ESRF	**Experiment title: Strain and composition of core/shell Ge/Si nanowires investigated by Grazing Incidence X-ray Diffraction and Diffraction Anomalous Fine Structure**	**Experiment number**: 02 02 797
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Report:

The interface between the Ge core andSiNx shell appears clearly as illustrated in the SEM pictureof Fig. 1(a). EDS analysis on a radial scan (Fig. 1(b)) highlights the germanium core of the nanostructure surrounded by the silicon nitride shell, respectively revealed by the Ge or both Si and N atomic signatures. The radial Ge/SiNx heterostructure is therefore well defined with no significant atomic inter-diffusion between the core and the shell at this scale of characterization, and SEM observations did not reveal any apparent defects. GIXD measurements were then carried out under synchrotron illumination on sample with standing nanowires to measure the strain of the germanium core lattice parameter. Samples were characterized at the X-ray energy E=10.8keV (λ=0.1148nm) around two different Bragg reflections of the substrate which coordinates in the hexagonal representation of the crystallographic lattice of germanium are (300)h and (220)h. Since these two crystallographic planes are perpendicular to the substrate surface, all measured strains are therefore along a radial direction in the nanowires. A typical diffraction spectrum is given in Fig. 2 for the (220)h reflection (all diffraction measurements around the (300)h reflection are identical and their analysis is therefore similar). The substrate contribution to the diffraction signal is clear with a narrow peak at the (220)h position of the scattering vector (Q=2.8284 nm–1). Two other contributions at lower Q are also extracted from the diffraction signal after fitting of the experimental data. Since the amorphous SiNx shell does not produce any diffraction signal these two other peaks are attributed to the Ge nanowires embedded in the SiNx. The planes closest to the substrate being highly strained to its lattice parameter and we conclude that the peak closest to the substrate one is originating from tilted nanowires while the diffraction signal at lower scattering vector is related to vertical nanowires. Such a splitting of the diffraction signal was previously reported for nanowires grown on a (111)-oriented substrate in a similar case. In the following discussion we will only focus on the left peak, corresponding to the vertical nanowires being strained along a radial direction. After acquiring and analyzing diffraction data from all samples, the nanowires radial strain versus γ=tshell/wirediameter-curve is plotted in Fig. 3 for both reflections (220)h and (300)h. We first notice that measurements around both reflections are similar, which allows us to exclude an influence of the lattice tilt in

the shift of the diffraction maxima. The overall evolution is an increase of the germanium tensile strain with increasing γ, i.e. when the shell thickness becomes larger compared to the nanowires diameter. The strain seems to increase linearly versus γ at low values, but a scattering of the experimental results is noticeable when γ becomes larger than 0.5. This scattering is likely to be caused by the partial peeling of the SiNx shell from the nanowire core. In this case the straining effect of the shell is less efficient and could lead to the scattering in the different measurements of its value.

In conclusion we showed that is possible to induce and control radial strain in germanium nanowires using a core–shell geometry.

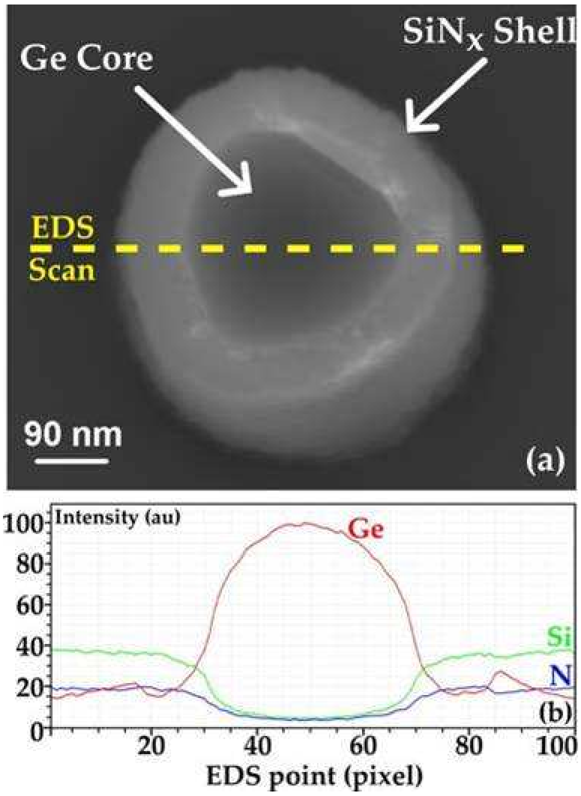

Fig. 1 *SEM and EDS analysis on the cross-section of a Genanowire (d = 200 nm) embedded in a SiNx shell (tsh = 66 nm). (a) SEM top view of the radial heterostructure after breaking the nanowires by ultrasonic agitation. The dashed line is the radial EDS scan. (b) Chemical distribution of Ge, Si and N along the radial scan highlighting the germanium core surrounded by the silicon nitride shell.*

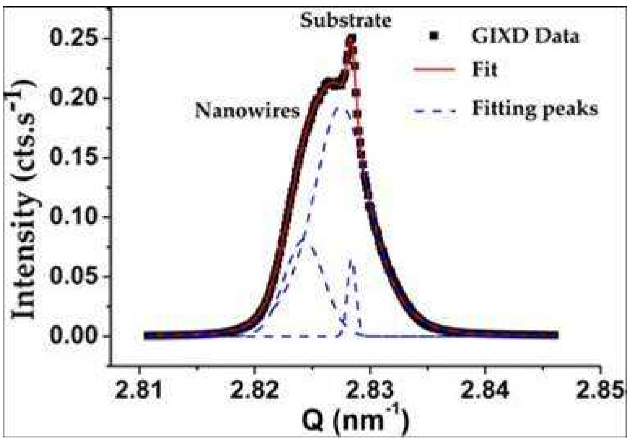

Fig. 2 *Grazing incidence X-ray diffraction spectrum around the (220)h Bragg reflection of the substrate. The illustrated result was obtained for a 100 nm diameter nanowire with a 44 nm thick SiNx shell.*

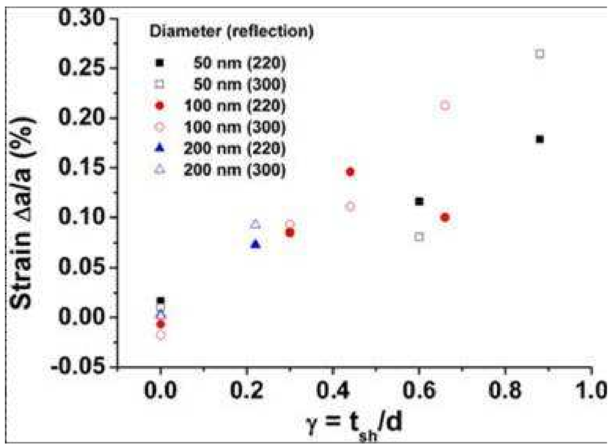

Fig. 3 *Evolution of the radial strain in germanium nanowires embedded in a silicon nitride shell versus the core–shell parameter γ, defined as the shell thickness divided by the nanowires diameter. Results are extracted from the two different reflections (220)h and (300)h.*

Publication(s):

-1 L. Dupré, D. Buttard, P. Gentile, Q. Benoit à la Guillaume, T. Gorisse, H. Renevier, V. Calvo “Controlling the strain of core-shell germanium nanowires: the use of a silicon nitride shell”, on line Physica Status Solidi RRL (2013).

-2 L.Dupré, PhD thesis Université de Grenoble, 24/10/2013.