ESRF

Experiment title:
The strain field and correlation of InP quantum dot arrays investigated by triple crystal grazing incidence x-ray diffraction

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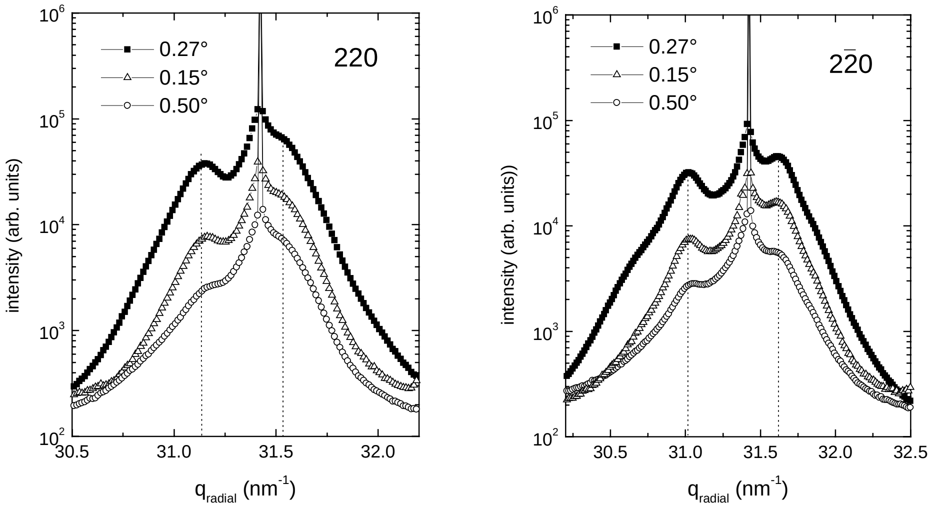
We report on triple crystal grazing incidence x-ray diffraction (GID) and grazing incidence small angle scattering (GISAXS) at superlattices of self assembled InP quantum dots (QDs). A Si 111 crystal analyser and a linear position sensitive detector (PSD) - resolving the vertical q_z direction - were used such that a three-dimensional (3D) mapping $I(q_{angular},q_{radial},q_z)$ of diffuse intensities in reciprocal space could be performed. This technique is useful since the features of diffuse scattering that are related to the strain distribution, the QD shape and spatial correlation are also 3D in their nature. However, this technique is rather time consuming and a 3D mapping takes at least 12 hours or more. Therefore, a comprehensive and systematic depth resolved investigation using different angles of incidence, different kind of reflections and different types of samples – as stated in our proposal - was not possible during the restricted time of 15 shifts. We have, therefore, focused on a selected sample of 10 periods of InP quantum dots (5 monolayers each layer) embedded in InGaP (5 nm each layer).

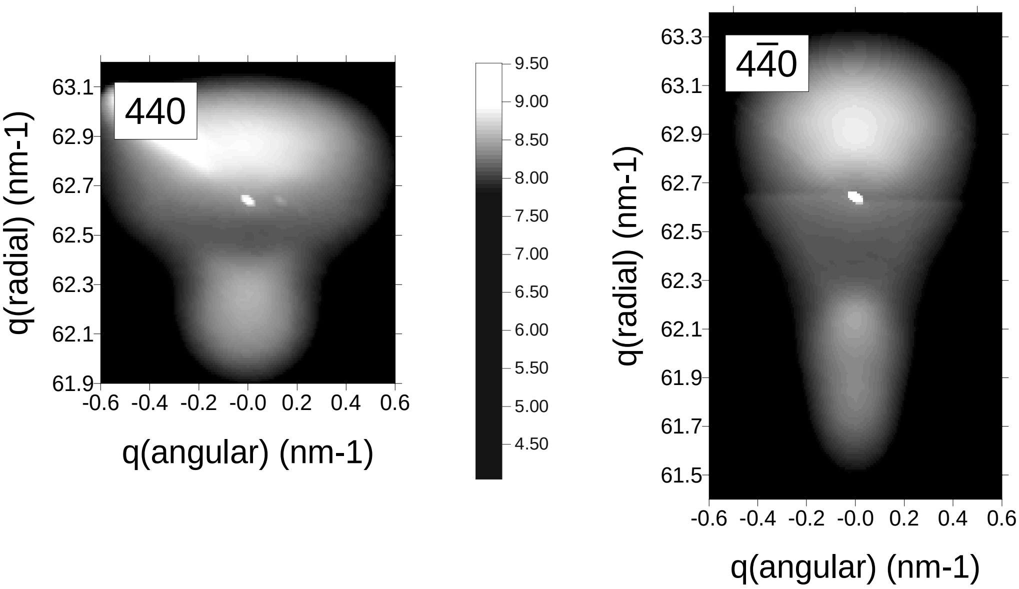
Fig.1a and Fig.1b show 1D radial cuts ($q_{angular} = 0$; integrated intensity over PSD) in the vicinity of the 220 and $2\underline{2}0$ reciprocal lattice points, respectively, performed at different angles of incidence α_i. The two peaks/shoulders (marked as dashed lines) left and right with respect to the substrate reflection ($q_{radial} = 31.44$ nm^{-1}) are caused by dilative and compressive parts inside the QDs and the embedding InGaP. It is known from preliminary theoretical simulations that the peak positions are determined by both elastic strains [1,2] (which are strongly influenced by the island shape) and size related properties (e.g. the spatial decay of the strain field in the vicinity of the QD). There are slight intensity changes between the curves that are caused by the different scattering depth. However, the peak positions do not significantly change when tuning the penetration depth from a few nanometers ($\alpha_i = 0.27°$ and $\alpha_i = 0.15°$) to values close to the entire thickness (t = 65 nm) of the superlattice ($\alpha_i = 0.50°$). This is a strong indication that there is no significant variation of the QD shape and size across the QD superlattice, i.e. the shape and size QDs are at least similar in the first and last layer of the superlattice. Unfortunately, the total thickness of the superlattice though being already close to the critical thickness is not large enough to allow for a higher sensitivity of depth resolution.

It is striking that there is a distinct anisotropy of diffuse scattering with respect to the [110] and [$1\underline{1}0$] directions. As known from investigations on free-standing islands [1,2] this is caused by different island elongations along these two directions. This leads to different elastic relaxation along [110] and [$1\underline{1}0$]. The anisotropy is also clearly seen for the QD superlattice in the vicinity of the 440 and $4\underline{4}0$ reciprocal lattice points (Fig.2a and b; 2D cut through 3D mapping). Surprisingly, the influence of lateral island correlation is missing in Fig.2a and b, although it is remarkable in the vicinity of the 220 reciprocal lattice points (not shown here; see also: [3]) and in respective GISAXS investigations carried out at ID10B (not shown here).



(a) (b)

Fig.1: *Radial scans of triple crystal grazing incidence diffraction (integrated PSD signal) on a 10 period InP/InGaP QD superlattice (a: 220, b: $2\underline{2}0$) recorded at different angles of incidence.*



(a) (b)

Fig:2: *2D cut through reciprocal space (at q_z =0.38 nm^{-1}) around the (a) 440 and (b) $4\underline{4}0$ reciprocal lattice points. The intensity scale is varying logarithmically as shown by the grey scale.*

Presently, respective simulations based on the distorted wave Born approximation are currently developed in order to evaluate the QD size, shape and vertical correlation inside the superlattice.

References

[1] M. Schmidbauer, M. Hanke, F. Hatami, P. Schäfer, H. Raidt, D. Grigoriev, T. Panzner, W.T. Masselink, and R. Köhler, submitted to Physica E (2001).

[2] M. Schmidbauer, F. Hatami, M. Hanke, P. Schäfer, W.T. Masselink, and R. Köhler, submitted to Phys. Rev. B rapid com. (2001).

[3] M. Schmidbauer, F. Hatami, P. Schäfer, M. Hanke, Th. Wiebach, H. Niehus, W.T. Masselink, and R. Köhler, to be published in Mat. Res. Soc. Symp. Proc. (MRS Fall Meeting Boston 2000).