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INVESTIGATION OF SPIN-GLASS TRANSITION IN SEMIMAGNETIC QUANTUM WELLS BASED ON $Cd_{1-x}Mn_xTe$ BY MEANS OF OPTICAL SPECTROSCOPY

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The spin-glass transition in $Cd_{1-x}Mn_xTe$ epitaxial layers and bulk samples with $0.24 \le x \le 0.43$ and in quantum well structures on the basis of $Cd_{1-x}Mn_xTe$ were investigated by means of optical spectroscopy. Reduction of dimensionality of $Cd_{1-x}Mn_xTe$ layers down to the quasi-two-dimensional case realized in $Cd_{1-x}Mn_xTe/Cd_{1-y}Mn_yTe$ heterostructures frustrates the spin-glass formation, which is in agreement with theoretical predictions. The spin-glass formation is also frustrated in the vicinity of interfaces between semimagnetic and nonmagnetic semiconductors in $CdTe/Cd_{1-x}Mn_xTe$ quantum wells.

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The spin-glass phase transition in semimagnetic semiconductors like $Cd_{1-x}Mn_xTe$ has been evidenced in magnetization experiments from the cusp in the temperature dependence of the magnetic susceptibility [1]. Recently the SQUID method has been applied to low-dimensional heterostructures in order to establish the effect of the dimensionality on the spin-glass phase formation [2]. The SQUID magnetometry is a direct method, but its facilities are limited to special structures with a relatively large volume of magnetic material. We report here on optical studies of the spin-glass transition in quantum well structures with the use of a method analyzing the temperature dependence of the magnetic-field-induced polarization degree of excitonic photoluminescence (PL) $P_c(B)$ suggested first in Ref. [3]. It was shown that $P_c(B)$ is controlled by thermodynamical fluctuations in the magnetic system and is proportional to the magnetization [4]. The critical temperatures T_{SG} determined from the cusp in the temperature dependence of the polarization degree of the excitonic luminescence in bulk material and in thick epitaxial layers were found to be in good agreement with results of previous direct magnetization experiments [1, 3]. We found no difference in T_{SG} for MBE- and Bridgman-grown samples. This fact is somehow surprising because the growth conditions differ strongly: the MBE process provides nonequilibrium growth conditions due to low growth temperatures (about 250–350°C) in comparison with the Bridgman growth from the melt. We studied a series of semimagnetic heterostructures containing either thin semimagnetic $Cd_{1-x}Mn_xTe$ wells embedded in nonmagnetic $Cd_{1-y}Mg_yTe$ barrier layers (structure type B) or nonmagnetic CdTe quantum wells in semimagnetic $Cd_{1-x}Mn_xTe$ barrier layers (structure type A).

The investigated type B heterostructure contains three single quantum wells of 60 Å, 30 Å and 15 Å. The polarization degree as a function of magnetic field shows a very similar behavior for all quantum wells at 1.6 K (Fig. 1a), whereas the temperature dependences of the polarization degree are very different. For

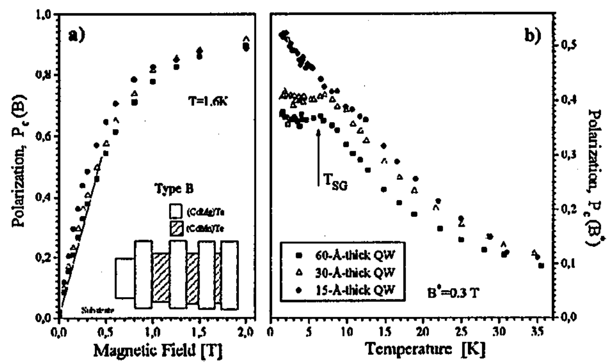

Fig. 1. (a) Magnetic-field-induced degree of polarization of the excitonic luminescence of a $Cd_{0.73}Mn_{0.27}Te/Cd_{0.53}Mg_{0.47}Te$ heterostructure (type B), containing three semimagnetic quantum wells with the well widths $L_z = 15$ Å, $L_z = 30$ Å and $L_z = 60$ Å, respectively. The data are taken at 1.6 K. The inset shows the sample structure. (b) Field-induced polarization degree for the three quantum wells as a function of temperature at 0.3 T. The data are taken under field-cooled conditions. In the case of the wider QW's ($L_z = 30$ Å and $L_z = 60$ Å) the cusp denotes the temperature of the spin-glass phase transition T_{SG}.

semimagnetic quantum wells with $L_z \leq 15$ Å no cusp in the temperature dependence of the polarized PL was detectable (see Fig. 1b), whereas we determine a well resolved cusp for the wider quantum wells. This fact may suggest that the spin-glass formation has been affected by the reduction of the dimensionality of $Cd_{1-x}Mn_xTe$ layers down to quasi-two-dimensional one.

The spin-glass formation is also influenced by the shape of the interfaces between semimagnetic and nonmagnetic layers in $CdTe/Cd_{1-x}Mn_xTe$ quantum wells (structure type A). We have studied a type A $CdTe/Cd_{0.57}Mn_{0.43}Te$ structure with single QW's of different thicknesses from 10 Å up to 78 Å. A pronounced maximum at the temperature of about 15 K in the 10 Å thick QW corresponding

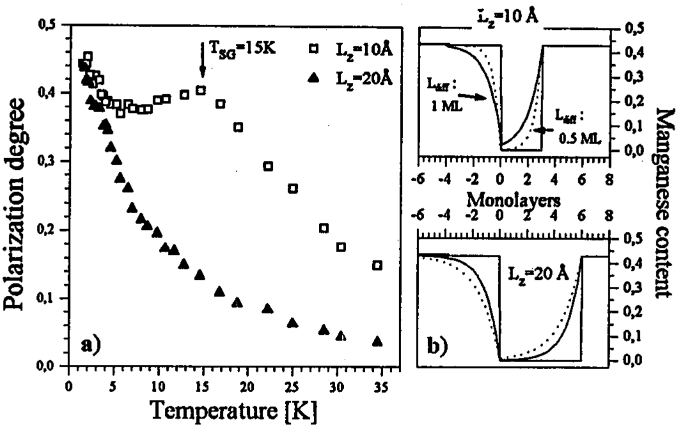

Fig. 2. (a) Field-induced polarization degree of a 10 Å and a 20 Å thick $CdTe/Cd_{0.57}Mn_{0.43}Te$ quantum wells as a function of temperature. The data are taken under field-cooled conditions and the spin-glass phase temperature T_{SG} for the wider well corresponds to the bulk values. (b) Calculation of the manganese profile for the two quantum wells assuming an exponential like profile [5] with intermixing lengths of one and of 0.5 monolayer, respectively. For the 10 Å thick quantum well this interface profile causes the magnetic coupling of semimagnetic barriers.

fairly well to T_{SG} for the $Cd_{0.57}Mn_{0.43}Te$ epilayer could be found (see Fig. 2a). We found no cusp in the temperature dependence of the polarization degree for the 20 Å thick QW. In Fig. 2b there are shown the profiles of Mn content across $CdTe/Cd_{0.57}Mn_{0.43}Te$ QW's under the assumption of an exponential shape suggested in Ref. [5]. 10 Å thick and 20 Å thick QW's were simulated with different characteristic diffusion lengths. Assuming a diffusion length of one monolayer, which is quite typical of these structures, results in magnetically coupled semimagnetic barriers for the 10 Å thick QW. Therefore, we conclude that caused by this coupling via diffused Mn spins for the thin quantum well (L_z = 10 Å) the frustration of the spin-glass formation is prevented. For the wider quantum wells there is no spin glass feature observable caused by the decoupling of the interfaces due to the low manganese content in the center of the wider quantum wells. The experiments are performed under field-cooled and zero-field-cooled conditions and the differences of the polarization degree are within our experimental error bars of about 3%. We observed that the spin-glass temperature is very insensitive on the magnetic history of the investigated heterostructures.

In conclusion, we demonstrate that the temperature dependence of the field--induced polarization degree is a useful method to investigate the spin-glass phase transition in low-dimensional semimagnetic structures. The critical temperatures determined from the temperature dependence of the polarization degree are in good agreement with the temperatures of spin-glass transition measured from magnetization experiments. We have shown that a reduction of the dimensionality of $Cd_{1-x}Mn_xTe$ layers from three-dimensional down to the quasi-two-dimensional case realized in $Cd_{1-x}Mn_xTe/Cd_{1-y}Mg_yTe$ QW structures causes the frustration of spin-glass formation. We have demonstrated that in CdTe/$Cd_{1-x}Mn_x$Te QW's the spin-glass formation is frustrated in the vicinity of the interfaces between non-magnetic and semimagnetic materials due to modification of magnetic properties at the interfaces. In QW's as thin as 10 Å the diffusion of Mn ions across the well layer provides a sufficient magnetic coupling of the interfaces.

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