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Report:

The magnetic properties of $Ge_{1-x}Mn_x$ layers with a small Mn content of few percent are substantially influenced by inhomogeneities of the distribution of Mn atoms in the Ge host lattice. Depending on the substrate temperature during MBE growth, coherent Mn-rich clusters or incoherent, hexagonal Mn_5Ge_3 precipitates can occur [1]. So far from TEM studies the following topotaxial relationship between the precipitates and the cubic Ge host lattice was found: The hexagonal a-axis is parallel to Ge[110], whereas the c-axis is aligned along the Ge [001] direction [1]. To investigate if this relation ship derived from the locally sensitive TEM studies persists for all precipitates within the whole $Ge_{1-x}Mn_x$ layer, we performed XRD in grazing incidence (GID). From GID we can deduce the average in-plane diameter and alignment accuracy of the precipitates depth sensitive and get information on their orientation. During the measurements the incidence angle α_i of the primary radiation was kept constant. α_i was chosen to be 0.32°, i.e., slightly below the critical angle α_c of the total external reflection (0.38° for the energy used), or $\alpha_\mathrm{i} = 0.45°$, yielding a penetration depth D_pen of about 10 nm and 1 μm, respectively. We performed, e.g., a long angular scan around the $(110)_{Mn_5Ge_3}$ peak found along the $[110]_\mathrm{Ge}$ direction. Keeping the detector angle 2θ fixed, we rotate the sample in azimuthal direction from the $[110]_\mathrm{Ge}$ direction by ±70° around the $[001]_\mathrm{Ge}$ surface normal. Instead of a hexagonal 60°-symmetry we found a 30°-symmetry for precipitates, which are only visible with an incidence angle above α_c, i.e. at $D_\mathrm{pen} \sim 1\mu$. These precipitates are hence formed deep within the Ge layer and are denoted as *buried* precipitates. The two equivalent in-plane orientations of the buried precipitates result in the following topotaxial relationship with the Ge host lattice: in both orientations the c_hex-axis is parallel to $[001]_\mathrm{Ge}$ direction and the

angle of the a_{hex}-axis with $[110]_{\text{Ge}}$ direction is either 0° or 30°. From the mean radial FWHM of several buried precipitate peaks we derive the in-plane diameter $D_{\|}$ of 15 ± 2 nm, which is in very good agreement with the values derived directly from TEM (15 ± 5 nm) and indirectly from the simulation of the diffusely scattered intensity of the Ge-host lattice (16 ± 4 nm)[1]. From the mean angular FWHM we derive a value of only $\sim \pm 0.4°$ for the variation of the in-plane orientation of the buried precipitates. Additionally, we found new Mn_5Ge_3 Bragg peaks along $[100]_{\text{Ge}}$, e.g. the (111), (310), (221), (311), (411) and (004) peak, that are related to precipitates with several different *inclined* topotaxial relationships. These peaks are already visible at a D_{pen} of only 10 nm and hence, are related to new classes of Mn_5Ge_3 *surface* precipitates. We can measure also for the surface precipitates a *finite* FWHM $\Delta\Phi$ along the azimuthal direction. From this we conclude that these precipitates nucleate close to the Ge-layer surface in various classes of crystallographic directions with respect to the Ge lattice, but within these classes the deviation from these orientations is not larger than $\sim \pm 0.5°$. The derived mean in-plane surface inclusion diameter $D_{\|,\text{surf}}$ of 22 ± 3 is slightly larger than the corresponding value for the buried inclusions [2].

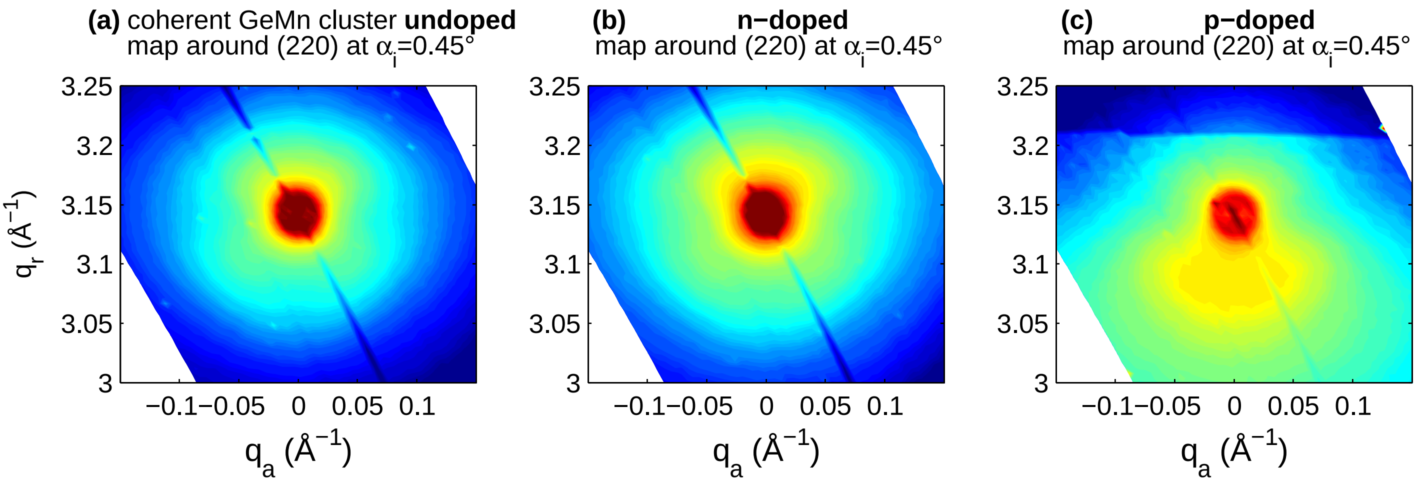

Fig.1: In-plane reciprocal space maps around the (220) Ge Bragg peak of $Ge_{1-x}Mn_x$ thin layer with x_{Mn}=3.4%.

Furthermore, we have investigated the effect of co-doping on the growth of coherent Mn-rich cluster within a 80 nm thin $Ge_{1-x}Mn_x$ layer. We record the diffusely scattered intensity of the Ge-host lattice around the (220) Ge lattice point (see Fig.1). From the distribution of the intensity in reciprocal space we can conclude on the parameter of the coherent Mn-rich inclusions, such as diameter, lattice mismatch and Mn concentration [1]. The samples were grown at the same growth parameter (substrate temperature of 55°C, Mn concentration of 3.4%), but with different co-doping levels: without doping (Fig.1(a)), with n-type (Fig.1(b)) and with p-type co-doping (Fig.1(c)), respectively. The intensity distribution differs within these three maps, most pronounced is the asymmetry of the diffuse intensity at lower q_r-values for the n-doped sample in Fig.(c). Quantitative analysis of the data by simulating these intensity distributions as described in Ref.[1] and Exp.report SI-1467 is under way.

[1] V. Holý, R.T. Lechner, S. Ahlers, et al., Phys. Rev. B **78**, 144401 (2008)

[2] R.T. Lechner, V. Holý, S. Ahlers, et al., to be published