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EXCITON TRANSFER IN MULTIPLE QUANTUM WELL STRUCTURES OF CdTe/CdMnTe GROWN BY MOLECULAR BEAM EPITAXY

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The direct evidence for the efficient transfer of excitons from 4 nm and 6 nm to 10 nm wide CdTe quantum wells is presented based on the results of photoluminescence and photoluminescence excitation investigation. Efficient transfer is observed for quantum wells separated by thick (50 nm) CdMnTe barriers containing 10% or 30% Mn fraction. A new mechanism of the transfer is proposed, which involves long range dynamic magnetic interactions between free/bound excitons and Mn ions in the CdMnTe barrier regions of the structure.

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1. Introduction

An inter-quantum well (QW) exciton transfer is commonly observed for asymmetric double QW structures separated with relatively thin barriers. The transfer process is explained by quantum tunneling transitions [1], which, however, are not efficient for barriers wider than about 4 nm [1] or 6–10 nm [2]. In this work we report the puzzling observation of a very efficient and fast (20–30 ps or faster) inter-QW exciton transfer in CdTe/CdMnTe multiple QW (MQW) structures with 10% or 30% Mn fractions in the 50 nm thick CdMnTe barriers. The mechanism of the transfer is proposed, which relates to dynamic magnetic interactions between excitons in the CdTe QWs and Mn ions in the CdMnTe barriers.

2. Samples

Four different CdTe/CdMnTe MQW structures grown by molecular beam epitaxy on top of (001) GaAs substrate were studied. The sample #1 consisted of three CdTe QWs 4 nm, 6 nm and 10 nm wide separated by the 50 nm wide CdMnTe barriers with 10% Mn fraction. The sample #2 (30% Mn fraction in the CdMnTe barriers), #3 (51% Mn fraction in the barriers) and #4 (68% Mn fraction in the CdMnTe barriers) consisted of four CdTe QWs 2 nm, 4 nm, 6 nm and 10 nm wide separated by the 50 nm wide CdMnTe barriers. The process of inter-QW exciton transfer was observed for the sample #1 and #2 and not for the samples #3 and #4.

3. Evidence for the inter-QW exciton transfer

In Fig. 1 we show the photoluminescence (PL) spectrum of the sample #1 taken at 2 K temperature. The PL consists of a set of three two-line spectra. The two-line PL from each of the QWs is due to a simultaneous observation of free (FE) and neutral donor bound (DBE) excitons.

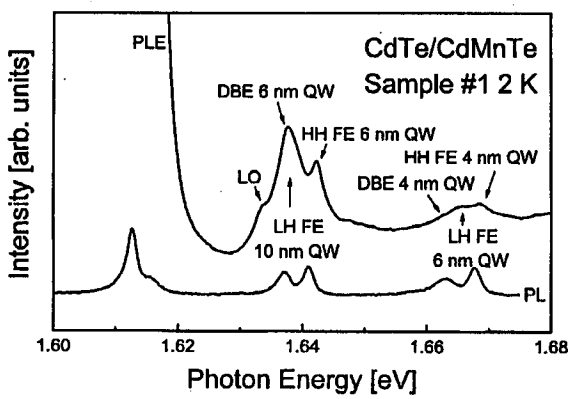

Fig. 1. Photoluminescence and photoluminescence excitation (for the 10 nm QW emissions) spectra measured at 2 K for the sample #1. The identity of the relevant PLE peaks is given.

The PL excitation (PLE) spectra were measured for all four heterostructures studied. In Fig. 1 we show the PLE spectrum measured for the 10 nm QW PL, which consists of the surprisingly strong PLE peaks due to excitons creation in the 6 nm and 4 nm QWs (see the PL spectrum shown for the easy reference). This observation means that there is the exciton transfer from 4 nm and 6 nm wide QWs to the 10 nm wide QW. The transfer is very efficient! The first of the transfer-related PLE peaks is equal to about 30% of the intensity of the resonant heavy hole (HH) FE 10 nm QW PLE peak. Evidence for the inter-QW transfer is also observed in the PLE spectrum of the 6 nm QW emission. Also here the HH FE 6 nm PL is excited by the exciton creation in the 4 nm QW. We observed similar evidence for the exciton transfer for the sample #2, but not for the samples #3

and #4. In addition to the HH FE, DBE PLE peaks are observed in the PLE spectrum shown in Fig. 1. This is the surprising result, since DBE peaks are not observed in typical PLE spectra of undoped QW structures, which is due to a relatively small density of the relevant states in a QW.

The transfer-related peaks are observed together with the light hole (LH) FE peaks, commonly observed in the PLE spectra of other heterostructures. The 10 nm LH FE and 6 nm LH FE excitation peaks overlap with those related to the exciton formation in the 6 nm QW and the 4 nm QW, respectively.

We performed magneto-optical investigations to confirm our identification of the PLE peaks. The idea of the experiment was very simple. We compared the Zeeman splitting of the PL and PLE lines, observed as shifts of the relevant peaks down in the energy with an increasing magnetic field. These investigations clearly confirm the identity of the PLE peaks in the excitation spectrum, since the identical Zeeman splitting is observed for the relevant PL and PLE peaks.

The magnetic field and temperature dependencies of the PLE spectra were measured. We observed that the transfer-related PLE peaks disappear with an increasing magnetic field and become weak for field above 4–5 T. A strong temperature dependence of the transfer-related PLE peaks was also observed. The transfer-related PLE peaks decay fast with an increasing temperature and are very weak, if observed, for temperature above 50–60 K. The PLE peaks related to HH FE and DBE excitons from the narrower QWs show similar temperature dependencies indicating that the mechanism of the exciton transfer must be identical for these two types of the excitonic transitions.

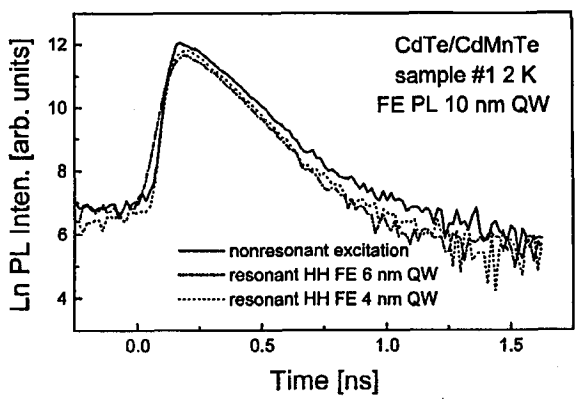

Fig. 2. PL kinetics of the HH FE 10 nm QW emission measured at 2 K for the sample #1 for three different excitation conditions indicated in the figure.

In Fig. 2 we show the results of the PL kinetics investigations in the picoseconds time range. At 2 K the PL decay times of the FE and DBE PLs from 10 nm and 6 nm QWs were in the range of 125–180 ps (125 ps for the FE 10 nm QW, 150 ps for the FE 6 nm QW and 170–180 ps for two DBE PLs). These are typical PL decay times observed at 2 K for the localized and bound excitons [3]. In Fig. 2 we show the PL kinetics for the HH FE 10 nm QW emission measured for the

excitation resonant with the HH FE 6 nm QW, HH FE 4 nm QW and for the nonresonant excitation (excitation energy set below the barrier energy). Identical PL rise (and decay) kinetics are observed for these three different excitation conditions. We have not observed a delayed PL rise of about 100 ps, as reported previously by Goede et al. [2]. Moreover, the PL rise and decay times are identical to those observed under the resonant HH FE 10 nm QW excitation. This result means that the inter-QW transfer process is very fast! It must proceed in the time scale comparable or shorter than the rise time of free exciton PL (20–30 ps).

4. Mechanism of the inter-QW exciton transfer

An inter-QW exciton transfer cannot be explained by the quantum tunneling mechanism of the transfer, which for the barrier 50 nm wide is inefficient [2]. Other transfer mechanisms, such as a long range electric dipole–dipole interaction, photon recycling, over barrier carrier/exciton migration, which can be enhanced by the Auger-type energy transfer process [4], also do not explain the experimental results. The present results can be explained by a long range dynamic magnetic interaction, which couples QWs. This mechanism of the inter-QW transfer is active only at low temperature and is efficient for the heterostructures with the magnetic CdMnTe barriers. The process is less efficient for the sample with 30% Mn fraction and not for the structures with 51% and 68% of Mn in the CdMnTe barriers. This likely relates to the strength of magnetic interactions in CdMnTe. Even though the nature of the magnetic interaction is not known, we believe that fast transfer times may occur in the process of dynamic spin polarization of chains of Mn ions in the CdMnTe barrier caused by an interaction with excitons in QWs (magnetic polaron effect). Long chains of Mn ions may couple two QWs, which results in a fast exciton transfer from one to another QW. The above mechanism of the spin polarization is expected also for bound excitons. Thus, they should also show in the PLE spectrum related to the transfer. We can also explain why the process of exciton transfer is so efficient in the present case. We have not observed a similar phenomenon of the inter-QW transfer in most of other CdTe/CdMnTe MQW structures studied and it was not observed by Goede et al. [2]. We believe that high transfer efficiency in the present case relates to its resonant character. The PLE peaks of the excitons from the narrower QWs overlap with the LH FE transitions from the wider QWs, making the transfer process resonant.

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