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Report:

The aim of the experiment was the investigation of the interface morphology of laterally homogeneous multilayers and laterally structured multilayer gratings.

The first type of samples studied were epitaxial MBE-grown Si/SiGe multilayers with a vertical period of 22.3 nm. Their reciprocal space structure consists of a specular truncation rod, modulated with the fine structure of multilayer Bragg peaks and thickness oscillations determined by the actual refractive index profile. The growth conditions lead to the correlation of interface roughness in subsequent layers. This causes a concentration of diffuse scattering into intense sheets around multilayer Bragg peak, thus called "Bragg sheets of diffuse scattering" or "sheets of resonant diffuse scattering" (RDS-sheets). Diffuse scattering also in non-specular direction gives evidence for the presence of interface roughness. For the measurement at ID1, we have used a two-dimensional detector (perpendicular to the plane of incidence) for the measurement of non-coplanar diffuse scattering. This non-coplanar geometry overcomes the restrictions imposed by the sample horizon (limiting Ewald spheres) which limit the explored reciprocal space in conventional coplanar scattering experiments. The high flux available at ID1 enables to measure the scattered intensity with good statistics even far away from the specular rod, while its vacuum-vessel set-up avoids the artefacts of air scattering.
For the studied sample, we have taken 'photographs' of the scattered intensity for a series of different azimuth and incidence angles, see Fig. 1. The laterally extended RDS-sheets made it possible to be sensitive even to high spatial roughness frequencies. The scans were done for several azimuthal orientations. Thus we could study the azimuthal asymmetry of the roughness replication pattern and relate it to (1) the miscut of the substrate, (2) the growth model of the strained multilayer.

The second set of samples consisted of amorphous W/Si multilayer gratings (vertical period 7.8 nm, lateral period 780 nm) grown by MOCVD. The samples differed in the wire-width to lateral-period ratio, due to different types of photoresist material used for the fabrication. Similarly to the experiment described above, we measured non-coplanar scattering by recording the azimuthal dependence of the scattering images for various angles of incidence. Fig. 2 shows the RDS-sheets, caused by replicated roughness, which we have observed for the first time on *amorphous* samples of this type. Contrary to the expected sheets perpendicular to the specular rod, which would be compatible with the usual models of growth of amorphous structures, we have observed *inclined* sheets, similarly to the case of epitaxial multilayers grown on miscut substrates. This finding shows that the roughness replication direction is not perpendicular to the sample surface. The dependence of the diffusely scattered intensity on the scattering vector and on the sample azimuth will now be correlated with the crystal growth model, in order to investigate the influence of the growth technology on the sample structure.

The reciprocal lattice of a laterally periodic grating consists of grating truncation rods (GTRs) positioned equidistantly along the Q_x axis. Measurement and fit of their intensity profiles in coplanar scattering geometry provides one with information on the layer and interface set-up. In this experiment, we have observed for the first time many GTRs excited simultaneously in the non-coplanar scattering geometry (with the plane of incidence parallel to wires). The intersections of the GTRs with the Ewald sphere produce an arc of high intensity superimposed on the background of diffuse scattering (see Fig. 2). In addition, there are less intense arcs of secondary scattering processes. The lateral arc brightness is a measure of the excitation of the GTR wavefields, which is sensitive to the sidewall roughness. We thus could measure and interpret for the first time the diffuse scattering in this geometry of grazing incidence with respect to the sample surface *and* to the grating sidewalls. The comparison with simulations will now yield not only the interface roughness, but also the sidewall roughness. Apart from being technologically relevant, this is also highly interesting from the point of view of scattering theory [1].

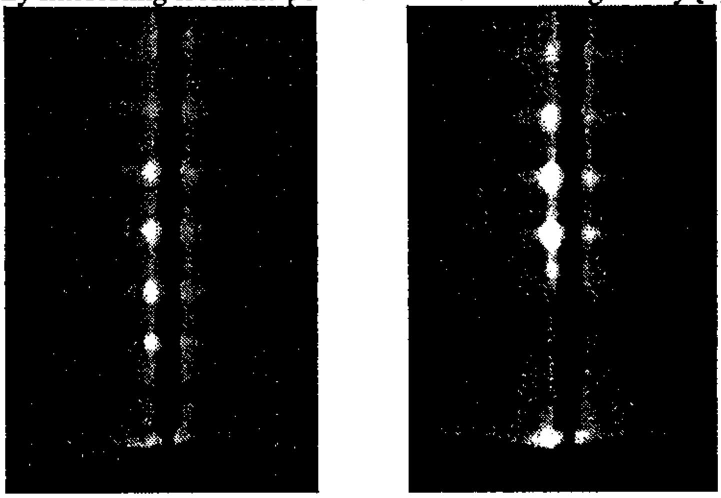

Figure 1. Diffuse scattering from a Si/SiGe multilayer measured at two different azimuths (90 degrees difference). RDS-sheets are straight because of the zero substrate miscut.

Figure 2. Non-specular X-ray reflectivity from a W/Si multilayer grating. Measurement at two different azimuths: 0° (perpendicular to wires, left) and 90° (parallel to wires, right). The RDS-sheets are inclined. The discussed bright arc of many coherently excited grating truncation rods is visible in the figure on the right.

This work has been presented at the ESRF User Meeting 1999.

[1] P. Mikulík, T. Baumbach, Phys. Rev. B 59 (1999), in print.