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LUMINESCENCE DECAY IN DEEP QUANTUM WELLS $CdTe/Cd_{0.5}Mn_{0.5}Te$ AT ROOM TEMPERATURE

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Time-resolved photoluminescence was used to study exciton recombination in deep $CdTe/Cd_{0.5}Mn_{0.5}Te$ single quantum well. The width of the investigated well was 100 Å. The study was performed at room temperature. The lifetime of the exciton determined in this work has a value comparable to that observed in shallow $CdTe/Cd_{0.85}Mn_{0.15}Te$ quantum wells. A strong enhancement of the photoluminescence decay time with increasing intensity of the exciting laser beam is observed which is indicative of saturation of the non-radiative recombination centers.

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Time dependence of the luminescence intensity from quantum wells made of CdTe surrounded by $Cd_{1-x}Mn_xTe$ barriers was subject of several studies [1–4]. Most of them dealt with relatively shallow wells corresponding to MnTe molar fraction in the barrier material that did not exceed $x = 0.3$. The interest in the time resolved luminescence studies originates in a need for precise information about the details of the nature of excitonic states which give rise to luminescent properties of heterostructures made of $CdTe/Cd_{1-x}Mn_xTe$ system and their predominant recombination mechanisms. Additional motivation for this type of studies is provided by the fact that the system consists of magnetic barriers which may give rise to a formation of either free or bound excitonic magnetic polarons in non-magnetic CdTe quantum wells [5, 6]. This, in turn, can be related to, e.g., a localization of the excitonic wave functions in the vicinity of the interfaces [7, 8]. Study of the dynamics of the recombination processes can also shed light on the relevant mechanisms of the formation of magnetic phases observed in the material.

The present communication reports on a study of the decay time of the luminescence from very deep $CdTe/Cd_{1-x}Mn_xTe$ quantum wells. The composition of the barrier in the sample studied by us corresponded to MnTe molar fraction

$x = 0.5$ (i.e., to the band gap discontinuity $\Delta E_g = 0.75$ eV). In this preliminary study we limited ourselves to measurements at 300 K only. In the future we plan to extend this investigation also to lower temperatures. We studied the dependence of the decay time on the intensity of the exciting laser beam. The intensity was changed in a wide range, covering three orders of magnitude, starting from 0.5 fJ to 0.5 pJ per pulse. For the pulse duration used for the measurements and taking into account the area of the sample which was illuminated the power sent to the sample ranged from 400 W/cm^2 to 400 kW/cm^2.

The sample was grown by molecular beam epitaxy in EPI 620 system on GaAs substrate with (100) orientation. Prior to growth of the quantum well structure several buffer layers were deposited: 0.2 μm of ZnTe, followed by 0.8 μm of CdTe, followed by 2 μm of $Cd_{0.5}Mn_{0.5}Te$. These buffers were intended to minimize the effect of a considerable lattice mismatch between the substrate and the layer containing the quantum wells. As shown by TEM images obtained on an analogous structure the lattice mismatch between GaAs and CdTe buffer resulted in formation of a network of dislocations in CdTe buffer. The development of the dislocation network was arrested by the consecutive $Cd_{0.5}Mn_{0.5}Te$ buffer. The topmost layer — which consisted of four isolated CdTe quantum wells (100, 60, 40, and 20 Å wide) separated by 500 Å thick $Cd_{0.5}Mn_{0.5}Te$ barriers — was effectively dislocation free. This resulted in good optical properties of the sample with luminescence line width of 100 Å at low temperature being of order of 2 meV. Further details of the luminescence study of this sample, including its temperature variation, can be found in Ref. [9]. The luminescence observed in [9] was shown to consist of at least two separate lines which can be ascribed to a free (or weakly localized) excitons and impurity-bound excitons.

The present report concentrates on a time-resolved luminescence study from the widest of the four quantum wells in our sample. The luminescence from this well was clearly observable also at the room temperature. The measurements were performed using the microscope-based instrument [10]. The energy of the laser line used for excitation was 725 nm (1.710 eV) provided by GaAs/AlGaAs laser diode. The excitation energy was intentionally chosen to be lower than the band gap of the barrier material (approximately equal to 2.18 eV at 300 K) in order to exclude the process of carrier collection from the barriers in the quantum wells. This process can have a pronounced effect on the photoluminescence decay time in quantum well structures [3]. The excitation energy was also lower than the energy of strong absorption due to internal Mn^{2+} transition. The exciting laser was focused on a spot with an area $\approx 4\,\mu m^2$ on the sample surface. The excitation pulse lasted for 30 ps. Spectral discrimination of the luminescence was provided by multiple cavity Fabry–Perot band pass filters with the width of the band transmitted being $\approx$ 10 nm (FWHM). As the detector we used in our study an actively quenched silicon single-photon avalanche diode.

The recorded photoluminescence decays from 100 Å $Cd_{0.5}Mn_{0.5}Te$ quantum well are shown in Fig. 1. The maximum efficiency of the luminescence in our experiment corresponded to 810 nm (1.531 eV). This is in good agreement with more accurate spectral discrimination in Ref. [9]. The curves shown in Fig. 1 for different excitation intensities were recorded using the same filter and, thus,

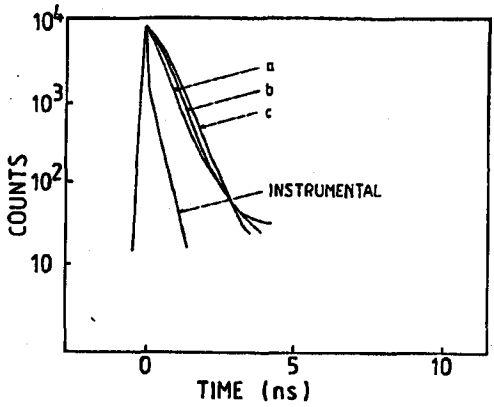

Fig. 1. Photoluminescence decay observed in 100 Å wide CdTe quantum well embedded between $Cd_{0.5}Mn_{0.5}Te$ barriers for different energies of the pumping laser pulse: *a* — 0.5 fJ, *b* — 0.05 pJ, *c* — 0.5 pJ. Curves were normalized to the same peak intensity.

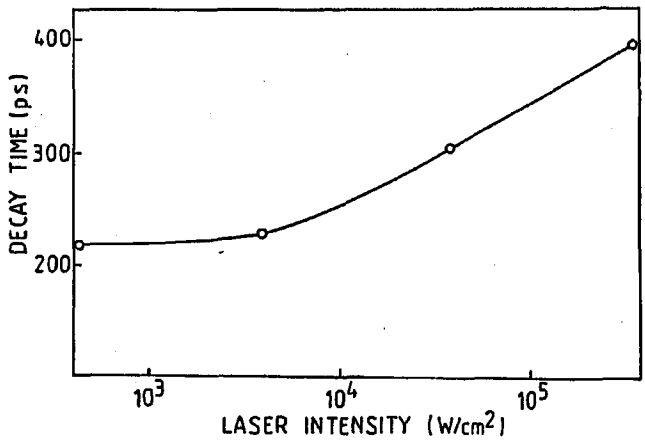

Fig. 2. Decay times of the room temperature excitonic luminescence from 100 Å $Cd_{0.5}Mn_{0.5}Te/CdTe/Cd_{0.5}Mn_{0.5}Te$ quantum well as a function of the excitation intensity. The line is only to guide the eye.

they correspond to the same wavelength of the observed luminescence. The decay can be fitted quite accurately by a single exponential function over a time domain which corresponds to luminescence intensity changes covering more than one order of magnitude. It was checked that the luminescence decay did not depend on the positioning of the exciting beam on a particular spot on the sample. The exciton lifetimes obtained in this way are plotted in Fig. 2 as a function of the excitation intensity. The values of the decay time τ increase from 220 ps to 390 ps in the excitation intensity range covered in our experiment. A strong enhancement of τ is observed at the highest excitation intensities. This enhancement indicates that the main recombination process of excitons at room temperature in the investi-

gated sample is non-radiative and that it is possible to saturate the non-radiative recombination centers at the highest intensities used. This finding is in agreement with the conclusion of the time resolved luminescence study of Polhman et al. [2] who showed that in shallow $Cd_{1-x}Mn_xTe$ quantum wells only the low temperature (below 50 K) luminescence decay is limited by radiative recombination of excitons while at high temperatures τ is due to non-radiative recombination. Our conclusion concerning the non-radiative character of the mechanism which determines the luminescence decay at 300 K is also compatible with the fast decrease in the spectrally integrated intensity of the luminescence with increasing temperature found in [9] in this highest temperature range.

Let us note that the luminescence decay time determined in this study is very similar in value to that obtained earlier for shallow $CdTe/Cd_{0.85}Mn_{0.15}Te$ quantum wells (band gap discontinuity in the constituent materials being equal to, approximately, 23 eV) of comparable width (70 Å) and for comparable excitation intensities (80 W/cm^2) [2]. Namely, the value of τ obtained in [2] was equal to 320 ps at 300 K. Our value of τ in the same conditions is 330 ps. This is in spite of a considerably stronger confinement of excitons in our case (i.e., much greater overlap of the electron and the hole function overlap). Polhman et al. [3] have found that the luminescence decay at low temperatures is practically independent of the quantum well width in a similar system of $CdTe/Cd_{0.75}Mn_{0.25}Te$. Their finding is in a strong contrast with a rapid dependence of τ observed in GaAs/GaAlAs quantum well structures. It is then not unreasonable to conclude, therefore, that in $Cd_{1-x}Mn_xTe$ system the luminescence decay time depends on the parameters of the wells only very weakly independent of the nature of the mechanism which limits the lifetime of the exciton (radiative recombination at low temperatures and non-radiative recombination at high temperatures). This fact may be indicative of the fact that the excitons in the system under study are subject to some sort of a localization (e.g., by the fluctuations of the well width and/or by the fluctuation of the Mn contents) in the vicinity of the well–barrier interfaces. Of course, these conjectures require further support from more detailed studies.

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