ESRF	**Experiment title:** Strain fluctuations in strained-silicon-on-insulator (SOI) lines using coherent diffraction	**Experiment number**: **MA-2242**
Beamline: BM02	**Date of experiment**: from: 25 November 2011 (08:00) to: 29 November 2011 (08:00)	**Date of report**: 28 February 2015
Shifts: 15	**Local contact(s)**: **Gilbert CHAHINE**	*Received at ESRF:*

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Report:

Objective

The electronic properties of semiconductor nanostructures are strongly influenced by their strain state –a fact which is exploited particularly in micro-electronics, as the mobility of charge carrier can be enhanced by a factor up to x2,5 in the case of strained silicon-on-insulator [1]. As the size of functional nano-structures is reduced, the ability to map strain at the nanoscale has become essential.

While transmission electron microscopy allows measuring strain maps on single objects, it involves destroying the sample and cannot map a large number of nano-structures. Recently, X-ray Coherent Diffraction Imaging has been used for the quantitative determination of strain in nanostructures down to around 100 nm.

The goal of this experiment was to study **strain fluctuations** in strained **silicon-on-insulator lines of thickness** down to a few 10's of nm, as used in silicon-on-insulator nano-structures. We used the same method we previously demonstrated [2], on 70 nm-thick lines taking advantage of the photon flux increase after the upgrade of beamline id01.

Experimental Method

In previous experiments [2] we found that significant damage could occur to the silicon/silicon oxide interface due to the high photon flux (10^5 photons/s/nm^2). Furthermore, the vertical beam size was smaller than originally expected due to the improved beamline optics, with an FWHM of 104 nm in the vertical direction (and ~250-300 nm horizontal), using the full illumination (300x300µm^2) of the Fresnel-zone-plate ('coherent' illumination corresponding to 60x250 µm^2).

From these characteristics, we opted to rather use the full, partially coherent illumination, and combine this with the fast diffraction mapping possible on id01 (so-called “k-map”), using the continuous scan mode of the piezo stage combined with the maxipix fast readout. A few coherent images using small illumination were also taken (not shown in this report), to allow later reconstruction of the local strain as demonstrated in [2].

The following samples were studied:

- first we evaluated the experimental stability using a test sample (with vertical nanowires for which the horizontal and vertical drift is easily followed) during the first day – it turned out that the stability can be improved by diffracting in the horizontal plane (with horizontal piezo stage and vertical sample)

- a thick [600 nm] strained Ge bridge- this was used as a test sample- for this sample we use k-maps and different tilt angles to determine both the 2theta angle as well as the mis-orientation of the Ge layer. Data collection for this took 6 hours. See figure 1.
- **Strained silicon-on-insulator lines** with a width of 225 nm and thickness 70 nm. Local strain state along such a line was already reported in [2]. In this experiment, we followed individual lines along 90 µm, at two different positions on the sample. This was done using a slow scan along the line, allowing to collect enough information to later reconstruct the inhomogeneous strain at each position of the line. See figure 2.
- **Strained silicon-on-insulator layer** of thickness 70 nm. For this layer we measured the diffraction using a fast-mapping, on an area of 90x90µm^2 using 0.5µm steps, with 0.03s/point. This was collected on two different positions on the sample. See figure 3.
- **Strained silicon-on-insulator lines** of width 110 nm and thickness 70 nm. We measured diffraction using a fast-mapping, on an area of 90 (along the lines) x 20 (perpendicular to the lines) µm^2 using 0.5µm (vertically) x 100 nm steps, with 0.05s/point. See figure 4.

Results

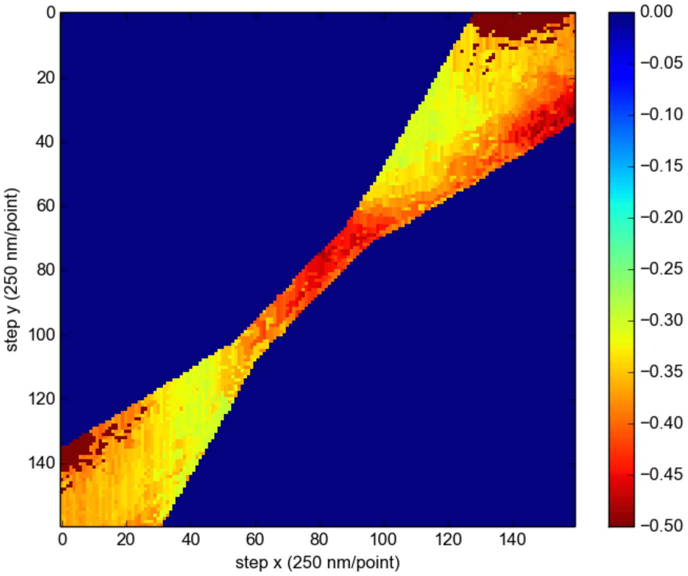

Figure 1: Strain map (ε_{zz}) of a Germanium bridge. The map size is 40x40nm^2, with a 250 nm resolution. The Ge Bridge is stressed in tension, resulting in a lower (-0.45%) c-parameter (direction perpendicular to the bridge).

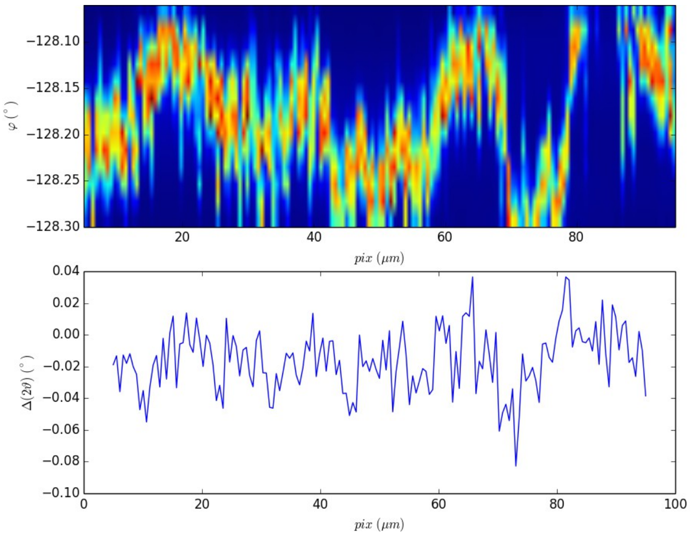

Figure 2: deformation along a strained silicon-on-insulator line: (top) tilt angle (°) value in the scattering plane as a function of the position along the line (µm). (bottom) relative fluctuation of the 2theta angle along the line. Both fluctuations were followed along 90 µm

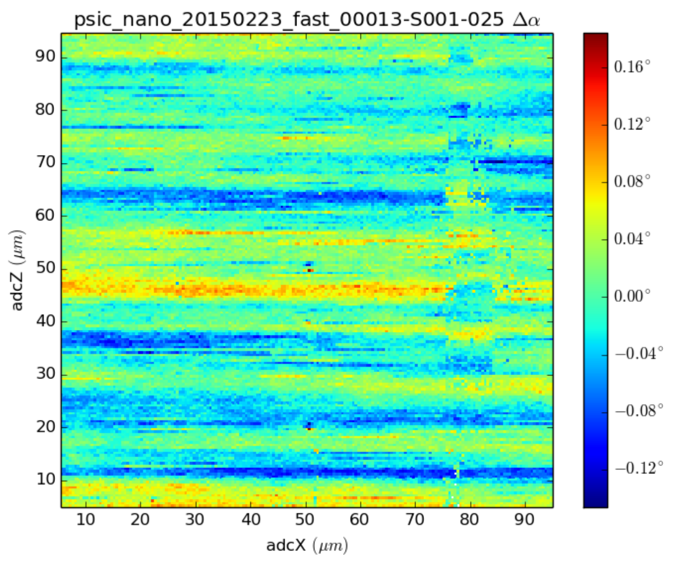

Figure 3: deformation on a 90x90 µm^2 area of a strained silicon-on-insulator layer of thickness 70 nm. The map represents the tilt angle (°) value perpendicular to the scattering plane. The lines are due to the induced strain in the sSOI fabrication process (vertical lines are also present, appearing by mapping the tilt in the scattering plane, as in Figure 2(top)).

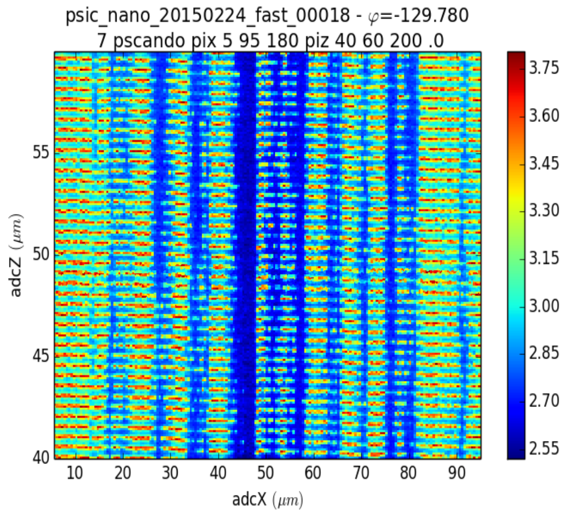

Figure 4: diffraction map for a sample with strained silicon-on-insulator lines with thickness 70 nm, width 110 nm and a vertical period of ~500 nm. The fast map was recorded with 0.05s/point, and a 500x100 nm^2 resolution. The diffraction image was recorded in each point, which will allow to reconstruct the strain and tilt at each position on the sample. The lines are almost horizontal, their apparent non-homogeneity is due to the fact that different parts of the lines are diffracting at different rotation angles.

Conclusions

This experiment was a success, allowing to measure the strain and tilts (along 2 directions) on several strained silicon-on-insulator lines or layers. The available flux was such that we could not measure smaller layers (down to 10 nm) in a reasonable amount of time to yield quantitative results (the k-map process has a minimum speed at which the piezo motor must move, so a 'slow' map would have to be used).

This will however become possible with the addition of a Kirkpatrick-Baez mirror, which combined with a pink beam will allow a 100x increase in flux, allowing quick data collection in a single pass (instead of 20-30 angles in monochromatic mode).

An article will be written on the results for the sSOI layers & lines.

[1] S. Baudot, S., F. Andrieu, F. Rieutord, and J. Eymery, J. Appl. Phys. 105 (2009),114302
[2] F. Mastroprieto et al. Phys. Rev. Lett 111 (2014), 215502