ESRF	**Experiment title:** **Strain distribution in silicon on insulator using grazing incidence x-ray diffraction**	**Experiment number**: SI-1663
Beamline: ID 10B	**Date of experiment**: from: 14.05-20.05.08	**Date of report**: 30. 08. 08 *Received at ESRF:*
Shifts: 15	**Local contact(s)**: A. Vorobiev	

S. Grigorian[1]*, A. Davydok[1]* and U. Pietsch[1], O. Perroud[2]* and O. Thomas[2]

[1] *Institute of Solid State Physics, University of Siegen, Walter-Flex str. 3, 57068 Siegen, Germany*

[2] *IM2NP, Université Paul Cézanne, Faculté des Sciences de St Jérôme,13397 Marseille, France*

Report:

The formation of periodic arrays in the nanometer length scale at semiconductor interfaces has become a topic of intense research. Strain distribution in such patterned nanostructures play an important role overall performance of any silicon based devices. Recently synchrotron-radiation measurements of such device containing silicon on insulator (SOI) periodic arrays have been performed [1]. High resolution x-ray diffraction was employed to study two-dimensional strain field caused by SOI lines and symmetric and asymmetric reciprocal space maps were obtained.

Typical structure of a SOI device is shown in the figure 1. 100 nm thick SOI lines are covered by a thin silicon oxide layer and a 160 nm Si_3N_4 stressor layer. The lines are oriented along [010] which corresponds to the [110] direction of the Si substrate. One key parameter for the understanding of the performance of the active layer is the spatial variation of strains, especially, at the SOI/Si_3N_4 interface. This can be performed by a depth-selective x-ray scattering experiment. Surface-sensitive technique was successfully applied to the study of the strain distribution of a lateral nanostructure containing an InGaAs single quantum well [2] and for investigations of lateral band-gap modulations in a quantum well heterostructures [3].

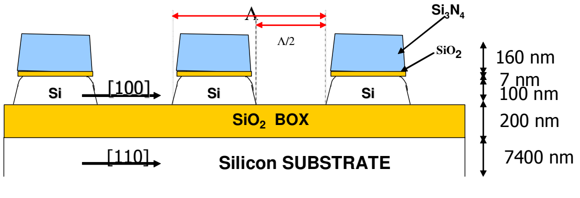

Figure 1. Geometry of SOI sample.

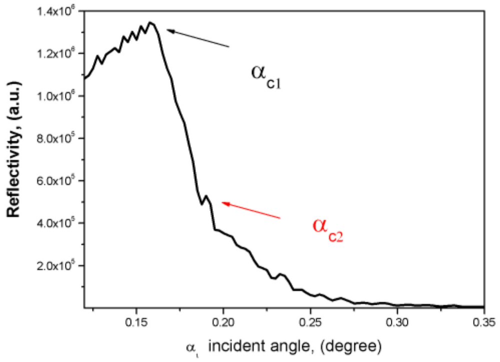

Figure 2. Zoom of Reflectivity curve in the shallow incident angle region provides two critical angles.

In the present experiment we employed grazing incidence x-ray diffraction (GID) [4]. By varying the angle of incidence of the x-ray beam around the critical angles for total reflection of the layers of interest, the penetration depth can be tuned to allow a direct comparison of the structural properties in the surface and the bulk of the nanostructure. Measurements have been done at the ID10B beamline using photon energy of 8.36 keV. Initially the SOI lines were oriented perpendicular to the incident beam. Transversal and radial scans have been detected in a vicinity of (400) reflection at $2\theta_B = 65.9°$ and under shallow angle of incidence. The depth-dependent scattering signal was recorded by a PSD containing 1024 channels. At the chosen setup one channel covered 0.0049°. High angular resolution was achieved by using a post-sample Si analyser crystal placed before PSD. Combination of in-plane transverse and radial scanning with z-coordinate obtained from PSD allows reconstruction of transverse and radial reciprocal space mappings (RSM), respectively.

The reflectivity curve shown in Fig. 2 reveals two critical angle at $\alpha_{c1} = 0.16$ ° and $\alpha_{c2} = 0.19$ °. At the first critical angle almost no diffracted signal can be seen in RMS, therefore it can be associated with the top Si_3N_4 stressor layer, whereas the second critical angle allow to probe SOI arrays of modulated nanostructure. In the following we discuss the RSM measured at incidence angles $\alpha_i = 0.18° < \alpha_{c2}$ and $\alpha_i = 0.2° > \alpha_{c2}$, where α_{c2} is the second critical angle of total external reflection of SOI system.

Fig. 3,4 show transverse (scanning perpendicular to diffraction vector) RSM taken for different incident angles which are probing mostly the upper part of SOI lines nearly to Si_3N_4 stressor layer or the whole SOI system, correspondingly. In the both maps maxima of intensities were found for $q_z = 0.268$ nm^{-1} at exact position of the α_{c1}. At incident angle of $\alpha_i = 0.2°$ RSM demonstrates well pronounced lateral as well as vertical pe riodicity (see Fig. 4). Vertical oscillations along q_z reveal thickness of crystalline layer of about 111 nm. From lateral q_y oscillations was resolved an overage periodicity of about 1,2 µm. This periodicity is slightly changing depending of q_z which indicates possible change of the shape due to strain influence on SOI system.

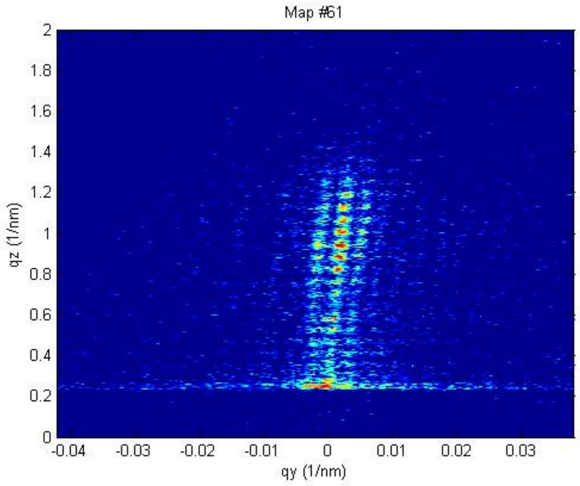

Figure 3. Transverse RSM at the incident angle of α_i=0.18°.

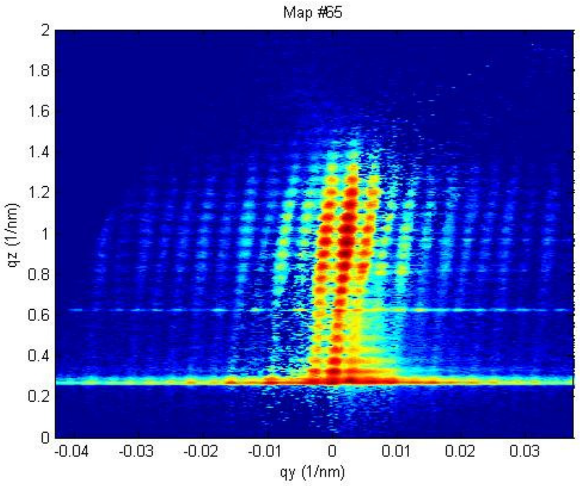

Figure 4. Transverse RSM at the incident angle of α_i=0.2°.

For transvers and radial scans the satellites peaks appear close to the Bragg peak of the Si substrate with a distance in reciprocal space inversely proportional to the lateral spacing of SOI lines. Additonally an asymmetry of the envelop function over the satellites peaks in the radial scans is a measure for the appearance of residual strain.

Radial (scanning along diffraction vector) RMS were applied to the study of the shape as well as the strain distribution of SOI system (see Fig. 5,6). As for transverse RSM the well pronounced modulations and strong diffracted signal can be seen only for the case of incident angle higher than α_{c2}. For small q_z highest scattered signal again was detected at exact position of the α_{c1}. Fig. 6 shows well pounced vertical modulation along q_z. Periodicity of these vertical modulations is about 113 nm which shows a good agreement with results of transverse RMS. Deviation from intensity maximum at q_x=46.177 nm^{-1} provides strain distribution in SOI lines induced by top stressor layer. At the smallest $q_z = 0.268$ nm^{-1} the signal mostly comes from the SOI region closest to Si_3N_4 interface. Here one can see the strongest influence of the of stressor layer by asymmetry and additional broadening of main peak.

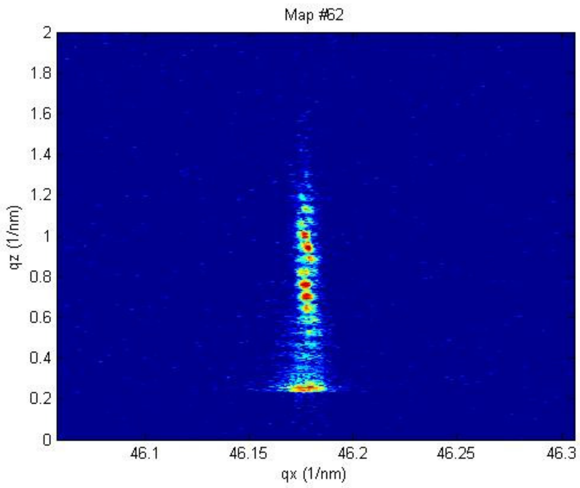

Figure 5. Radial RSM at the incident angle α_i=0.18°

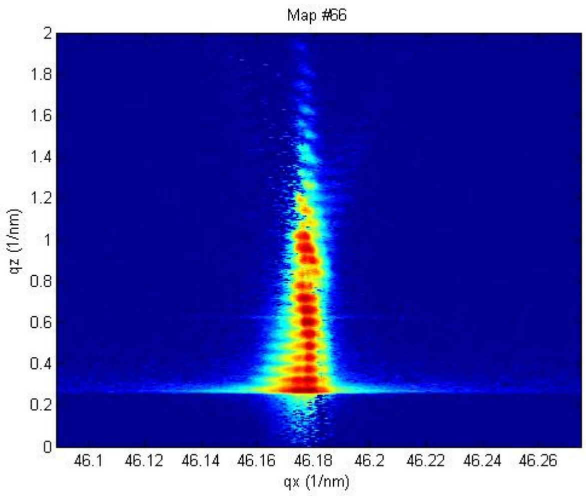

Figure 6. Radial RSM at the incident angle α_i=0.2°

Going deeper inside the SOI lines by increasing q_z the profiles become symmetrical indicating compensation of the stressor induced strain in bulk of SOI. For the largest q_z in the bottom region close to SiO_2 the box asymmetry again starts to be visible with being more intense at the right-hand side (see Fig .6). The strongly tensile strained interfacial region of SOI is caused by relaxation of Si_3N_4 stressor layer. This top layer is followed by nearly compensated intermediate part and afterwards compressively strained region close SiO_2.

Therefore radial RSM allow detailed monitoring of the strain distribution within interplay of tensile and compressive strain along whole SOI system. A spatially resolved strain distribution extracted from GID RSM can be further employed to design transport properties of active layer in SOI heterostructures.

References

[1] M. Gailhanou et al., *Strain field in silicon on insulator lines using high resolution x-ray diffraction*, Appl. Phys. Lett. 90, 111914(2007)

[2] S. Grigorian et. al. , *Grazing-Incidence Diffraction Study of Strain-modulated Single Quantum Well Nanostructures,* J. Phys. D. Appl. Phys. 36, A222 (2003)

[3] J. Grenzer et al., *Nanoengineering of lateral strain-modulation in quantum well heterostructures*, Phys.Rev.B69, 125316 (2004)

[4] U. Pietsch, V. Holy and T. Baumbach, High-*Resolution X-ray Scattering from Thin Films and Lateral Nanostructures* (Springer Verlag, Berlin, 2004)