crystal in front of the scintillation detector. It gave an in-plane resolution better than 10^{-3}nm^{-1}. Measurements were performed at two symmetry equivalent in-plane reflections: the transverse scan at the $(0\bar{4}0)$ reflection by keeping the length of the scattering vector $Q = 2\pi/a \cdot (H, K, L)$ (a is the Si lattice parameter) constant and the longitudinal scan at the (400) reflection by changing the length of the scattering vector Q. Whereas the transverse $(0\bar{4}0)$ scan is only sensitive to the periodical material contrast, the longitudinal one is also influenced by the (periodic) deformation of the host lattice in the direction perpendicular to the stripes.

The figure shows reciprocal space maps measured in the vicinity of the strain-sensitive (400) Bragg reflection. The analyzer streak (strong intensity line from lower left to higher right corner) and the monochromator streak (opposite direction, fig. 2a) dominate the maps. These streaks are a characteristic feature of high-resolution experimental set-up.

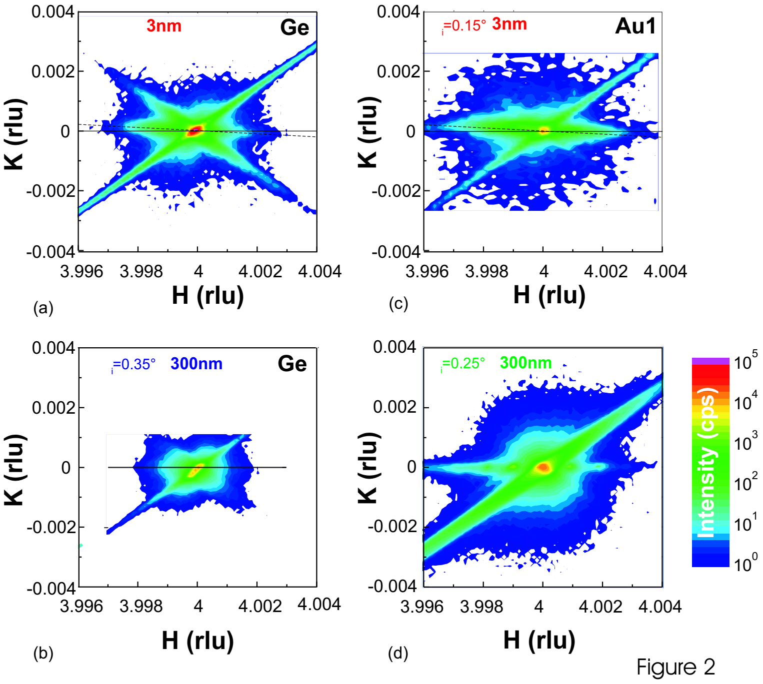

Figure: Reciprocal space maps of the strain sensitive (400) reflection for the Ge (a and b) and Au1 (c) and Au2 (d) implanted samples. The implantation direction was always along the line $K = 0$. The dotted line in fig. a, c shows that the implantation direction was about 3 degres off.

The main information is the intensity distribution along H at $K = 0$ which refers to the direction of implanted grating structure. The large extension of intensity close to the main Bragg peak of the substrate is caused by the strain distribution in the sample. It is larger for incidence angles $\alpha_i < \alpha_c$ (fig. a, c) and smaller for $\alpha_i > \alpha_c$ (fig. b, d). In case of Ge^+ one clearly can see that the implantation direction was not exactly parallel to [100] direction (fig. a). This misalignment is of the order of 3 degree. Interesting to note that intensity distribution along K for the misaligned samples are broader than for these which are exact aligned along the [100] direction (compare fig. a and fig. d). At large penetration depths ($\Lambda = 300nm$) the intensity distribution along $K = 0$ disappears (fig. b); only a slight increase of the diffuse background scattering remains around the Bragg peak position. The intensity distribution for sample Au2 (fig. d) differs significantly from those of Au1 and Ge. While the intensity distribution for the two other samples (Ge and Au1) is smooth, the Au2 sample exhibits a series of distinct gratings peaks which appear due to a periodical modulation of the surface; the AFM measurements confirm this weak periodical modulation, however the modulation is of the order of the surface roughness. The extension of intensity at $K = 0$ is much more pronounced in this sample as in two other samples (Ge and Au1).

The depth distribution of implanted ions in the investigated samples was calculated by the SRRIM program [2]. The maximum ion range distribution was estimated to be equal 30 nm and 60 for $35keV$ Au and $70keV$ Ge, respectively. This is comparable with the maximum strain depth as found by GID measurements.

It can be shown that due to implantation a periodical defect structure is created consisting of both implanted and not implanted stripes [3]. The evaluated depth distribution of defects within the implanted stripes corresponds to that obtained by TRIM calculation. The induced strain distribution, however, shows no periodicity. This can be explained by an overlap of the strain fields created in each implanted stripe.

We would like to acknowledge O.Konovalov and Sean O'FLAHERTY for the support during the measurements.

References

[1] http://www.esrf.fr/UsersAndScience/Experiments/SCMatter/ID10B/
[2] http://www.srim.org/; J. Ziegler, *The Stopping and Range of Ions in Solids*, Pergamon, New York, (1985).
[3] J. Grenzer, U. Pietsch, and L. Bischoff, phys. stat. sol. (a), 17 (2005) / DOI 10.1002/pssa.200420005.