Effect of magnetization fluctuations on exciton trapping in $Cd_{1-x}Mn_xTe$ semimagnetic semiconductors

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It is shown, in the particular case of $Cd_{0.873}Mn_{0.127}Te$ crystals, that the emission lineshape of trapped excitons (the M^0X line) for semimagnetic semiconductors corresponds to emission of excitons trapped by both fluctuations of the crystal-field potential and fluctuations of the magnetization of the crystal. The magnetization fluctuations essentially determine the emission at $T=1.8$ K. This emission component stems from the presence of local internal magnetic fields in these crystals at temperatures near the phase transition to a spin-glass state.

Excitons in semimagnetic semiconductors, as in ordinary substitution solid solutions based on II–VI semiconductor crystals, become trapped by fluctuations of the crystal field. In addition, magnetic-polaron effects are seen in semimagnetic semiconductors. These effects stem from an exchange interaction of electrons and holes bound in excitons with *d* electrons of the magnetic lattice ions. As a result, there is an additional trapping of excitons, both those bound at point defects and those trapped by fluctuations of the crystal field.[1] There is considerable theoretical[2,3] and experimental[4–7] interest in magnetic-polaron effects in semimagnetic semiconductors. At magnetic-ion concentrations $x>0.10$, the trapping of excitons not only by fluctuations of the crystal-field potential but also by fluctuations of the crystal magnetization becomes important. A possible manifestation of the latter effect—a trapping of excitons in low-temperature luminescence spectra of semimagnetic semiconductors—was pointed out in Refs. 6–9. An experimental observation of an emission of excitons trapped by magnetization fluctuations in a semimagnetic semiconductor was reported in Ref. 10.

In this letter we are reporting the first observation and study of the emission of excitons trapped by magnetization fluctuations at temperatures slightly above the temperature of the phase transition to a spin-glass state in a semimagnetic semiconductor. In particular, we studied $Cd_{1-x}Mn_xTe$ crystals. We studied the effect of the temperature and of a weak magnetic field on the trapping of excitons by this mechanism.

EXPERIMENTAL RESULTS AND DISCUSSION

The experiments were carried out on $Cd_{0.873}Mn_{0.127}Te$ crystals grown by the Bridgman method. The spectra of the exciton reflection and photoluminescence were measured with an SDL-1 spectrometer. The luminescence was excited by an LGN-404A argon laser ($\lambda=514.5$ nm).

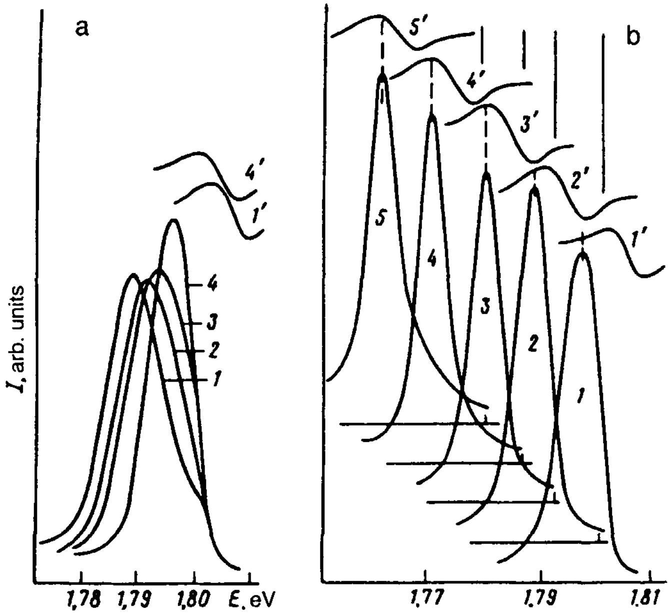

FIG. 1. Photoluminescence spectra of trapped excitons and exciton reflection spectra of $Cd_{0.873}Mn_{0.127}Te$ crystals at the following temperatures. a: 1–4—T= 1.75, 2.5, 3.5, and 4.5 K, respectively. b: 1–5—T=7.0, 15.0, 20.0, 30.0, and 50.0. Curves 1′–5′ are exciton reflection spectra at the corresponding temperatures.

Figure 1 shows photoluminescence spectra of the $Cd_{0.873}Mn_{0.127}Te$ crystals recorded at various temperatures. At $T > 4.5$ K (Fig. 1b), we see an M^0X line in the photoluminescence spectrum. As was shown by the analysis in Ref. 1, this line stems from the emission of excitons which are trapped by fluctuations of the crystal field. In contrast with the crystals with $x < 0.05$, the depth of the exciton trapping in these crystals exceeds that calculated in accordance with Ref. 11, by an amount determined by the exchange interaction between the exciton carriers and the d electrons of the Mn ions. At 1.8 K (Fig. 1a), a knee is observed on the short-wave wing of the M^0X line in the photoluminescence spectrum. In other words, there is structure in the M^0X line. As the temperature is raised, the intensity of the short-wave component of the line rises, while that of the long-wave component decreases. In addition, the maximum of the long-wave component shifts up the energy scale, and at $T = 4.5$ K essentially all we can see in the photoluminescence spectrum is the short-wave component of the M^0X line. Its energy position corresponds to the position of the knee observed at $T = 1.8$ K. At intermediate temperatures ($1.8 < T < 4.5$ K), the photoluminescence spectrum broadens significantly by (the maximum width is observed at $T = 3$ K), because of a contribution to the emission from two components of the M^0X line, with roughly equal intensities. The manifestations of a complex structure of the M^0X line, due to the superposition of two components, are evidence that exciton states differing in the nature of their trapping are participating in the emission process. The efficiency of the exciton trapping associated with the long-wave component of the M^0X line in the photoluminescence spectrum falls off sharply with

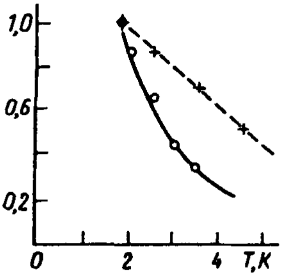

FIG. 2. Temperature dependence of $H_i(T)/H_i(1.8)$ (solid curve), $\delta(T)/\delta(1.8)$ (O), and $\Delta(T)/\Delta(1.8)$ (+).

increasing temperature. As was mentioned in Refs. 6–9, excitons in the semimagnetic semiconductor $Cd_{1-x}Mn_xTe$ may be trapped by fluctuations of both the crystal field and the magnetization. The magnetization fluctuations play a particularly important role at temperatures slightly above the temperature of the phase transition to the spin-glass state. At values $x > 0.1$, this transition can occur at low temperatures ($T \geqslant 1.0$ K). At $x = 0.15$, for example, the transition to the spin-glass state occurs at[12] $T_{SG} = 1.2$ K. Magnetization fluctuations at temperatures $T > T_{SG}$ give rise to random internal magnetic fields (H_i), with a strength given by[12]

$$H_i(T) = [A/(T+B)]\exp(T/T_0), \qquad (1)$$

where we have $A = 0.2$ T, $B = 1$ K, and $T_0 = 3.0$ K for the crystals studied in the present experiments ($x \sim 0.15$). From relation (1) we find $H_i(1.8) = 0.04$ T.

The solid curve in Fig. 2 is the temperature dependence of H_i, divided by $H_i(1.8)$, constructed from relation (1). The points and the dashed curve show the temperature dependence of the energy distances between the components of the M^0X line (δ) and between the long-wave component of the M^0X line and the position of a free exciton (Δ), divided by the corresponding values at $T = 1.8$ K. It can be seen from Fig. 2 that the temperature dependence of δ is described quite well by the temperature dependence of the quantity $H_i(T)/H(1.8)$. In the case of Δ, there is no such correlation with the value of $H_i(T)/H(1.8)$. This result is evidence that the trapping of excitons by magnetization fluctuations occurs after the excitons have been trapped by fluctuations of the crystal-field potential. That a preliminary trapping of excitons plays an important role in the formation of a magnetic polaron in the case of both the paramagnetic phase and the spin-glass state of $Cd_{1-x}Mn_xTe$ crystals was pointed out in Refs. 13 and 14.

Analysis of the results in Fig. 2 leads to the conclusion that the long-wave component of the M^0X line is due to an emission of excitons trapped in regions of the crystal containing local internal magnetic fields. The emergence of a short-wave component of the M^0X line is due to an emission of excitons trapped by fluctuations of the crystal-field potential in regions of the crystal in which there are no such fields. The regions of the crystal with internal magnetic fields are clusters with a size of about 3 nm, as was shown in Ref. 15. Raising the temperature over the interval 1.8–4.5 K results in a change in the relation between the different regions of the crystal and thus a redistribution of the intensity between the two components of the M^0X line, in the direction of the shorter-wave component.

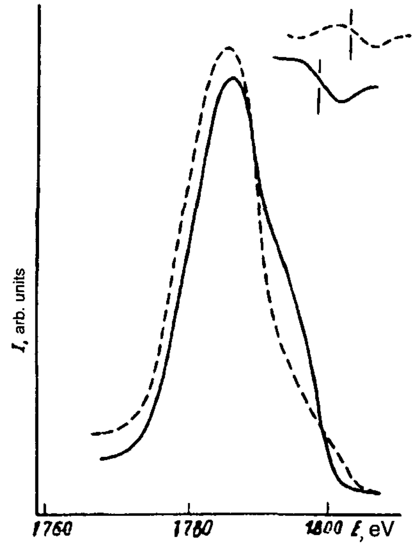

FIG. 3. Emission spectra of trapped excitons in a magnetic field **H**=0.35 T at $T=1.8$ K. Solid curve— **E** ⊥ **H**; dashed curve— **E** ∥ **H**).

In the region $4.5 \leqslant T \leqslant 15$, the M^0X line is due primarily to an emission of excitons trapped by fluctuations of the crystal field. At $T>20$ K, we observe a signal corresponding to a short-wave asymmetry of the M^0X emission line, stemming from the participation of untrapped exciton states in the emission process.

When the crystal is immersed in a weak external magnetic field ($H=0.35$ T; Fig. 3), the photoluminescence spectrum shifts down the energy scale. In addition, we find differences in the frequency position and shape of the spectra observed for orthogonal positions of the polarizer (**E** ∥ **H** and **E** ⊥ **H**). Furthermore, there is a splitting of the exciton-reflection band into components, observed in different polarizations. This result is evidence that the external magnetic field affects both trapped and free excitons.

The positions of the maxima of the M^0X emission line for the two polarizations with respect to the components in the exciton-reflection spectrum are thus different (Fig. 3). In the **E** ∥ **H** case the M^0X line is at a greater distance; i.e., the trapping depth of the exciton states for this polarization is greater than in the case **E** ⊥ **H**, and it is essentially the same as the value found for this crystal in the absence of an external magnetic field. Such changes are also seen in the shape of M^0X line at $T=1.8$ K: In the polarization **E** ∥ **H**, as in the case **H**=0, there is a slight knee on the short-wave wing of the line, due to an emission of excitons trapped by fluctuations of the crystal-field potential. In the case **E** ⊥ **H**, the shape of the M^0X line is approximately that characteristic of **H**=0 at $T=2.5$ K.

In a weak magnetic field, in the polarization **E** ⊥ **H**, there is accordingly a decrease in the trapping depth of the exciton states. It should be assumed that the decrease in this case is due to a decrease in the strength of the internal magnetic fields. The onset of an anisotropy in the trapping of the exciton states for the polarizations **E** ∥ **H** and **E** ⊥ **H** is evidently due to an orientation of the exciton magnetic polarons by the weak external field. Manifestations of an orientation of magnetic polarons in a magnetic field **H**~0.5 T have been observed previously[16] for $Cd_{1-x}Mn_xSe$ crystals. As was mentioned above, at $T = 1.8$ K for the polarization $\mathbf{E} \parallel \mathbf{H}$, an external magnetic field causes essentially no change in the trapping depth of exciton states in comparison with that at $\mathbf{H} = 0$. It can thus be suggested that in a zero magnetic field at $T = 1.8$ K there is a saturation of the spin orientation of the exciton carriers and of localized magnetic moments in $Cd_{0.873}Mn_{0.127}Te$ crystals.

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