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Report:

We have investigated 10 period SiGe/SiC multilayers grown by solid source molecular beam epitaxy, where the Ge concentration was matched to the C content to compensate the in-plane strain, using x-ray reflectivity. We have recorded the coherent reflectivity and ω-scans, 2θ-scans and offset ω-2θ-scans through the diffusely scattered intensity distribution in order to evaluate the roughness of the interfaces in the multilayers and its correlation properties both parallel and perpendicular to the growth direction (Fig. 1). A wavelength of λ = 1.05 Å close to the absorption edge of Ge was used.

Moreover, we have measured multilayers of self assembled Ge dots grown on (001) oriented Si substrates where part of the misfit strain is relieved due to the islanding. We have studied the vertical and lateral arrangements of the island in these multiple quantum dot superlattices using x-ray reflectivity and x-ray diffraction and tried to assess the strain relaxation of these coherently strained islands. The diffraction patterns consist of two parts: a sharp coherent contribution from the remaining two-dimensional part of the structure and broader diffuse peaks from the dots and the elastically deformed region around them. Simulations of the measured curves allow to extract parameters like the lateral and vertical correlation lengths and the average lattice constant in the dots. We have acquired linear scans in reciprocal space (q_z- and q_x-scans as well as offset q_z-scans), which revealed a shift of the diffuse superlattice peaks with respect to the coherent ones in q_z-direction.

We have also tried to measure the diffraction pattern of self organized InAs quantum dots grown on both (001) and (113) oriented GaAs substrates in order to see whether the primary intensity of a bending magnet is sufficient for their study. Whereas it is sufficient for x-ray reflectivity (Fig. 2), it turned out that this is not the case for x-ray diffraction, since the superlattices partly have a total thickness of only 25 to 50 nm and the dots are quite small.

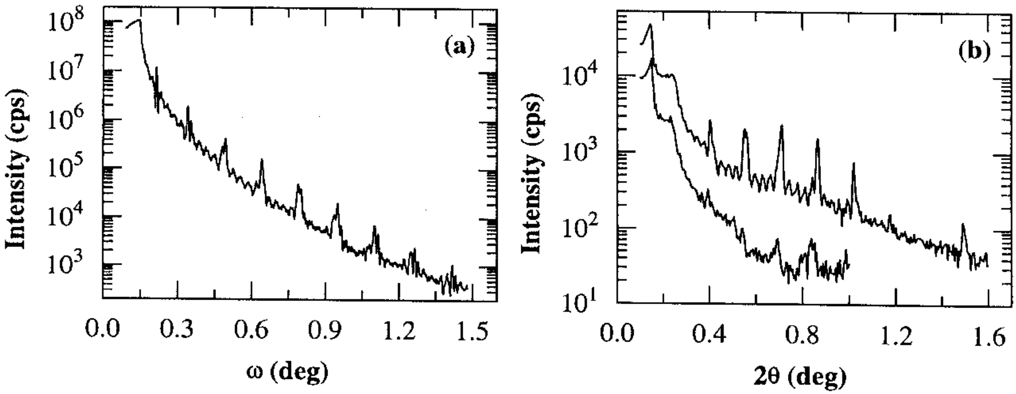

Fig. 1. Specular ω-2θ-scan (a) and 2θ-scans (b) for samples Z315 (upper curve) and Z314.

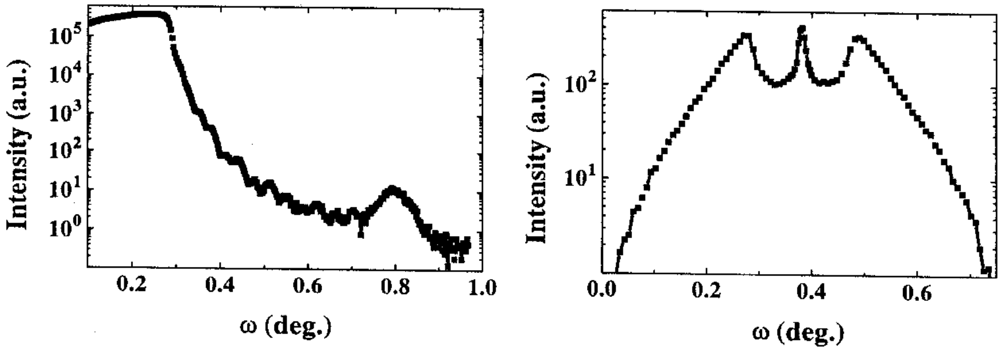

Fig. 2: Specular ω-2θ-scan and ω-scan for a 10 period InAs quantum dot multilayer grown on a (113) oriented substrate.

Furthermore, we investigated the depth profile of Ge in SiGe heterobipolar transistor (HBT) structures prepared by differential epitaxy on Si substrates. Using the small size of the synchrotron beam it was possible to measure diffraction curves of real device structures (transistor arrays of ring oscillators) and to compare these results with conventional laboratory measurements at large (4 x 8 mm^2) test structures. Characteristic differences in the main layer parameters (cap layer and SiGe layer thickness, and maximum Ge content) were found depending on structural size, SiGe coverage, and deposition parameters. This allows a calibration of the routinely used lab measurements of epitaxy process controlling.
Additionally, the homogeneity of the layer parameters in device elements was measured across a whole wafer. This allows conclusions about the temperature distribution during the deposition process.