Ferromagnetic resonance study of magnetic anisotropy in Ge$_{1-x}$Mn$_x$Te layers on KCl (001) substrate

W. Knoff, A. Łusakowski, J. Domagała, R. Minikayev, and T. Story

Institute of Physics, Polish Academy of Sciences, al. Lotników 32/46, 02-668 Warsaw, Poland

Ge$_{1-x}$Mn$_x$Te is a IV-VI diluted magnetic (semimagnetic) semiconductor which exhibits ferromagnetic properties induced by high concentration of conducting holes. The ferromagnetic Curie temperature of Ge$_{1-x}$Mn$_x$Te layers can be increased up to 190 K by independent optimization of Mn$^{2+}$ ions content and carrier concentration [1,2]. Similarly to GeTe crystals, Ge$_{1-x}$Mn$_x$Te undergoes ferroelectric transition from high-temperature cubic (rock salt) structure to low-temperature rhombohedral structure with the mutual shift of cation and anion sublattices resulting in ferroelectric properties of this material. Recently [3,4] the coupling between structural and magnetic properties was observed in Ge$_{1-x}$Mn$_x$Te layers grown on BaF$_2$ (111) substrate resulting, in particular, in perpendicular magnetic anisotropy. Motivated by the suggested key role of lattice distortion in magnetic anisotropic properties of Ge$_{1-x}$Mn$_x$Te, in this work we apply ferromagnetic resonance (FMR) technique to study magnetic anisotropy in Ge$_{1-x}$Mn$_x$Te layers deposited on KCl (001) substrates. Due to large mismatch of thermal expansion coefficients between the layer and the KCl substrate we expect the layer to be (at low temperatures) under in-plane biaxial compressive strain and corresponding Poisson tensile strain along the growth direction.

The 0.6 micron–thick Ge$_{0.85}$Mn$_{0.15}$Te layers were grown by molecular beam epitaxy on freshly cleaved KCl (001) substrates with 20 nm – thick PbTe buffer layer. Testing various growth regimes and buffers we obtained monocrystalline (001)-oriented Ge$_{1-x}$Mn$_x$Te layers. The crystal structure and thermal mismatch induced distortion was determined by the XRD measurements performed at room temperature. Our experimental study of the angular dependence of the FMR resonant field $H_R$ revealed strong magnetic anisotropy evidenced by about 2 kOe difference (at T=6 K) of the $H_R$ between the in plane (high resonant field) and normal to the plane (lower resonant field) orientation of the applied magnetic field. In contrast to previously studied Ge$_{1-x}$Mn$_x$Te/BaF$_2$ (111)-oriented layers the overall 180 degrees period of the angular dependence of the $H_R$ is now modulated with maxima and minima every 45 degrees corresponding to [110] and [100] directions. We studied the $H_R$ angular dependence for rotating the field in the (010), (110) and (001) planes confirming the dominant role of ferroelectric distortion along [111] direction which is inclined with respect to the surface of the (001)-oriented film.

We analyze the angular dependence of the $H_R$ in (001)-oriented layers taking into account uniaxial anisotropy due to ferroelectric distortion as well as shape (dipolar) anisotropy and crystal field anisotropy contributions of symmetry allowed for biaxially distorted rhombohedral crystal. These results are also discussed in terms of a microscopic model recently proposed in DFT calculations of magnetic anisotropy in Ge$_{1-x}$Mn$_x$Te [5].

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