Magnetic and Structural Properties of Ferromagnetic GeMnTe Layers


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Abstract. Ferromagnetic Ge\(_{1-x}\)Mn\(_x\)Te thin films with x ≤ 0.19 were deposited on (111) oriented BaF\(_2\) monocrystals using molecular beam epitaxy technique. X-ray diffraction carried out at high temperatures for samples with x ≤ 0.05 revealed ferroelectric transition from rock-salt to rhombohedral structure at \(T=625-675\) K. The magnetic properties investigated with SQUID magnetometry and ferromagnetic resonance technique exhibit an easy magnetization direction normal to the plane in as grown samples. We attribute this finding to lattice strain due to mismatch of thermal expansion coefficients or to the crystalline stress related to inhomogeneous distribution of Mn ions in the sample volume. Thermal treatment changes the easy axis into in-plane direction which can be associated with distinct improvement of the structural properties.

1. Introduction

GeTe is the only one from the family of IV-VI narrow gap semiconductors, which demonstrates ferroelectric transition observed as transformation (an inner displacement along a [111] direction) from paraelectric rock-salt to ferroelectric rhombohedral structure while the temperature is lowered [1]. Incorporation Mn into GeTe crystal matrix brings an additional mechanism – magnetic interaction via quasi-free carriers (Ruderman-Kittel-Kasuya-Yosida interaction) between spin of \(S=5/2\) originating from Mn\(^{2+}\) ions (3d\(^5\) electron configuration) and makes this material ferromagnetic. Increase of Mn content in Ge\(_{1-x}\)Mn\(_x\)Te brings about uptrend of ferromagnetic Curie temperature up to maximal \(T_C=150\) K for \(x=0.5\) whereas temperature of ferroelectric transition shows opposite behaviour, i.e. decrease from around \(T=670\) K for GeTe down to total decay about \(x=0.3\) [2]. Such situation gives an opportunity to simultaneously control both transitions dependently on both Mn ions as well as the holes concentrations. The most interesting question is a role of coupling of these mechanisms, especially in the region located in between \(x=0.25\) and \(0.30\) where the crossing of both ferroelectric and ferromagnetic transitions is expected to take place.
2. Growth and characterization of layers.

Thin films GeTe, GeMnTe and GeMnTe/GeTe heterostructures up to 1 µm thick were grown on (111) surface of cleaved BaF$_2$ monocrystals using molecular beam epitaxy (MBE) technique. Concentration of Mn up to x=0.19 in Ge$_{1-x}$Mn$_x$Te layers was determined by the energy dispersive X-ray fluorescence analysis (EDXRF). The reflection of high energy electron diffraction (RHEED) technique used during the growth process shows streaky patterns indicating layer-by-layer (Frank-van der Merve) mode of growth. However post-growth examination of structural properties performed by X-ray diffraction (XRD) revealed stratification of some samples especially in GeMnTe. The secondary ion mass spectrometry (SIMS) confirms inhomogeneous distribution of Mn ions in such layers. In spite of this observation a relatively small full width at half maximum (FWHM) parameter of the X-ray rocking curves was found to be in the range 100-600 arcsec. To check ferroelectric properties of GeMnTe a high temperature (from 300 to 700 K) XRD measurements were performed. Clear structural transition was observed in GeMnTe (Fig. 1). More complicated phase diagram is presented for GeMnTe/GeTe where no clear single transition is observed.

The standard four-probe Hall measurements at temperature 77 and 300 K in magnetic fields up to 1.3 T show anticipated p-type conductivity with high carrier concentration of the order of $10^{20}$ cm$^{-3}$ in GeTe and $10^{21}$ cm$^{-3}$ in