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MAGNETIC PROPERTIES OF MOLECULAR BEAM EPITAXY GROWN HIGH x $Cd_{1-x}Mn_xTe$

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Magnetization measurements performed on molecular beam epitaxy grown $Cd_{1-x}Mn_xTe$ structures revealed basically similar magnetic properties of thick epilayers to their bulk counterparts. However, remarkably different properties were detected for a superlattice. These are attributed to a smearing out of the Mn profile in the superlattice.

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Though it has already been well established that the reduction of the dimensionality does change various electronic properties, the magnetic manifestation of the reduced dimensionality still awaits to be fully explored. In particular, for spin glasses the question of the lower critical dimension (the dimension below which systems cannot support long range spin-glass order) has attracted enormous theoretical effort, yielding 2D as the expected threshold dimension [1]. However, the progress in experimental work is well behind the theoretical investigations. It is believed that diluted magnetic semiconductors [2, 3] structures grown by molecular beam epitaxy(MBE) are particularly suitable for magnetic studies of the dimensional crossover. Awschalom et al. [4] have already claimed the disappearing of the spin-glass feature with decreasing of $Cd_{1-x}Mn_xTe$ layers thickness below about 40 Å in CdTe–$Cd_{1-x}Mn_xTe$ superlattices. Nevertheless, a comprehensive study on this issue is still required.

This paper reports our preliminary results of magnetic properties of high x $Cd_{1-x}Mn_xTe$ MBE epilayers and a superlattice structure, which we regard as the initial step towards further studies of superlattices with progressively decreasing thickness. All investigated samples were grown by MBE on InSb (001) substrates at the University of Hull [5]. The measurements of temperature dependent magnetization $M(T)$ were performed on a SQUID magnetometer at $H = 1$ kOe. In the standard manner the zero-field cooled (ZFC), the field cooled (FC) and the thermoremanent magnetization (TRM) were measured. The DC magnetic susceptibility $\chi(T)$ was calculated from the relation $M(T) = \chi(T)H$.

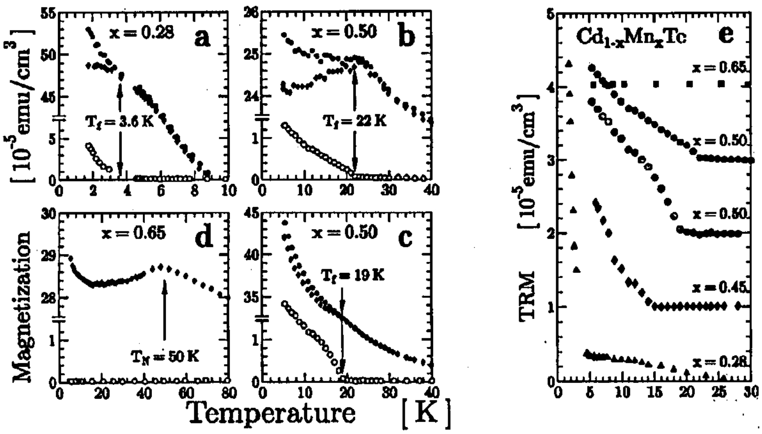

Fig. 1. Low temperature dependence of the magnetization at $H = 1$ kOe for 2 μm thick layers of $Cd_{1-x}Mn_xTe$ (a, b, d) and CdTe—$Cd_{0.50}Mn_{0.50}Te$ superlattice (c). Symbols represent: • — FC, full rhombus — ZFC magnetization, o — TRM. (e) Joint plot of TRM for the samples from Fig. 1a–d (grey circles — the superlattice) and for a bulk $Cd_{0.55}Mn_{0.45}Te$. The data were shifted apart for clarity.

Low temperature $M(T)$ and TRM for 2 μm thick epilayers with $x = 0.28$ and 0.50 are collected in Figs. 1a and 1b. The transition to the spin-glass phase is clearly visible, with the freezing temperature, T_f, being in general agreement with values expected for their nominal compositions. Though T_f can be established from the departure point of FC and ZFC plots, the best indication of T_f was obtained from the vanishing of the TRM [6]. Another interesting feature comes out from a joint plot of all measured TRM traces (Fig. 1e), where it is demonstrated that the slopes of the TRM decrease monotonically with x. Therefore, the TRM measurements give also a good measure of the Mn concentration. The fact will be employed further on.

The non-equilibrium nature of MBE growth causes the crystallographic structure of the layers to match that of the substrate, and so allows the growth of zinc blende structure $Cd_{1-x}Mn_xTe$ at high x, where bulk growth produces mixed phases. This was confirmed by the observation of antiferromagnetic behaviour in the sample with a nominal x of 0.65, with Néel temperature of 50 K (Fig. 1d). This is much higher than previously observed in bulk for this composition [2].

Let us consider now magnetic properties of the superlattice structure which consisted of 200 layers of $Cd_{0.50}Mn_{0.50}Te$, each 100 Å thick, separated by 50 Å layers of CdTe. They are contrasted with the result from the thick layer with the same Mn content in Figs. 1c and 1b. The two samples thus contain the same amount of magnetically active material, but their $M(T)$ and TRM exhibit different temperature dependencies. In particular, the superlattice showed: (i) a considerably smaller transition temperature $T_f = 19$ K ($T_f = 22$ K for the thick layer) and (ii) a giant paramagnetic-like increase in both FC and ZFC. However, the above effects cannot be simply attributed to the effect of the reduced dimensionality on the magnetic state. On the contrary, we assign these to an imperfect, non-rectangular, Mn profile in the superlattice. First of all, it should be pointed out that the TRM for the superlattice marks not only smaller T_f, its slope is smaller as well. As mentioned before, this indicates a decrease in Mn concentration in CdMnTe layers. Secondly, as it has been shown by high resolution electron microscopy (HREM) lattice images method [7], due to a surface diffusion lower for Mn than for Cd, CdMnTe layers do not grow uniformly. The effect leads to non-abrupt interfaces which may be as wide as 7 monolayers for a 100 Å thick layers. This smears out the ideal rectangular superlattice profile and leads both to a reduction of the Mn content in CdMnTe layers and to an occurrence of a very low x $Cd_{1-x}Mn_xTe$ in the interface regions. The latter effect is responsible for the observed paramagnetic catastrophe in superlattice.

To evaluate the degree of the effect, we assumed the profile to remain rectangular, but with some uniform concentration of Mn in the CdTe spacers, i.e. $Cd_{1-x}Mn_xTe$–$Cd_{0.50}Mn_{0.50}Te$ superlattice. The Curie–Weiss relation $\chi = C/(T+T_0)$ was fitted then to the difference between $\chi(T)$ dependencies for the superlattice and the thick layer (see Fig. 2). A very good fit was obtained with the

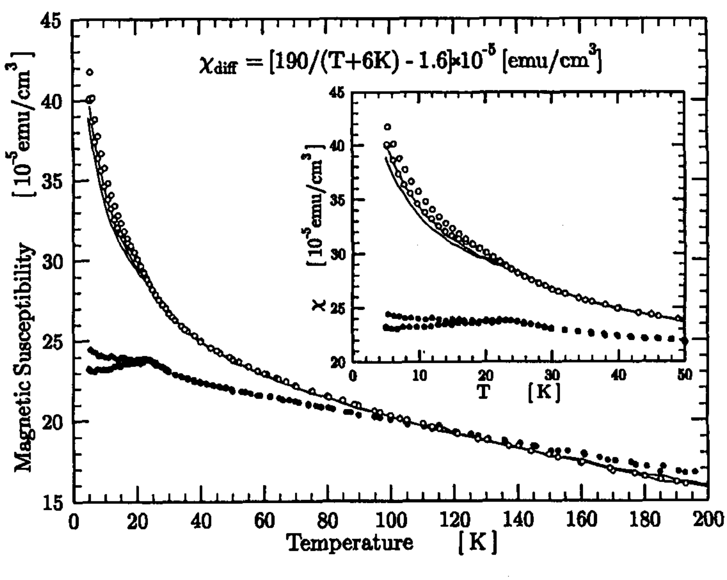

Fig. 2. Temperature dependence of the magnetic susceptibility for the thick layer of $Cd_{0.50}Mn_{0.50}Te$ (full symbols) and the CdTe–$Cd_{0.50}Mn_{0.50}Te$ superlattice (open symbols). The solid line represents the Curie–Weiss relationship, χ_{diff}, with C and T_0 adjusted to fulfil the condition: $\chi(T)_{superlattice} = \chi(T)_{thick\,layer} + \chi_{diff}$. The inset blows up low-temperature part of the data.

Curie–Weiss constant C corresponding to $x_{eff} = 0.03 \pm 0.01$ and $T_0 = (6 \pm 1)$ K. Since an even Mn distribution in CdTe spacers was assumed, we regard these numbers as very reasonable and so supporting the above conjecture. The very similar numbers come out from the same approach to $\chi(T)$ data for CdTe–MnTe superlattice [8]. There $x_{\mathrm{eff}} = 0.05 \pm 0.01$ and $T_0 = (1 \pm 1)$ K were found, which suggests that the profile smearing effect is a general feature and should be taken into account, when further studies of dimensionality crossovers are considered.

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