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RECOMBINATION PROCESSES IN DOPED CdTe/CdMnTe MULTIPLE QUANTUM WELL STRUCTURES GROWN BY MOLECULAR BEAM EPITAXY

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An influence of doping level on exciton properties in n-doped multiple quantum well structures of CdTe/CdMnTe is studied for multiple quantum well structures prepared in the way that donor (indium) concentration changes within the length of the sample. We show that the formation scenario for neutral donor bound excitons in low-dimensional structures can be different from that observed in bulk samples. We further show that in the case of such quantum well structures we can selectively excite either photoluminescence emission of localized or donor bound excitons, which is a consequence of surprisingly weak energy transfer link between two types of excitonic transitions.

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1. Introduction

Two-line structure of photoluminescence (PL) from a given quantum well (QW) is often related to a simultaneous observation of free (FE) and neutral donor bound (DBE) excitons [1]. In this work we discuss properties of DBE excitons in multiple QW (MQW) structures of CdTe/CdMnTe. Recombination process in unique two-well (16 monolayer (ML) and 30 ML wide) structure is discussed. The MQW structure was δ-doped with In in the middle of the QWs, with the doping level varying in four steps within the length of the sample. The so-obtained so-called wedge QW structure contained undoped regions, via moderately doped regions up to relatively heavily doped regions with the doping level exceeding 10^{12} cm^{-2}. For such structure we could study properties of FE and DBE excitons at different doping levels moving the excitation spot within the length of the sample. We could thus avoid any possible influences of small changes of the growth conditions expected for a series of samples with varying doping level.

2. Experimental results

In Fig. 1a and b we show the results of PL and PL kinetics (in picoseconds time scale) investigations performed for the 16 ML wide QW. PL from the undoped region of the structure consists of a broad single line attributed to the FE transition. With an increase in the doping level a DBE PL shows at a low energy

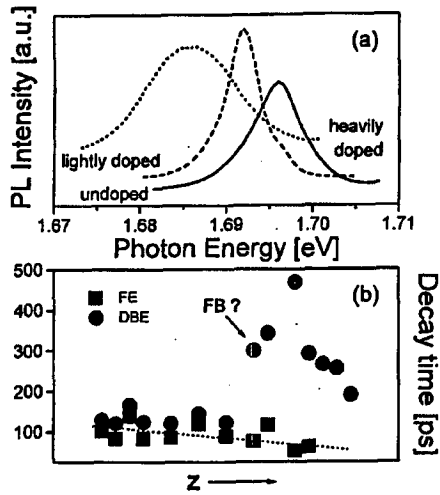

Fig. 1. (a) Photoluminescence spectrum measured at 2 K for the 16 ML wide QW in the "wedge" CdTe/CdMnTe heterostructure with a varying doping level. In (b) the dependence of PL decay times for free and bound excitons is shown with excitation spot moved along the sample towards regions of an increased doping.

wing of the emission and becomes dominant even for a lightly doped QW. With a further increasing doping level both FE and DBE transitions are replaced by a new low energy emission, which we attribute to the free-to-bound (FB, donor-free hole) recombination, as is shown in Fig. 1a.

Figure 1b presents the results of PL kinetics measurements performed at 2 K with the excitation pulse (3 ps long) moved along (z direction in Figs. 1 and 2) the sample. PL decay times were measured at the spectral positions of FE and DBE transitions (see Fig. 1b). FE PL decay time is reduced from about 100 ps in the undoped region of the QW to about 50 ps in the heavily doped region. For the DBE transition the PL decay time is slightly longer (about 125 ps) and then rapidly increases and decreases when moving to the heavily doped region of the QW. This rapid increase and then decrease appears once a strong FB contribution to the PL is observed and likely is due to the overlap of the DBE with FB PL transition. Different PL and PL kinetics results are observed for the 30 ML wide QW. Even for the undoped region of the QW a DBE PL dominates over the FE recombination (see Fig. 2a). Then, with an increasing doping level both these PLs shift towards a lower energy and the FE emission becomes weaker. This is accompanied by a gradual appearance of the third PL at a low energy side of the

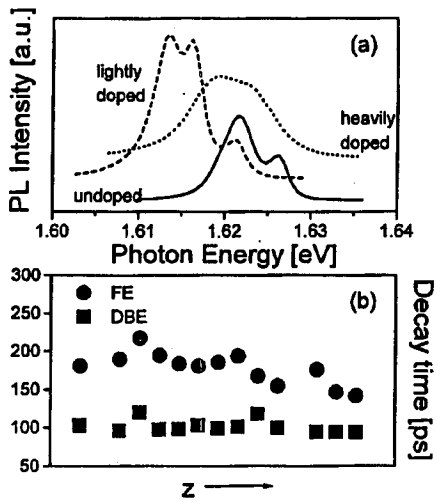

Fig. 2. (a) Photoluminescence spectrum measured at 2 K for the 30 ML wide QW in the "wedge" CdTe/CdMnTe heterostructure with a varying doping level. In (b) dependence of PL decay times for free and bound excitons is shown with excitation spot moved along the sample towards regions of an increased doping.

spectrum. This PL is of the FB (donor-free hole) origin. For the heavily doped part of the sample the PL emissions shift up in the energy and the FE contribution is no longer resolved.

Figure 2b shows a remarkable property of the PL kinetics for the FE and DBE transitions in the 30 ML wide QW. FE PL decay time (about 100 ps) does not change with a varying doping level, showing some "jumps" (also observed for the DBE emission) in the regions of changing doping level. The DBE PL decay time is here of about 180 ps and starts to decrease to about 140 ps, when the PL related to the FB transition appears.

The results shown in Figs. 1 and 2 were taken at the nonresonant excitation conditions. Once we shifted the excitation energy we noticed that the relative intensity of the FE and DBE transitions critically depends on the excitation energy. For the resonant excitation conditions (into light hole FE peaks) a strong FE emission was observed for the widest QWs, with only weak DBE contribution (even for doped regions of the QW). In turn, once the excitation energy was shifted into the continuum of the electron–hole states only the DBE emission was observed.

3. Discussion

DBE excitons in bulk samples are formed by either a subsequent electron (first carrier) and hole (second carrier) trapping or by a localization of FEs. If the latter process is efficient, the FE PL decay time (τ_{dec}) in the doped QWs should be related to the concentration of the available exciton traps (N_{D}) by a simple equation: $\tau_{\mathrm{dec}} = \tau_{\mathrm{rad}}(1 + c_{\mathrm{trap}}\tau_{\mathrm{rad}}N_{\mathrm{D}})^{-1}$, where τ_{rad} is the radiative decay time of FEs and c_{trap} is the trapping rate of FEs by neutral donor impurities.

Consequently, for QWs with an increased donor concentration a shorter PL decay time of FEs should be measured. For FEs in the 16 ML wide QW such shortening of the PL decay time is observed. However, for the 30 ML wide QW the PL decay time of FEs remains unchanged once we shifted the excitation spot from the undoped to the heavily doped regions of the QW.

We performed detailed PL kinetics investigations to explain this puzzling relation between the FE PL decay time and the doping level. For the 16 ML wide QW excitons were not localized even at 2 K. Then, the FE PL decay time was reduced once donor concentration was increased. For the 30 ML wide QW excitons were localized. In such case once FE is formed, by either a direct resonant excitation or by a electron–hole binding, its localization can occur before it can be trapped by donor impurities present in a QW plane. Thus, due to a localization of FEs two types of excitons are "decoupled". Then, a resonant excitation of FEs results in only a weak DBE PL.

Another interesting result is that for the QW structures with interface fluctuations a strong DBE emission is observed only under the excitation into continuum of electron and hole states. We speculate that a strong scattering of free carriers at interface roughness efficiently changes their k-values and reduces a chance of free excitons formation by a binding of electrons and holes at $k = 0$.

4. Conclusions

Concluding, the present results indicate that the DBE formation mechanism and the FE-to-DBE coupling critically depend on morphology of QW interfaces. In the case of localized excitons the FE-to-DBE transfer is inefficient and the two excitonic emissions decouple at low temperatures. Under such conditions the DBE formation proceeds mostly by a subsequent trapping of free electrons and then holes.

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References

[1] M. Godlewski, M. Surma, G. Karczewski, J. Jaroszyński, T. Wojtowicz, J. Kossut, J.P. Bergman, B. Monemar, *J. Cryst. Growth* **159**, 989 (1996).

[2] M. Godlewski, J.P. Bergman, B. Monemar, *Lith. Phys. J.* **35**, 563 (1995).