Ferromagnetic transition and magnetic anisotropy in $Sn_{1-x}Mn_xTe$ epitaxial layers grown on BaF_2 and GaAs substrates

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In our quest for high crystal quality SnTe-based materials exhibiting both topological crystalline insulator and ferromagnetic properties we grew a series of $Sn_{1-x}Mn_xTe$ layers with Mn content up to $x \leq 0.084$ and experimentally studied their magnetic, structural and electric properties. In this work, we compare magnetic properties of the layers grown on various substrates: BaF_2(111), BaF_2 (001), and GaAs (001).

$Sn_{1-x}Mn_xTe$ layers of thickness in the range 0.2 – 1.5 µm were grown by molecular beam epitaxy. For the growth on GaAs a 4-micron-thick CdTe buffer layer was grown first. The crystal structure, chemical composition and interface morphology were examined by X-ray diffraction, transmission electron microscopy (TEM) and X-ray spectroscopy (SEM/EDS) techniques. Magnetization measurements were carried out with a superconducting quantum interference device (SQUID). For magnetic anisotropy studies we applied the ferromagnetic resonance (FMR) technique.

We found that in $Sn_{1-x}Mn_xTe$ ($0.03 \leq x \leq 0.084$) layers, even for the highest Mn content studied and optimal hole concentration, the ferromagnetic transition temperature is below $T_C < 10$ K, i.e., about twice smaller than in corresponding bulk crystals [1]. It is related to our experimental finding that in these layers the saturation magnetization amounts to about half of the value expected for a given concentration of Mn^{2+} ions. It indicates that in our optimal growth regime the substitution of Mn ions at cation sites of the rock-salt lattice of SnTe is limited [2].

The analysis of the angular dependence of the FMR resonance field revealed a dominant magnetic shape anisotropy contribution for all investigated layers with easy magnetization axis located in the plane of the layer. However, while all (001) oriented layers were found to exhibit perfect cubic symmetry, those grown on BaF_2 (111) substrate reveal in angular dependence of FMR resonant field the linewidth features characteristic of material with rhombohedral distortion along the [111] growth direction. Such distortion is known in SnTe and GeTe-based crystals. In contrast to closely related $Ge_{1-x}Mn_xTe$ layers, where such crystal distortion induces perpendicular magnetic anisotropy [3], in $Sn_{1-x}Mn_xTe$ layers the easy direction of magnetization remains in the plane of the layer.We summarize experimental results on magnetic anisotropy contributions due to dipolar interactions (shape anisotropy) and single-ion magnetocrystalline effects in layers differentiated by: layer thickness and substrate material related strains, stoichiometry regime in SnTe matrix and Mn content.

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