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TEMPERATURE STUDY OF PHOTOLUMINESCENCE FROM DEEP $CdTe/Cd_{1-x}Mn_xTe$ QUANTUM WELLS

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The photoluminescence studies in CdTe/CdMnTe quantum wells are reported in the temperature range 10–300 K. The MnTe concentration in the barriers is $x = 0.3$, 0.5, 0.63 and 0.68. Thus the potential wells in our samples are very deep, of the order of ≈ 800 meV in the conduction band and ≈ 200 meV in the valence band in the case of the $x = 0.68$ sample. In spite of the large lattice mismatch (related to high x value) between the wells and the barriers the observed line widths are as narrow as 2 meV in the case of 100 Å. Clear manifestations of internal strain are observed. In particular, the temperature coefficient of the luminescence energies shows strong dependence on the width of wells.

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Superlattices and quantum wells composed of diluted magnetic semiconductors (DMS) are studied for a decade now [1, 2]. From many possibilities offered by DMS systems the most thoroughly investigated structures are those consisting of CdTe (quantum wells) and $Cd_{1-x}Mn_xTe$ (barriers). In the majority of cases, the MnTe molar fraction in the structures studied so far was limited to $x \leq 0.3$ (superlattices involving pure cubic MnTe being an exception). The reasons for limiting the studies to small molar fractions were, probably, related to difficulties in preparation of quantum well structures of sufficient quality suitable for optical and magneto-optical investigations. These difficulties are related to a considerable lattice mismatch between CdTe and highly concentrated $Cd_{1-x}Mn_xTe$ ($a_{CdTe} = 6.481$ Å, $a_{CdMnTe} = (6.481 - 0.148x)$ Å) which may result in formation of dislocations and other structural imperfections that reduce the optical quality of the material.

Here we present a study of a luminescence from a series of $CdTe/Cd_{1-x}Mn_xTe$ quantum wells with MnTe molar fraction in barriers as high as $x = 0.68$. The samples studied by us were grown by molecular beam epitaxy on either GaAs(100) or CdTe(100) substrates. The growth was performed in EPI 620 apparatus at

the substrate temperature approximately 270°C. In the case of GaAs substrates, prior to the growth of quantum wells, we deposited several buffer layers: ZnTe ($\approx$ 100 Å), CdTe (0.8 μm), followed by $Cd_{1-x}Mn_xTe$ buffer (2 μm) with x equal to that in the barriers. Here, we limit ourselves to a discussion of four samples with $x = 0.3, 0.5, 0.63, 0.68$.

The growth of the buffer layers was performed at the temperatures that were by 50°C higher than that maintained during the growth of the quantum wells and the barriers. A cap layer with typical thickness of $\approx$ 1000 Å completed the structure. During the growth of buffers the process was interrupted several times for 120 s which was intended for allowing the growing material to improve its structural quality. Similarly, during the growth of the quantum wells and barriers the growth was interrupted for 60 s at each interface. Each sample contained four isolated quantum wells (100 Å, 60 Å, 40 Å, 20 Å wide), separated by 500 Å thick barriers.

One of structures reported here was grown on CdTe substrate cut from crystal obtained by vapor phase epitaxy. This particular sample was grown without ZnTe buffer with 1500 Å $Cd_{1-x}Mn_xTe$ buffer grown immediately before the quantum wells. The value of x in this sample is 0.63.

The growth proceeded in (100) direction. The structural quality of the buffers was checked by X-ray diffraction. The typical double rocking curve width in the case of sample grown on GaAs was 300–400 arcsec and in the case of CdTe substrates 100 arcsec.

With the barriers made of CdMnTe with such large amount of MnTe we expect that the electrons and the holes will be (a) very strongly localized in their quantum well, (b) the light and the heavy hole states will be strongly split by uniaxial component of the internal strain, (c) there will be considerable blue shift of the luminescence from the well region due to the hydrostatic component of the strain.

We studied the luminescence excited by argon-laser beam (488 nm) thus the internal Mn^{2+} luminescence was also possible to excite. The line width of the observed luminescence at 10 K ranged from 2 meV (for 100 Å wells) through 7 meV (for 40 Å wells) to 15 meV (for 200 Å wells). The line width is comparable to that seen in samples obtained in other laboratories [3]. In the case of 100 Å, 60 Å and 40 Å quantum wells in all our samples a doublet structure of the luminescence lines could be resolved with the distance between two features being of the order of 3 meV. The relative intensity of the lines in the doublet changed with the temperature with the high energy feature growing at an expense of the low energy feature (see Fig. 1). We tentatively associate the doublet structure as being due to free and donor-bound exciton*. The relative intensity changes with temperature are consistent with this identification.

The measurements were performed at temperatures ranging from 10 to 300 K. The luminescence persisted up to room temperature which is indicative of very strong localization of exciton. We checked that the spectrally integrated intensity

*More detailed studies of the luminescence by M. Godlewski (to be published) in our sample confirm this identification.

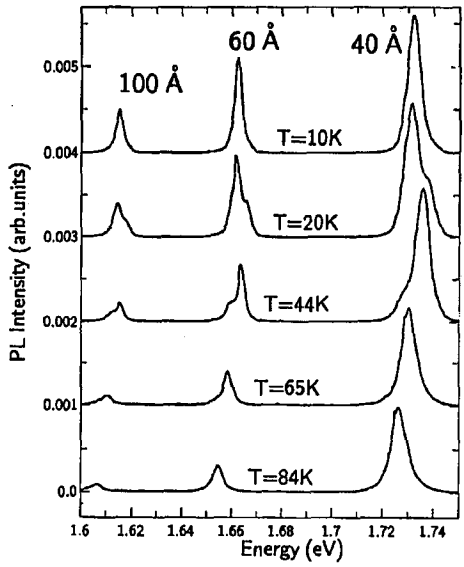

Fig. 1. Photoluminescence spectra in $x = 0.5$ $CdTe/Cd_{1-x}Mn_xTe$ quantum wells at various temperatures ranging from 10 K to 90 K. Only the luminescence from 100 Å, 60 Å and 40 Å is presented. The spectra show clear doublet structure of each luminescence line with relative intensity depending on the temperature. Similar splitting was observed for 20 Å well, not shown here.

of the luminescence from the 100 Å quantum well in the $x = 0.5$ sample shows a strong decrease as the temperature increases from 50 K to 300 K. This may indicate that a non-radiative exciton recombination is dominating in this range of temperatures. Below 30 K the integrated intensity depends less rapidly on the temperature.

Since the luminescence gives access to the information about the ground state of exciton only we could not directly measure the splitting between the heavy and light hole state and, thus, estimate the internal strain. Also, it is difficult to discriminate the blue shift of the luminescence due to the strain from that due to size quantization. The difficulty stems from uncertainties in determination of the valence and the conduction band offsets and the deformation potentials a, b (particularly, the decomposition of a into parts responsible for shifts of the valence and conduction band edges under hydrostatic component of the strain). Figure 2 shows the temperature variation of the energy position of the luminescence peak due to free excitons in one of the samples. Overall temperature dependence resembles that of the energy gap in CdTe. However, it is clear that the temperature coefficient dE_L/dT does depend on the width of the quantum well. This fact can be explained in terms of the temperature induced changes of the internal strain.

The temperature coefficients were determined for $T \geq 100$ K. The narrowest 20 Å wells are characterized by the greater dE_L/dT value. For all investigated samples it is equal to $\approx 3.8\text{–}3.9 \times 10^{-4}$ eV/K. Our data suggest that here is a slight

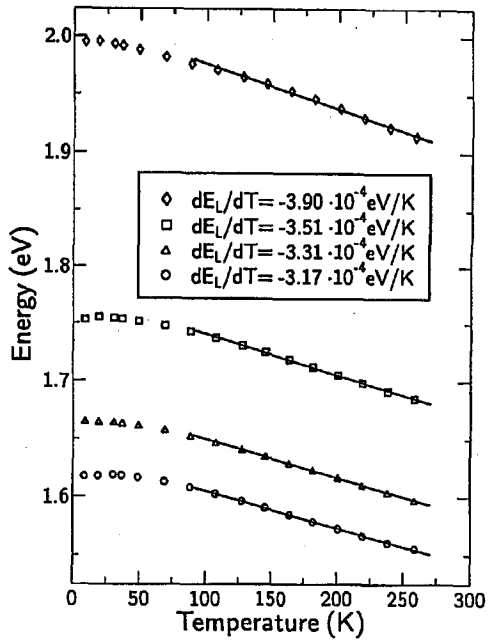

Fig. 2. Temperature variation of the luminescence peaks E_{L} due to free excitons 100 Å (circles), 60 Å (triangles), 40 Å (squares), 20 Å (diamonds) quantum wells in the sample with $Cd_{1-x}Mn_xTe$ barriers with $x = 0.68$. The solid lines show the best fit of a linear E_{L} vs. T dependence in the temperature range 100–300 K. The values of $\mathrm{d}E_{\mathrm{L}}/\mathrm{d}T$ coefficients are given at each curve.

increase in $\mathrm{d}E_{\mathrm{L}}/\mathrm{d}T$ from 3.8×10^{-4} eV/K to 3.9×10^{-4} eV/K when the composition of the barriers changes from $x = 0.3$ to $x = 0.68$. However, for wider wells such trend is not observed. On the other hand, there is clear decreasing trend of $\mathrm{d}E_{\mathrm{L}}/\mathrm{d}T$ as we proceed from 20 Å to 100 Å quantum well in each of the samples. For the widest well (100 Å) the value of $\mathrm{d}E_{\mathrm{L}}/\mathrm{d}T$ is equal to 3.3×10^{-4} eV/K which is still higher than the temperature coefficient of the energy gap alone (3×10^{-4} eV/K). Although these above values of $\mathrm{d}E_{\mathrm{L}}/\mathrm{d}T$ and the observed trends are qualitatively understandable in terms of the strain-related effects, a quantitative theoretical calculation of $\mathrm{d}E_{\mathrm{L}}/\mathrm{d}T$ in our system is hindered by lack of detailed knowledge of (a) temperature dependence of the lattice constants for the range of temperatures investigated by us, (b) temperature dependence of the elastic constants C_{11}, C_{12} [4], (c) accurate values of the deformation potentials a_{c}, a_{v} and b and their temperature dependence. The knowledge of $C_{11}(T)$ and $C_{12}(T)$ for each composition is of particular importance. However, there seems to be a considerable scatter of the values of these quantities determined by various authors [4–6]. Before a meaningful comparison of our experimental $\mathrm{d}E_{\mathrm{L}}/\mathrm{d}T$ values and those obtained from an appropriate calculation is possible the above mentioned uncertainties and discrepancies must be resolved.

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