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# PL oscillations in Cd$_{1-x}$Mn$_x$Te

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## Abstract

A new magneto-optical effect is described in the present paper. The local sample heating induced by a focused laser beam of 100 mW power results in chaotic oscillations of the whole excitonic part of the photoluminescence (PL) spectrum of Cd$_{1-x}$Mn$_x$Te ($x = 0.095$). The spectral region of the PL oscillations coincides with the range of the expected excitonic emissions when the magnetic field is varied from 0 to 10 T. The PL oscillations observed at the low magnetic field (0.1 T) have a different character. Then only the PL intensity changes chaotically and not the PL band position. An intuitive explanation of the observed oscillations is given.

## 1. Introduction

The "edge" part of the Cd$_{1-x}$Mn$_x$Te ($x = 0.095$) PL consists (at 4 K, 5 mW laser power at 514.5 nm and for an external magnetic field of 0.1 T) of the free exciton (FE) emission at 1.736 eV (14 003 cm$^{-1}$), the neutral acceptor bound exciton (ABE) emission at 1.722 eV (13 892.4 cm$^{-1}$). Free electron–acceptor (free-to-bound) emission and donor–acceptor pair (DAP) emissions are observed at lower energies.

The energy positions and the relative intensities of the PL bands depend on the magnitude of the applied external magnetic field, or speaking more correctly, on the sample magnetization. A characteristic feature of the semimagnetic semiconductor is a strong enhancement of the above effect. The giant Zeeman splitting is observed, which is directly proportional to the sample magnetization. The latter depends on the Mn fraction in the sample, the external magnetic field applied and on the sample temperature [1,2].

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The giant Zeeman splitting (effective $g$ factor up to 100 [1,2]) causes a large shift of the all "edge" emissions towards lower energies with an increase of the external magnetic field. The shift is due to the fast thermalization within Zeeman sublevels of excitons and free or bound carriers. Due to this fact, the PL starts from the lowest Zeeman component of excitons, as observed in our experiment.

The Zeeman splitting of the FE is much larger than that for the ABE, because the FE electron and hole can freely adjust the direction of their spins to the magnetic field direction. This is not possible for the ABE. For two holes in the ABE such free adjustment of their spins to the direction of the external magnetic field is forbidden due to the Pauli principle. Antiparallel spin configuration of holes means that the Zeeman splitting of the ABE (due to an electron) is much smaller than that of the FE. Due to this fact, we have observed that for the magnetic fields larger than 2.5 T the FE becomes the lower energy state of the two excitonic systems. Therefore the formation of the ABE state

is no longer energetically favorable, i.e., the destabilization of the ABE emissions occurs.

## 2. Experimental

CdMnTe samples studied were grown by the Bridgman method. The Mn concentration in the sample was determined from the optical reflection study giving $x = 0.095$ with a small fluctuation within the sample. The photoluminescence and its magnetic field dependence was studied with a triple monochromator under the excitation with the 514.5 nm line of a CW $Ar^+$ laser. The sample was mounted on a cold finger in a closed cylinder filled with helium gas and immersed then in liquid helium in a cryostat mounted in the 20 T magnet.

## 3. PL oscillations

The magnetic field dependence of the "edge" part of the $Cd_{1-x}Mn_xTe$ ($x = 0.095$) PL is shown in Fig. 1. These data were measured for the sample at liquid helium temperature and for the 5 mW of focused laser power (514.5 nm line of argon laser).
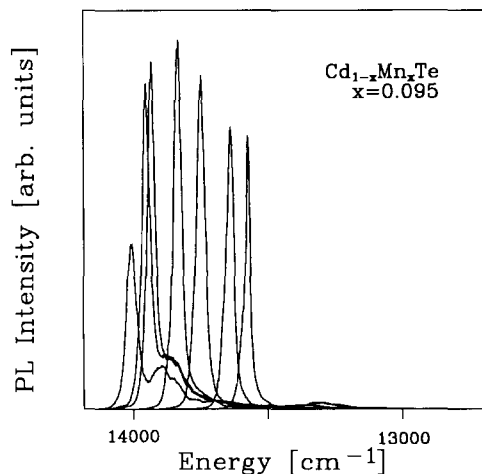


Fig. 1. The "edge" part of the $Cd_{1-x}Mn_xTe$ ($x = 0.095$) photoluminescence spectrum measured at 4.2 K for (from left to right) 0, 1, 1.25, 3, 5, 10 and 18 T external magnetic field and for a 5 mW of argon laser power at 514.5 nm.
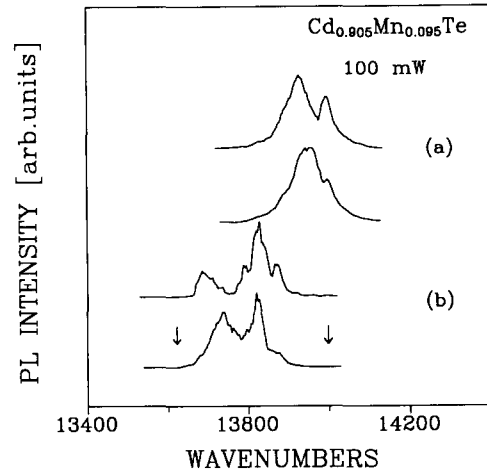


Fig. 2. The oscillations in the intensity and shape of the "edge" part of the $Cd_{1-x}Mn_xTe$ ($x = 0.095$) photoluminescence measured at 4.2 K after turning on the 100 mW focused laser power. The spectrum shown in (a) was taken at 0.1 T and in (b) at 10 T external magnetic field. Two subsequent scans are shown in each case. The first was taken after turning on the light and the second about 300 s later.

For the 10 T external magnetic field the FE line shifts to $13\,631\ cm^{-1}$ from its initial $14\,003\ cm^{-1}$ position at 0.1 T magnetic field. The shift of the FE PL is accompanied, as explained above, by the destabilization of the ABE emission. A narrowing of the FE line is also observed. The latter means that for the increased magnetic field the sample becomes magnetically homogeneous. For the low field the fluctuations of the local magnetization cause a distribution of exciton Zeeman splittings, i.e., the FE line is inhomogeneously broadened.

A distinctly different PL spectrum was observed for the excitation intensity increased to 100 mW. The spectra shown in Fig. 2 were measured for the external magnetic field set at 0.1 T (a) and 10 T (b) directly after turning on the focused laser power and after 300 s. For the spectrum measured at 0.1 T large oscillations in the PL intensity were observed. The oscillations appeared after turning on the light and disappeared after few hundred seconds. The magnitude of the oscillations was initially very large and was of about 30–40% of the FE PL intensity.

For the 10 T experiment the character of the PL spectrum changed. The PL was oscillating chaotically in a wide spectral region and large changes in the intensity and in the shape were observed. In the beginning the PL oscillations occurred in the wide spectral range in which the excitonic emission is observed for the external magnetic field varied between 0 and 10 T. This region is indicated by arrows in Fig. 2. The spectral region of the oscillations narrowed in time and their magnitude decreased. Then the PL oscillations disappeared on a similar time scale as those observed for the 0.1 T external magnetic field.

The resulting PL spectrum was shifted towards higher energy by about $160\,\mathrm{cm}^{-1}$ with respect to the low laser power spectrum. This is an indication of the increased lattice temperature resulting in a decrease of the sample magnetization. From the $160\,\mathrm{cm}^{-1}$ shift of the FE PL we estimate about 40% decrease of the sample magnetization caused by the high laser power.

## 4. Discussion

The FE PL measured at the 10 T external magnetic field and for the 100 mW excitation is shifted, as described above, towards higher energy with respect to the FE position measured under the low laser power excitation. The increase of the sample temperature affects the FE energy, due to the temperature dependence of the band gap and of the sample magnetization. The former shifts the FE line to lower energy, the latter shifts the FE PL to higher energy. The observed shift of the FE PL of about $160\,\mathrm{cm}^{-1}$ is thus due to the difference of the two effects discussed above. Our experimental results show that the latter process (shift caused by the decrease of the magnetization) is the dominant effect. However, the resulting increase of the sample temperature is not known.

The experimental results obtained show that the thermal equilibrium is reached a few hundred seconds after turning on the light. This result is consistent with the recent experimental findings by one of us [3]. The thermally induced absorptive properties of $Cd_{1-x}Mn_xTe$ were measured for Mn fractions between 0.3 and 0.6 [3]. The formation of

thermal lenses that is caused by the large laser power was studied. The dynamics of this effect indicates the multisecond time scale (for room temperature and $B = 0$ T) for reaching the thermal equilibrium. These measurements indicate a very small thermal conductivity of CdMnTe ($K = 0.025\,\mathrm{W/cm\,K}$ for $x = 0.4$ at room temperature), which is approximately 10 times smaller than values for common II–VI semiconductors.

The very low thermal conductivity of the semimagnetic semiconductor $Cd_{1-x}Mn_xTe$ must be related to the strong magnetic interactions between manganese ions. This is why we expect that the thermal conductivity is probably still lower at low temperatures and at high external magnetic field. The experimental results obtained are in fact the first confirmation of the above assumption. These measurements indicate also a possibility of a large lattice heating, occurring already at a moderate laser power.

The low thermal conductivity explains the long time necessary for reaching the thermal equilibrium in the sample. The above explanation is not sufficient to account for the chaotic oscillations of the PL intensity and shape. To explain such property of the emission we must assume a formation of nonequilibrium regions (domains) in the sample of different local temperature (magnetization), which move throughout the sample until thermal equilibrium is reached.

Several properties of CdMnTe may explain the magnitude of the observed oscillations and their time scale. The thermal conductivity of CdMnTe at low temperature and high magnetic field must be very low. Also the thermal capacitance of the sample must be very low. This is confirmed by the very long decay time of the oscillations observed. A few hundred seconds were required to reach thermal equilibrium in the sample, even though the sample was on a cold finger in a He filled cylinder immersed in the liquid helium bath.

We would also like to indicate two further properties of the system studied. a) A strong local heating of the lattice may decrease the sample magnetization enough to promote the ABE recombination channel, which is not active at 10 T magnetic field and low laser power. We have shown recently that such an effect can lead to a large decrease of the

total PL intensity because of a very large Auger recombination rate for the ABE [4,5]. b) The local decrease of the magnetization shifts the "edge" emissions towards higher energies with respect to emission from lower temperature (higher magnetization) regions. The migration of the PL excitation leads then to a "spectral broadening" of the emission towards higher energies, which in fact was observed in our experiment (see Fig. 2). Then the PL "narrows spectrally" until the thermal equilibrium is reached. We propose that there are two effects to explain the spectral region and the magnitude of the observed oscillations.

## 5. Conclusions

The very small thermal conductivity of CdMnTe and its small thermal capacitance result in a nonequilibrium lattice heating by the applied laser power. The observed chaotic oscillations of the PL are tentatively explained by the formation of domains of different local temperature (magnetization), which move in the multisecond time scale through the sample. The thermal equilibrium is reached few hundred seconds after turning on the high laser power.

## Acknowledgement

## References

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