ROBL-CRG	**Experiment title:** Influence of ion beam channelling for ripple formation at amorphous-crystalline interface after ion-bombardment	**Experiment number**: 20-02-673
Beamline: BM 20	**Date of experiment**: from: 31.01.09 to: 3.2.09	**Date of report**: 10.05.2009
Shifts: 9	**Local contact(s)**: Carsten Baehtz	*Received at ROBL:*

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Report:

With ion beam induced patterning nanostructures such as dot or ripple-like features evolve on solid surfaces via a self-organization process. Certain factors as the beam parameters [1] and the initial roughness [2] highly influence the competing processes of sputtering and surface diffusion during the formation. Our recent experimental findings indicate that also the crystallographic structure of the sample can influence pattern formation in semiconductor materials which is not taken in consideration in hitherto theories [3, 4]. In this experiment at ROBL we studied the role of the crystal orientation, i.e. different lattice planes and their packing density, of the initial surface in the specific case of medium-energy (35keV) Xe^+–induced ripples on Si. For this ion species and energy ripple formation was found on Si(001) surfaces for incidence angles between 55° and 75° off-normal. However, it was so far not adressed if this rather small angular window is related only to the orientation of the surface to the ion beam or to the orientation of the (001) lattice planes before amorphization as well.

In this experiment we studied the ripple formation on silicon surfaces as a function of the miscut angle. We prepared samples with a defined deviation of the surface normal from the [001] direction. The (001) lattice plane of these wafers were tilted by 2°, 5° and 10° towards [110]. All samples were bombarded with Xe ions at an incidence angle ψ of 65° (with respect to the surface normal) at an ion energy of 35 keV at the Forschungszentrum Dresden-Rossendorf. Under these conditions a rippled pattern with a typical wavelength of 150 nm is formed on the surface and at the amorphous-crystalline interface located several tens of nanometers below. The ion-beam projection was orientated parallel, antiparallel or perpendicularly to the miscut direction (Fig. 1) leading to an effective incidence angle with respect to the Si (001) direction between 55° and 75°.

For a set of 9 samples we performed coplanar X-ray diffraction experiments at an X-ray energy 7,8 keV in order to probe the orientation of the ripple pattern with respect to the (001) lattice planes. 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. For all samples we recorded reciprocal space maps (RSM) around the (004) Bragg peak in coplanar scattering geometry.

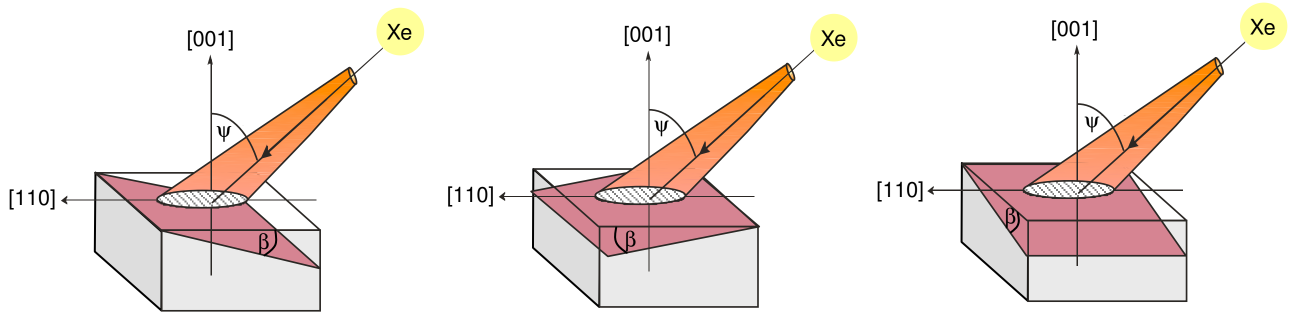

Fig. 1a): ion beam projection parallel to the miscut direction

b) ion beam projection antiparallel to the miscut direction

c) ion beam projection perpendicular to the miscut direction

Fig. 2 shows examples of such maps measured for the three different cases (Fig.1) for the 10° miscut angle. In the RSMs q_z is oriented parallel to the [001] direction. It can be seen that the crystal truncation rod (CTR) which goes parallel to the surface normal is tilted by the miscut angle to q_z and that the satellite peaks which come from the ordered subsurface ripples follow the rotation of the CTR. That means that the ordered nanostructure follows the surface but not the crystal planes. Also, there is no significant difference wether the (001) plane is tilted by +10° (a) or -10° (b), i.e. whether the effective indicence angle in respect to the (001) plane is 55° or 75°, respectively. Preliminary analysis shows that the satellite peaks of all three samples have also the same intensity, equal shape and FWHM indicating a similar shape and degree of ordering of the ripples as on silicon (001) substrates without a miscut. The different shape of the central Bragg peak is an artefact of the resolution function. As the maps were recorded without an analyser crystal for the sake of time, the width of the Bragg peak is strongly influenced by the footprint of the beam on the surface which was different in all three cases due to the miscut. The wavelength determined from the reciprocal maps very well accords with the one extracted from AFM measurements. However, note that the orientation with respect to the crystalline material can not be determined from AFM. In the perpendicular case (c) the miscut cannot be seen in the map because the X-ray beam goes across it.

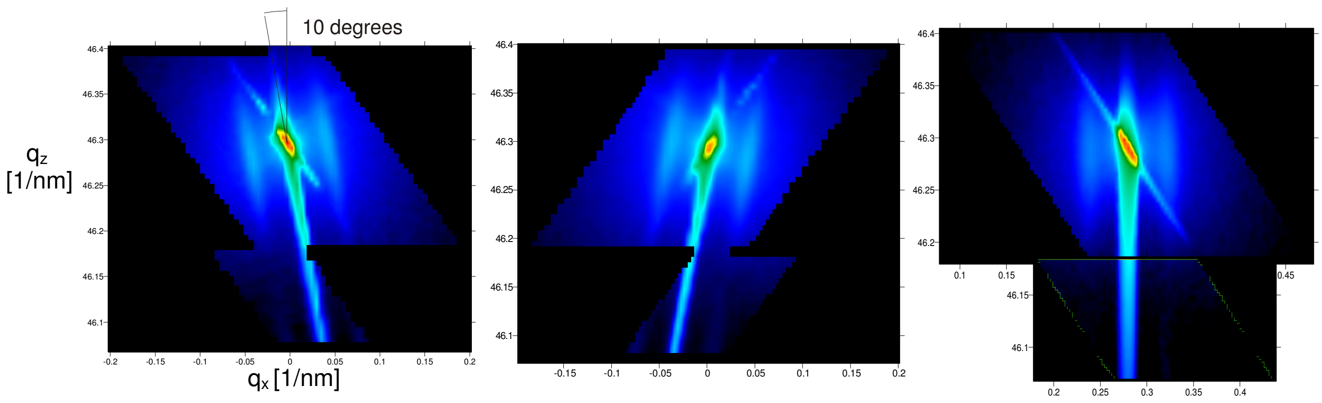

Fig. 2: 35keV β=10° parallel ϕ=0° 35keV β=10° antiparallel ϕ=0° 35keV β=10° perpendicular ϕ=0°

The results indicate that in the case of medium energy ion bombardment with rather heavy ions, the formation of a periodic ripple pattern is rather related to the incidence angle with respect to the surface than to the lattice planes.

[1] T.K.Chini et al. *"Energy dependent wavelength of the ion induced nanoscale ripple"*, Phys. Rev. B. **66**, 153404 (2002)
[2] P.Karmakar et al. *"Role of initial surface roughness on ion induced surface morphology"*, Appl. Phys. Lett. **93**, 103102 (2008)
[3] J. Grenzer et al. *"Ripple structures on surfaces and underlying crystalline layers in ion beam irradiated Si wafers"*, Phys. stat. sol., accepted (2009)
[4]J.Munoz-Garcia et al., "*Coupling of morphology to surface transport in ion-beam irradiated surfaces: Oblique incidence*", Phys. Rev. B **78**, 205408 (2008)