Controlling Ferroelectric Distortion with Magnetic Field in the Multiferroic GeMnTe Semiconductor

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GeMnTe is one of the rare materials that, at low temperatures, are simultaneously ferroelectric (FE) and ferromagnetic (FM). Ferromagnetism is induced by interaction of free holes with the magnetic moments of Mn ions, while the FE moment results from relative displacement of the cation and anion fcc sublattices along a <111> body diagonal, accompanied by transition from cubic to rhombohedral structure. In bulk crystals all <111> directions are equally probable, whereas in thin layers grown on (111) BaF_2 substrates biaxial strain leads to preferential orientation of the FE distortion perpendicular to the layer surface [1]. In order to enable ferroelectric distortions along other body diagonal directions InP, which is almost lattice matched to GeMnTe, was chosen as a substrate.

The present results were obtained on a series of 500 nm thick $Ge_{1-x}Mn_xTe$ layers grown by molecular beam epitaxy (MBE) on BaF_2 (111) and InP (111)A surface substrates. The Mn content, x, was varied between 0.2 and 0.4. The growth on both substrates was conducted simultaneously in the MBE chamber to ensure the same growth conditions, such as Mn and free carrier concentrations. The room temperature lattice constants as well as corresponding FE distortion directions were determined by high resolution x-ray diffraction reciprocal space mapping. The magnetic properties of the layers were derived by SQUID magnetometry. The changes in magnetocrystalline anisotropy were monitored by angular dependent ferromagnetic resonance (FMR) measurements performed at 9.5 GHz with use of a BRUKER ESR spectrometer.

X-ray diffraction mapping confirmed that at room temperature the oblique <111> FE distortion directions in the GeMnTe/InP system occurred considerably more frequently than in the corresponding GeMnTe/BaF_2 layers. In the low temperature ferromagnetic phase, however, only FE distortion along one of the three oblique body diagonals was observed, in contrast to samples grown on BaF_2, where the distortion axis is always perpendicular to the layer surface. Moreover, the specific oblique <111> distortion axis was uniquely determined by the orientation of the applied magnetic field. We demonstrate multiferroic behavior in the GeMnTe/InP layers by the observed complete switching of the spontaneous electric dipole moment from one oblique <111> axis to another induced by the appropriate change of the direction of the applied magnetic field.

[1] H. Przybylińska, G. Springholz, R.T. Lechner, M. Hassan, M. Wegscheider, W. Jantsch, and G. Bauer, Phys.Rev. Lett. **112**, 047202 (2014).

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