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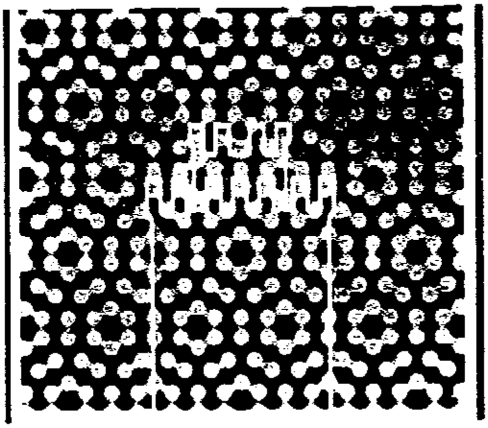

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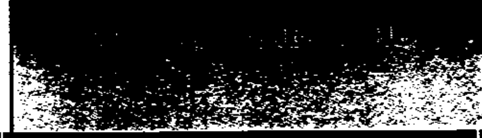

EXCHANGE INTERACTION BETWEEN Mn AND EXCITONS IN CdTe/CdMnTe SUPERLATTICES

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We present direct evidence of the interaction between localized $3d^5$ electrons of Mn^{+2}-ions and excitons in (111) $CdTe/Cd_{1-x}Mn_xTe$ superlattices. The effective g-factor, for a given well width, increases with increasing barrier thickness. The main character of the third component of the total angular momentum is obtained for the lowest-lying excitons.

The substitution of the Cd atom in the semiconductor CdTe by Mn leads to a diluted magnetic semiconductor. They show a giant Zeeman splitting of the bands in external magnetic fields [1], as a result of the exchange interaction between the localized $3d^5$ electrons of the Mn^{2+} ions and itinerant band electrons[2]. Superlattices (SL's) of diluted magnetic semiconductors offer new possibilities to study the effects of dimensionality on magnetic behavior[3]. The effects of magnetic fields on their optical properties have been investigated by photoluminescence (PL) and PL excitation (PLE) up to 15 Tesla[4], and also by time-resolved spectroscopy [5]. In this work we study the effects of the penetration of the exciton wavefunctions in the semimagnetic barriers and analyze the main character of the third component of the angular momentum of the lowest-lying excitons.

The samples were grown by molecular beam epitaxy on (100)-GaAs substrates. A 0.15µm (111)-oriented CdTe buffer layer was followed by a CdTe/$Cd_{1-x}Mn_xTe$ superlattice. Two samples with x=0.13, constant well width (d_1= 100 Å) and barrier thicknesses, d_2=100 Å and 50Å were investigated. The PL and PLE measurements were performed with a LD700 dye-laser. The incident light was circularly polarized. The emitted light was analyzed into its σ^+ and σ^- components. Magnetic fields, up to 13T, were applied in the Faraday configuration.

The PL of CdMnTe alloys, due to excitonic recombination, becomes circularly polarized in the presence of a magnetic field, as a result of the internal exchange field, which produces large Zeeman splittings of the bands[6]. A strongly polarized emission has been reported for CdTe/CdMnTe

SL's, but only for band-edge emission, not involving excitonic recombination[4]. We show in Fig.1 PL spectra in the four possible polarization configurations, excited with light of 1.76eV. The excitonic emission is strongly polarized and is splitted into two components. The peak position is determined by its polarization and it is nearly independent of the polarization of the exciting light. We attribute the right-handed (left-handed) polarized emission to bound-excitons associated to $|1/2,\pm 1/2\rangle$ conduction- and nearly degenerated $|3/2,-3/2\rangle$ and $|1/2,-1/2\rangle$ ($|3/2,3/2\rangle$ and $|1/2,1/2\rangle$) valence band states[7]. The σ^+ PL spectra red shift with magnetic field until a saturation is reached. The splitting and the polarization behavior of the PL indicate a strong exchange interaction of the excitons with the Mn^{2+}-ions in the CdMnTe layers.

We summarize in Fig.2 the shift with magnetic field of the lowest excitonic transitions obtained from PLE. We label the red-shifting (blue-shifting) excitons, corresponding to spin-down (spin-up), with an A (B). From the shift at low field, we obtain an effective g-factor of ∿17 and ∿25 for the 50Å-barrier and 100Å-barrier SL's, respectively. The presence of the Mn^{+2}-ion in the CdMnTe layers amplifies the magnetic field on the excitons[8], due to penetration of the excitonic wavefunction into the paramagnetic barriers. The effect is larger for the sample with 100 Å-barriers indicating the larger sampling of the magnetic ions by the excitons. The influence of the number of Mn^{+2} ions is also observed as as increase of the value of the field at which the magnetization of the CdMnTe becomes saturated for the 100Å-barriers sample. The splitting of the second exciton is much smaller and it behaves rather differently than the ground-state exciton.

The main character of the third component of the total angular momentum for the lowest exciton can be obtained from an analysis of the circular polarization of the emission, exciting with light of σ^+ and σ^- helicities. The PLE spectra, unpolarized at zero field, become strongly polarized in the presence of a small magnetic field. Fig. 3 depicts PLE spectra at 7 Tesla recorded with the monochromator at the peak position of the σ^+ polarized PL. If we consider a $|J,m_J\rangle$ electron-hole representation, a simplified scheme for the valence band can be obtained from the results of Fig.3. The fact that the 1.632eV peak is not observed in $\sigma^-\sigma^-$ indicates that the state $|3/2,3/2\rangle$ does not contribute appreciably to A. Similarly, the absence of the 1.638eV peak in $\sigma^+\sigma^+$ suggests the non-participation of $|3/2,-3/2\rangle$ in B. The relatively large intensity of the 1.638eV peak in $\sigma^-\sigma^+$ points to the participation of $|1/2,-1/2\rangle$ in A and of $|1/2,1/2\rangle$ in B. On the other hand, the observation of the 1.632eV (1.638eV) peak in $\sigma^+\sigma^-$ ($\sigma^-\sigma^-$), but with low intensity, indicates some small admixture of $|J,+\rangle$ and $|J,-\rangle$ states. The situation is actually field dependent: the ratio of the intensity of the peak labeled A in $\sigma^+\sigma^+$ to that obtained in $\sigma^+\sigma^-$ increases monotonically from 1 at 0 Tesla to $\sim$12 at 13 Tesla. We propose that the A exciton is mainly composed of a mixture of $|J,-\rangle$ states whereas the B exciton is mainly an admixture of $|J,+\rangle$ states. We should also mention that the processes of spin relaxation of the photocreated carriers may influence the degree of polarization obtained in our photoluminescence excitation experiments [9,10].

In summary, we have shown the strong effects of the exchange interaction between the Mn^{+2} ions and excitons in (111) CdTe/CdMnTe superlattices. The value of the effective g-factor and the saturation of the magnetization, increases with increasing barrier thickness. The character of the two components of the lowest exciton, has been obtained from an analysis of the polarization of photoluminescence excitation spectra.

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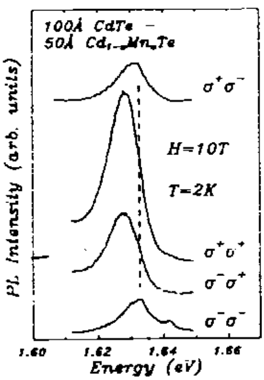

Figure 1. PL spectra for the four polarization configurations. The dashed-line shows the shift between σ^+ and σ^- emission.

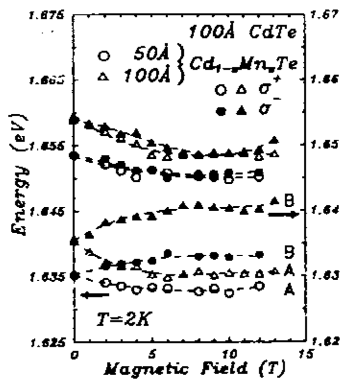

Figure 2. Energy vs. magnetic field in CdTe/CdMnTe superlattices. Open (close) symbols are obtained from PLE recorded with $\sigma^+(\sigma^-)$ exciting light. The left scale corresponds to a sample with 50 Å barriers (circles) and the right one to 100 Å barriers (triangles).

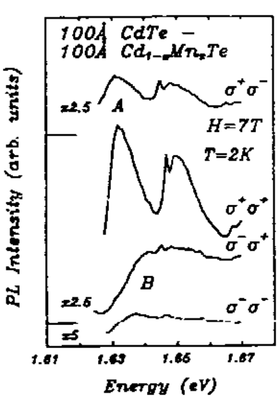

Figure 3. PLE spectra for the four polarization configurations. The spectrometer was set at 1.623eV. The spectra are enlarged by the factors shown on their left and their offset is shown by the horizontal lines.