ROBL-CRG	**Experiment title:** Anisotropic strain-distribution in ion-beam irradiated silicon	**Experiment number**: 20-02-683
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Report:

Many properties of surfaces and interfaces can be modified by controlling their roughness. Among them are electrical, optical or magnetic properties. One process to tune surface roughness in a controlled manner is ion beam sputtering (IBS). By IBS, nanopatterns in the form of wave-like rippled structures on solid surfaces can be achieved by ion beam bombardment under oblique incidence [1]. Whereas in the low ion energy region the ion beam is usually provided by a compact, broad beam ion source that delivers a homogeneous ion flux with several cm in diameter, a rather small ion beam (diameter ~1cm) provided by an ion implanter has to be used in the latter case. In order to achieve a homogeneous irradiation of the whole sample surface, the small beam is scanned across the sample surface. In a previous work we found an anisotropic defect concentration in the region of the amorphous-crystalline interface in medium-energy Xe beam induced ripple patterns on Si(001) [2]. It was proposed that the aforementioned scanning process of an across the tilted sample creates an anisotropic defect distribution.

Aim of the present experiment at ROBL was to study the ion beam induced strain and defect distribution in samples irradiated with different ion beam "shapes" (figure 1, text below). For this experiment, 1x1 cm² Si(001) substrates with no intentional miscut were irradiated at room temperature with Xe^+ ions with a kinetic energy of 25keV and an incidence angles of θ=70° (ripple patterns form on the surface) and θ=80° (no ripple patterns form). The projection of the ion beam on the substrate was parallel to the [110] direction. The ion-irradiation was done using a Danfysik 1050 Low Energy Ion Implanter in the Forschungszentrum Dresden-Rossendorf. In normal operation, the ion beam with a mean diameter of 15mm was swept over an square area of 45x45mm² with the tilted sample located in the centre. As proposed in the previous work the projection of the homogeneous ion beam onto the sample surface may lead to an inhomogeneous beam-profile in the plane of the sample surface (case '1:1' in fig. 1). In addition, samples were prepared increasing the sweeping amplitude by a factor of $\cos(\theta)^{-1}$ parallel or perpendicular to the tilting-direction (cases '2:1' and '1:2' in fig. 1).

With those prepared samples we performed coplanar X-ray diffraction experiments at an X-ray energy 8 keV. The incoming X-ray beam was collimated by a set of slits in front of the sample. To achieve sufficient resolution in reciprocal space a combination of slits and an analyser-crystal was used. We

measured reciprocal space maps (RSM) around the asymmetric Si (113) reflection, making an angle of 25.2° with respect to the Si (001) surface. To probe an ion beam induced asymmetry, measurements have been performed with the incidence x-ray beam either parallel or perpendicular to the ion-beam direction. In addition, high resolution measurements of the symmetric Si (004) and the forbidden Si (002) reflection have been performed.

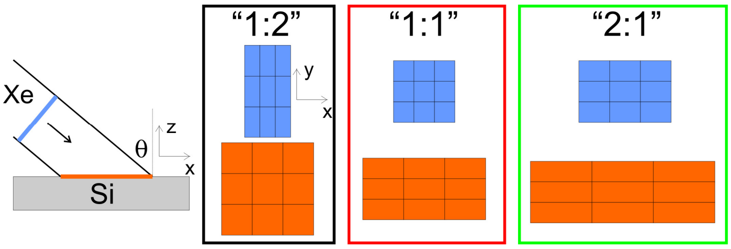

Figure 1: Scheme of the three different implantation conditions. Varying the shape of the ion beam perpendicular to it's direction changes the final symmetry in the surface plane of the sample inclined by the angle θ.

As example, figure 2 shows measured reciprocal space maps for the sample irradiated by 70° in the "1:2" configuration, either with the inplane scattering component parallel (left) or perpendicular (right) to the projection of the ion beam on the surface. Due to the periodic ripple pattern in the crystalline material, the left RSM shows satellite peaks around the Si (113) reflection measuring a wavelength λ=105nm of the periodic pattern. Interestingly, the intensity of the satellite peaks is not symmetric, exhibiting a slightly increased intensity on the smaller q_x side.
In addition, the intensity distribution along the crystal truncation rod is asymmetric too, exhibiting an increased intensity at the smaller q_z side (fig. 3). The same asymmetry was found around the symmetric (004) reflection. In combination, the measurements indicate the presence of a tensile strain in the crystalline region, created by the ion beam bombardment. However, no strong asymmetry could be found in the inplane-direction perpendicular to the ripples (fig. 2, right). A possible reason is that the (expected) small asymmetry becomes amplified by the presence of the satellite peaks, whereas the signal to noise ratio is too large if no satellite peaks are present. Detailed analysis will be subject to further evaluation of the data.

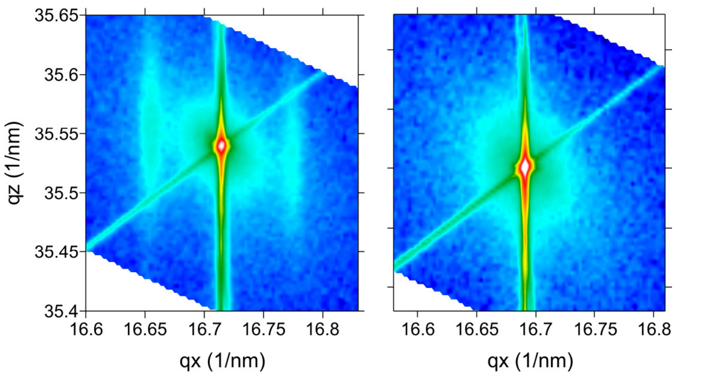

Figure 2: Reciprocal space maps around the asymmetric Si (113) and (1-13) reflection of a sample irradiated by 25keV Xe ions. If the direction of the x-ray beam is parallel to the direction of the ripple pattern on the surface (left), sattelite peaks measure the wavelength of the nanostructures (here, λ=105nm). The intensity distribution is slightly asymmetric towards smaller |q| values, indicating expansion due to the ion implantation.

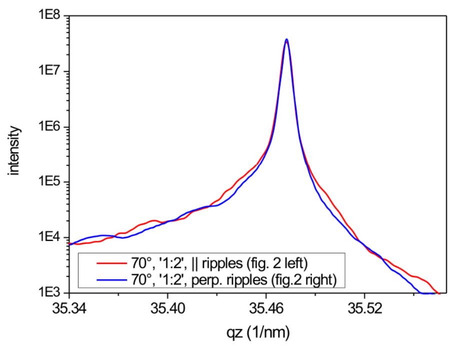

Figure 3: cut along the crystal truncation rods in fig. 2. The asymmetry indicates expansion of the lattice planes perpendicular to the surface

[1] W. L. Chan and E. Chason, J. Appl. Phys. **101**, 121301 (2007)
[2] A. Biermanns, U. Pietsch, J. Grenzer, A. Hanisch, S. Facsko, G. Carbone and T.H. Metzger, J. Appl. Phys. **104**, 044312 (2008),