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MAGNETIC CHARACTERIZATION OF MOLECULAR BEAM EPITAXY GROWN $Cd_{1-x}Mn_xTe$ STRUCTURES*

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The paper reports on the application of SQUID magnetometry to probe magnetic ion distribution in epilayers and at interfaces of diluted magnetic semiconductors. We present also new results on the possible influence of the magnetic confinement on the formation of the spin-glass phase, and on antiferromagnetic phase transition in zinc-blende MnTe.

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Results of previous studies [1] on magnetic properties of CdMnTe epilayers grown by molecular beam epitaxy (MBE) on InSb substrates [2] revealed that magnetization measurements may serve as an effective tool for investigation of Mn distribution within the epilayer. Namely, we found systematically greater values of the high temperature magnetic susceptibility in MBE layers than in their bulk counterparts. Since spin–spin interactions in $Cd_{1-x}Mn_xTe$ are antiferromagnetic it was concluded in [1] that a smaller clusterization occurred during the non-equilibrium growth. However, this process did not lead to a change of magnetic properties at low temperatures, where transitions to either spin-glass ($x < 0.60$) or antiferromagnetic ($x = 0.70$) phases were observed to occur at the same temperatures as in bulk samples. The latter fact suggests that the growth technique does not affect these properties of the distribution function of magnetic atoms which is important for the long range magnetic order. Also, an enhanced paramagnetic contribution to the magnetic susceptibility at low temperatures has been found in CdTe/CdMnTe superlattice. The latter effect was assigned to the presence of isolated paramagnetic ions in the interface regions as a result of an intermixing of Mn and Cd ions and/or a smaller number of magnetic bonds at the interface.

In this paper we report results of magnetic measurements performed on both thick ($Cd_{0.60}Mn_{0.40}Te$ and MnTe) epilayer and CdTe/$Cd_{0.50}Mn_{0.50}Te$ superlattices grown by MBE on GaAs substrates [3]. In order to reduce effects of

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the lattice mismatch, GaAs was buffered with 3 μm of CdTe. The measurements of temperature dependent magnetization $M(T)$ were performed in a home-made SQUID magnetometer system at $H = 1$ kOe. The epilayers were orientated parallel to the magnetic field. We measured the zero-field cooled (ZFC), the field cooled (FC), and the thermoremanent magnetization (TRM). The DC magnetic susceptibility $\chi(T)$ was calculated from the relation $M(T) = \chi(T)H$.

Figure 1 collects results of $\chi(T)$ for 3 μm $Cd_{0.60}Mn_{0.40}Te$ epilayer and three $CdTe/Cd_{0.50}Mn_{0.50}Te$ superlattices. The superlattices have the same CdTe thick-

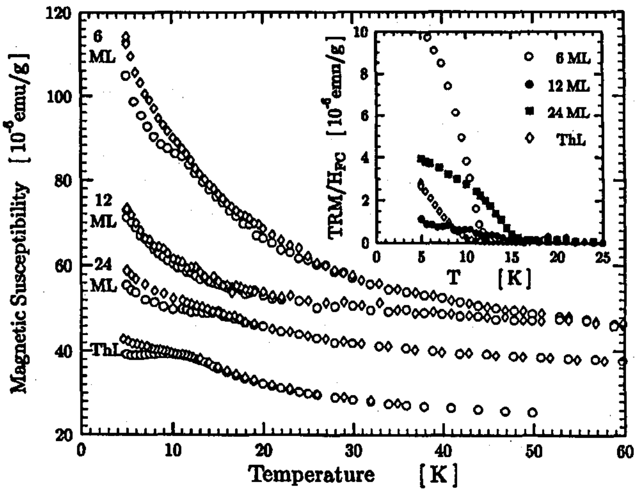

Fig. 1. Temperature dependence of the magnetic susceptibility for (ThL) — 3 μm thick layer of $Cd_{0.60}Mn_{0.40}Te$, and three $Cd_{0.50}Mn_{0.50}Te$ superlattices: (24 ML) — 100× (16 ML CdTe / 24 ML CdMnTe), (12 ML) — 150× (16 ML CdTe / 12 ML CdMnTe), and (6 ML) — 200× (16 ML CdTe / 6 ML CdMnTe). Circles stand for ZFC and diamonds for FC measurements. The inset collects TRM results for the above structures obtained after FC in 1000 Oe.

ness of 16 monolayers (ML) and decreasing thickness of CdMnTe layers (24, 12, and 6 ML) repeated 100, 150, and 200 times respectively. The thick layer showed, contrary to the layers grown on InSb [1], values of $\chi(T)$ fairly similar to those of the bulk material. The superlattices, on the other hand, exhibit progressively increasing values of $\chi(T)$ with the decrease in the superlattice period. We assign this, as previously [1], to the enhanced paramagnetism originating in the interface region. This contribution was parameterized as $NCT^{-\alpha}$, with N being the number of periods of each superlattice, and treating C and α as adjustable parameters. However, it proved impossible to correctly reproduce $\chi(T)$ values for all three superlattices using one set of C and α. However, in all three superlattices α was found to be rather small, $\alpha \approx 0.2 \pm 0.1$.

Investigations of the magnetic behaviour of low-dimensional CdMnTe are only in initial state. For canonical spin-glasses theory predicts a critical dimensionality of between two and three for the spin-glass state [4], therefore this state could be expected to vanish as the thickness of CdMnTe layer is reduced. The study of such an effect was initiated by Awschalom et al. [5]. They found that in CdMnTe, grown directly on GaAs, the spin-glass tended to vanish as the layer thickness was reduced to 12 monolayers (ML). Our surprising observation is that while in the 12 ML sample we can hardly see any fingerprints of the spin-glass formation (the FC measurement follows the ZFC one and the TRM is the smallest of them all, see inset to Fig. 1), the spin-glass effects are clearly visible in the thinnest 6 ML superlattice.

The MBE technique allows to grow cubic $Cd_{1-x}Mn_xTe$ with Mn concentrations, where bulk growth methods produce material of mixed structural phases. We investigated two zinc-blende MnTe layers with different layer thickness: 1.9 μm and 5.6 μm [6]. Both layers showed antiferromagnetic phase transition at $T = 67 \pm 1$ K (see Fig. 2). This temperature differs by 7 K from the transition temperature re-

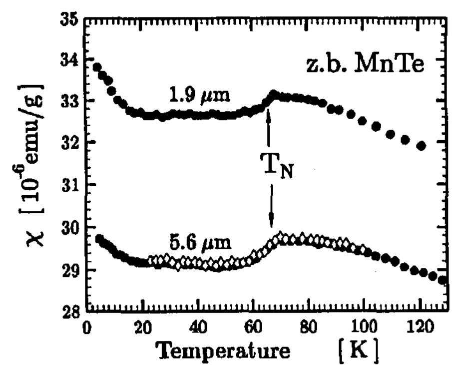

Fig. 2. Temperature dependence of the magnetic susceptibility for two zinc-blende MnTe epilayers. Symbols represent different layer orientation: • — parallel, and ◇ — perpendicular to the magnetic field. The antiferromagnetic Néel temperature was taken at the maximum of $d\chi/dT$.

ported earlier for zinc-blende MnTe obtained by ionized cluster beam method [7], but perfectly matches the Néel temperature known from neutron scattering studies on MBE grown MnTe [8]. Also, both layers exhibit fairly similar absolute values of the magnetic susceptibility. This indicates good uniformity of the 5.6 μm layer, underlying a good command of the growth process. Finally, we checked the influence of the orientation of the layer with respect to the magnetic field. As seen in Fig. 2 neither the transition temperature nor the strength of the transition depends on the orientation.

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