



Experiment title: Investigation of atomic ordering at crystal interfaces by triple-crystal grazing incidence x-ray diffraction	Experiment number: HS-43 1	
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Report: (Ordering of Self-Assembled Si_{1-x}Ge_x Islands studied by Grazing Incidence X-Ray Small Angle Scattering)

We have investigated strongly strained Si_{1-x}Ge_x islands grown on Cz grown Si (001) substrates by liquid phase epitaxy (LPE) at a temperature of 600° C (Bi solution). The growth has been performed in Stranski-Krastanov growth mode and the islands are monodisperse truncated pyramids terminated by (1 1 1)-facets, as can be observed by atomic force microscopy (AFM) and scanning electron microscopy (SEM) (see Fig. 1). The homogeneity in size and shape over macroscopic distances can be qualitatively understood when taking into account that LPE takes place rather close to thermal equilibrium. For that reason the island base width w does not depend on growth kinetics, but simply scales with the Ge concentration x only. In addition, ordering effects appear as clearly visible in Fig.1. Here, the preferential ordering direction is $\langle 100 \rangle$ and we observe extended rows of islands along these directions (i.e. island base diagonal). The aim of our study was to investigate strength and direction of ordering as a function of the island density. We have investigated our samples already in a previous grazing incidence small angle scattering (GISAXS) experiment carried out at BW2 beamline at HASYLAB/DESY [1]. However, the resolution was restricted to $\Delta q_x = 1.8 \cdot 10^{-3} \text{ \AA}^{-1}$, so that samples with low island densities, i.e. large island spacings, ($\langle d \rangle > 400 \text{ nm}$), could not be investigated. Also the inherent line width of the observed satellite peaks which contains information about the lateral island-island correlation length, ξ , was restricted by the experimental resolution. We have carried out GISAXS at ESRF at BM5 (Optics Beamline) and we have achieved a resolution of $\Delta q_x = 6.0 \cdot 10^{-4} \text{ \AA}^{-1}$ (FWHM) at an x-ray energy of 9.0 keV. This gives us the opportunity to measure the inherent line width of the ordering satellite peaks. We have investigated samples from medium ($w/\langle d \rangle = 0.45$) up to high ($w/\langle d \rangle = 0.75$) island densities. Samples with island densities well below $w/\langle d \rangle < 0.45$ have been investigated by AFM. We can briefly summarize our results as following:

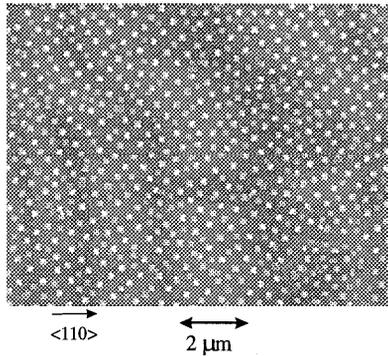


Fig.1: SEM micrograph of a sample with medium island density ($w/d \approx 0.45$).

- For very small coverages, ($w/d < 0.1$) we can observe ordering developing along the base diagonal, i.e. along the $\langle 100 \rangle$ directions.
- With increasing coverage the degree of ordering increases. At medium island densities correlation along $\langle 100 \rangle$ is dominating, however, there is already slight ordering developing along $\langle 110 \rangle$.
- At high island densities we can observe additional ordering along $\langle 110 \rangle$. At very high island density (Fig.2) the ordering along $\langle 110 \rangle$ is even stronger than along $\langle 100 \rangle$: $\xi_{\langle 100 \rangle} = 400$ nm, $\xi_{\langle 110 \rangle} = 600$ nm, $w = 160$ nm, $\langle d \rangle = 215$ nm.

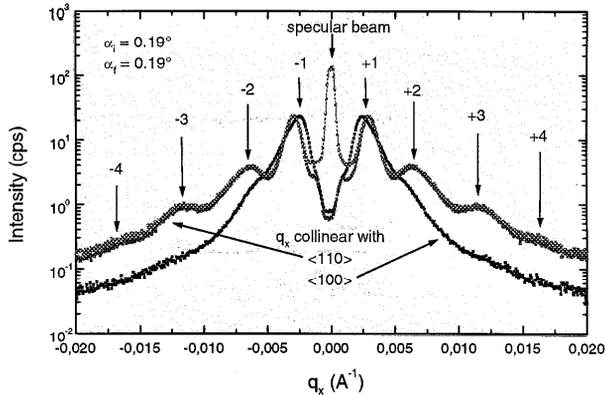


Fig.2: GISAXS intensity profile for a sample exhibiting high island density ($w/d > 0.75$) with the scattering vector q_x collinear with $\langle 110 \rangle$ and $\langle 100 \rangle$. In order to illustrate the experimental resolution (FWHM of specular beam) the curve along $\langle 110 \rangle$ is shown with and without using an absorbing wire. From the peak positions and widths of the satellite peaks (-4, -3, . . . 3, 4) the mean lateral distance $\langle d \rangle$ and the lateral island-island correlation length, ξ , respectively, can be evaluated.

Our preliminary experiment was successful concerning the resolution achieved. However, the photon flux at BM5 was about a factor of 10 below the flux at BW2 (HASYLAB). The discussed ordering of the islands, however, has to be measured along all azimuthal sample orientations. Moreover, the resolution has to be improved by utilising an analyser crystal. These future investigations are only possible at a beamline exhibiting a higher brilliance.