Ferromagnetic GeMnTe Epilayers and Heterostructures with T_C Values above 200 K

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Introduction

Magnetic semiconductors have attracted great interest as possible key elements for realization of spintronic devices. For such applications, ferromagnetic (FM) semiconductors with high Curie temperatures T_C are required that can be integrated in heteroepitaxial multilayer structures. A promising material is the IV-VI ferromagnetic semiconductor $Ge_{1-x}Mn_xTe$, which has been reported to have a T_C ~ 150 K for bulk material and of 130 K for thin films grown by molecular beam epitaxy (MBE) techniques [1], respectively. In contrast to the Mn-based III-V compounds, in the IV-VI materials the carrier density can be controlled independently of the concentration of the magnetic ions, and the ternary solid solutions are thermally stable and exist over a very wide composition region.

In this work, the magnetic and structural properties of $Ge_{1-x}Mn_xTe$ epilayers as well $Ge_{1-x}Mn_xTe$ heterostructures with MnTe and PbSe spacer layers were studied. The aim is to investigate the influence of the non-magnetic spacer layers on the magnetic properties of the FM semiconductor layer, as it was shown for other IV-VI superlattice (SL) structures [2], [3].

Sample Preparation

The samples were grown by MBE using compound GeTe and elemental Mn and Te_2 sources. The Mn concentration x_{Mn} was varied from 0.23 to 0.65, whereas the hole concentration was varied by excess Te_2 flux from $5 \times 10^{18} cm^{-3}$ to $1 \times 10^{21} cm^{-3}$ to find the optimum value for the highest T_C. The 1 µm epilayers were grown directly on (111) BaF_2 substrates or on 2 µm thick PbSe buffer layers. Under appropriate growth conditions single crystalline epilayers are obtained as proven by *in situ* reflection high energy electron diffraction (RHEED) studies. *Ex situ* x-ray diffraction investigation (XRD) revealed that the $Ge_{1-x}Mn_xTe$ epilayers show a cubic NaCl structure with (111) orientation.

Experiments

Magnetization measurements were performed with a super conducting quantum interference device (SQUID) magnetometer to determine the magnetic properties of the samples.

In Fig. 1 we compare the magnetization data of 3 samples with the same x_{Mn} value: Of one $Ge_{0.66}Mn_{0.34}Te$ single layer sample, as well as of two superlattice (SL) samples consisting of 20 × [3 nm $Ge_{0.66}Mn_{0.34}Te$ / 27 nm PbSe] and 40 × [86 nm $Ge_{0.68}Mn_{0.32}Te$ /

3.5 nm MnTe], respectively. The epilayer sample and the $Ge_{1-x}Mn_xTe$ / MnTe SL show clear ferromagnetic (FM) hysteresis loops and T_C values of above 200 K derived from magnetization vs. temperature curves (see Fig. 1). In strong contrast to the pronounced FM behavior of these two samples, the $Ge_{0.66}Mn_{0.34}Te$ / PbSe SL depicts only paramagnetic behavior (see Fig. 1).

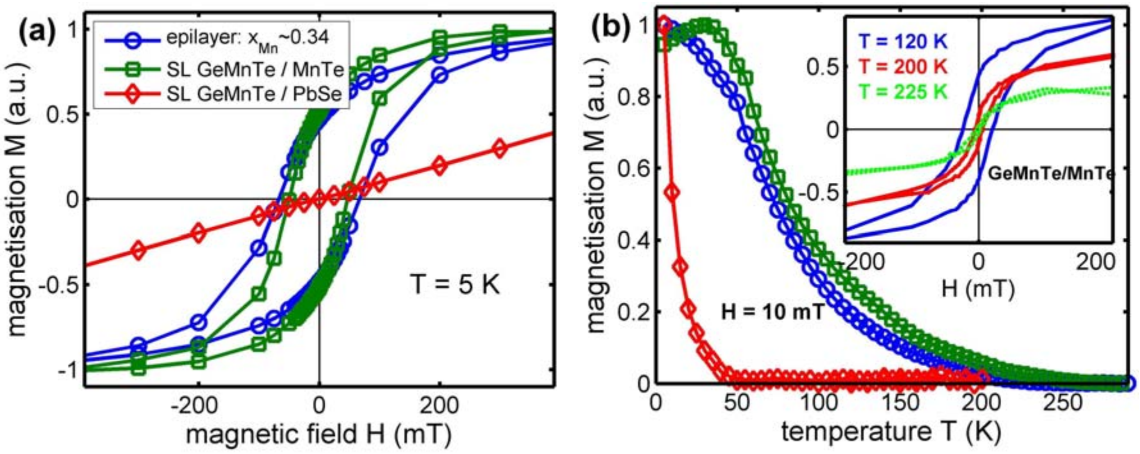

Fig. 1: (a) Magnetization M vs. magnetic field H of a GeMnTe epilayer, a GeMnTe/MnTe and a GeMnTe/PbSe superlattice at T = 5 K. (b) M vs. temperature T of the samples in (a) at magnetic field H = 10 mT. inset: Ferromagnetic hysteresis loops of the GeMnTe/MnTe SL at temperatures T = 120 K, 200 K and 225 K.

Conclusion

We suggest that this is due to a smaller band gap of the non-magnetic spacer layer PbSe with respect to GeMnTe, which forms wells in the GeMnTe/PbSe heterostructures. From FTIR spectroscopy we derive an effective band gap value of around 280 meV for PbSe and 1800 meV for MnTe compared to 700 meV for $Ge_{0.66}Mn_{0.34}Te$. Hence, for the PbSe SL the conducting holes in the FM layer are transferred to the non-magnetic layer and the ferromagnetic ordering caused by the carrier induced RKKY interaction breaks down. In contrast, MnTe has a higher band gap value and thus in the GeMnTe/MnTe SL the holes remain in the GeMnTe layer.

References

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