ESRF

	Experiment title: Determination of tensile strain in Ge micro-structures with X-ray micro-diffraction	**Experiment number**: HS-4406
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Report:

Crystalline thin films are ubiquitous in microelectronics and microelectromechanical systems, where high local stress levels can either be detrimental for their integrity or enhance their electronic performance. Consequently, local probes for elastic strain are essential in analyzing such devices. Here a scanning x-ray nanoprobe experiment for the direct determination of strain in crystalline films with a resolution close to the focused x-ray beam size is reported. By scanning regions of interest of several tens of microns at different rocking angles of the sample in the vicinity of two Bragg reflections, reciprocal space was effectively mapped in three dimensions at each scanning position, obtaining the in-plane and out-of-plane strain components. Highly strained Ge devices with potential optoelectronics applications were used to demonstrate the potential of this technique, whose results are compared with finite element models for validation.

X-ray diffraction measurements were conducted at the ID01 beamline where a monochromatic beam of an energy of 8 keV was focused by a FZP to a beamsize of 630 x 230 nm² (horizontal x vertical). The sample was placed at the focal distance of the FZP on a diffractometer equipped with a scanning piezoelectric stage, which allowed its positioning with nanometer precision along its surface plane. A rotation below the sample stage around the horizontal direction served for alignment of the Bragg reflections and for rocking scans. The focus of the FZP was carefully aligned in the vertical direction with this rotation axis with a precision of 10 µm, in such a way that the beam remained on the same spot on the sample within 100 nm precision during rocking scans. A Maxipix detector with 516 x 516 pixels and 55 µm pixel size was fitted to the detector arm of the diffractometer at a distance of 774 mm downstream of the sample.

A range of 1.5 ° around the Ge Bragg peak sample scans were performed covering a total area of 34 x 90 µm² with a step size of 1 µm. In order to speed up the measurements, a so-called continuous scan modality was implemented (similar to other works, e. g. [1]) in which for each line of the mesh scan, the piezoelectric stage continuously moved along one direction and periodically triggered detection. During this time, a buffer of images was stored without feedback to the control system. These measurements were performed at both the (004) and the (0-44) reflections, collecting a total number of 98735 detector frames per reflection.

The obtained detector frames around the two different Bragg peaks at each spatial position were then reconstructed into 3D reciprocal space maps. The average Bragg position was obtained by computing the center of mass (COM) of the Bragg peak. The deviations of the COM from zero in the Q_yQ_z- and the Q_xQ_z-plane obtained from the (004) maps allowed the bending of the bridge to be determined with respect to the x- and y-direction, respectively. After tilt correction the COM positions were then used to calculate the in-plane- and out-of-plane-lattice constants, and to directly determining the strain components ε_{zz} and ε_{yy}, respectively, averaged over the illuminated area. This analysis was performed at each real-space scanning point, effectively obtaining a 2D strain map of the sample.

The strain maps obtained from (004) and (0-44) meshes can be found in Fig. 1, together with strain maps calculated from finite element method calculations. Measurements and calculations agree very well, revealing a large tensile strain in the bridge and a smaller strain in the wider part of the structure.

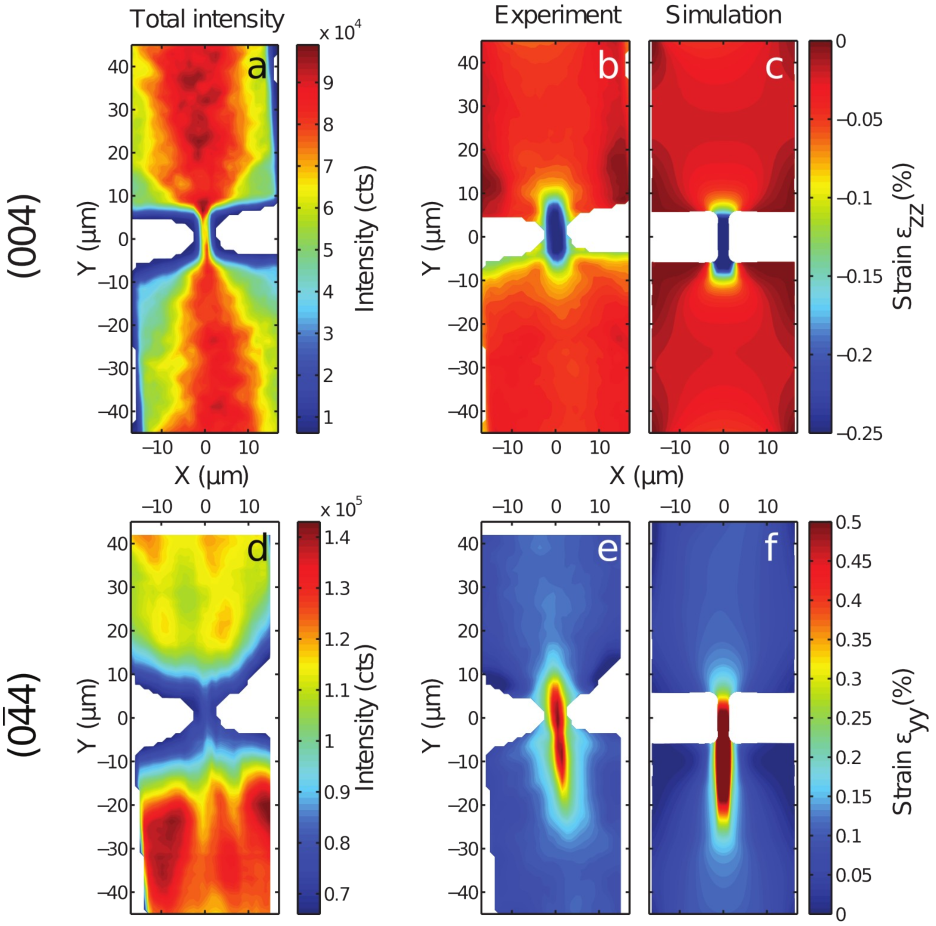

Fig. 1: Comparison of measured and calculated strain in an underetched micro-bridge structure. (a) Total integrated intensity of the measured (004) Bragg reflection. (b) Measured strain along the [001] direction ε_{zz} and (c) FEM calculation for a structure of identical dimensions. Both results are plotted on the same color scale for the strain values. (d) Total integrated intensity of the measured (0-44) Bragg reflection. (e) Measured strain along the [010] direction ε_{yy} and (f) FEM calculation. The slight asymmetry with respect to the x-direction observed in (c) and (f) arises from asymmetric cracks considered in the FEM model according to defects observed in SEM inspections of the sample. The beam impinged on the sample along the positive y-direction.

The method reported here constitutes a fast and practical way of mapping strain on a sample of many tens of micrometers in lateral size with sub-micron resolution, ultimately limited by the size of the beam. The information gained in the experiment was the average strain along the direction of the incoming beam with a sensitivity of 0.002 %.

References:

[1] A. Menzel, C. M. Kewish, P. Kraft, B. Henrich, K. Jemovs, J. Vila-Comamala, C. David, M. Dierolf, P. Thibault, F. Pfeier, and O. Bunk. Scanning transmission x-ray microscopy with a fast framing pixel detector. Ultramicroscopy, 110:1143-1147, 2010.