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HIGH HYDROSTATIC PRESSURE EFFECTS ON THE  
EXCITON SPIN STATES IN CdTe/Cd<sub>1-x</sub>Mn<sub>x</sub>Te SINGLE  
QUANTUM WELLS

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Photoluminescence (PL) was measured in a CdTe/Cd<sub>0.76</sub>Mn<sub>0.24</sub>Te single quantum well (SQW) structure under hydrostatic pressure up to 2.68 GPa and magnetic fields up to 30 T at 4.2 K. Pressure coefficients of exciton energies were found to be well width dependent. Magneto-PL experiments revealed negative pressure dependence of  $N_0(\alpha - \beta)$  in barriers and saturation of  $T_0$  by the pressure.

## 1 Introduction

The strong exchange interaction between the spins of carriers and those of local magnetic ions in diluted magnetic semiconductors (DMS's) underlies a variety of spin-engineering semiconductor science. This interaction is now understood in terms of sp-d hybridization as well as antiferromagnetic spin clusters among the dilute magnetic ions. A search for more efficient spin functional systems is under investigation by utilizing technologies of alloying and quantum spatial confinements of carriers and magnetic spins. A systematic knowledge of the sp-d hybridization and of the magnetic properties is desired.

Variation of the quantum well widths controls exciton wavefunction penetration into the magnetic barriers, and thus the amount of magnetic ions within the exciton Bohr orbits widely in case of high magnetic ion concentration in

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the barrier. A higher magnetic field study renders more precise determination of physical parameters associated with magnetic properties of DMS's since it is capable of saturating more spins of antiferromagnetic coupling clusters. In this paper, we will report on PL measurements in a CdTe/Cd<sub>0.76</sub>Mn<sub>0.24</sub>Te SQW structure under hydrostatic pressure up to 2.68 GPa and magnetic fields up to 30 T. Pressure effect on the sp-d hybridization as well as magnetic properties could be investigated for a wide range of Mn content in different QW's.

## 2 Experimental

The sample was a CdTe/Cd<sub>0.76</sub>Mn<sub>0.24</sub>Te SQW structure which consisted of 13, 19, 38 Å thick CdTe wells sandwiched by 480 Å Cd<sub>0.76</sub>Mn<sub>0.24</sub>Te barriers. Hybrid buffer layers between the SQW's and (100)GaAs were constructed. Pressure of 0.08, 0.43, 0.85, 2.08 and 2.68 GPa was generated in a diamond-anvil cell using methanol-ethanol (4:1) mixed liquid as a pressure medium. The R<sub>1</sub> fluorescence line of the ruby was used to calibrate the pressure. A single fiber was attached to the anvil cell. The power density of the excitation light of 514.5 nm from an argon ion laser was estimated at about 1 W/cm<sup>2</sup> at the sample surface. Spectral resolution of the whole optical system was of 0.4 meV.

We observed four luminescence signals assigned to band-edge exciton PL's from three wells and a barrier, respectively, at low temperatures. Figure 1(a) shows pressure dependence of energies (E<sub>0</sub>) of the PL peaks at 4.2 K. We fitted the dependence to the function

$$E_0(P) = E_0 + a \cdot P + b \cdot P^2, \quad (1)$$

where  $P$  is the pressure in GPa. The fitting results are shown in Fig. 1(b) together with the data of Meyer *et al.*<sup>1</sup> in CdTe/Cd<sub>0.91</sub>Mn<sub>0.09</sub>Te SQW structure. In our results, the coefficient  $b$  was much smaller for all the wells than that of Meyer

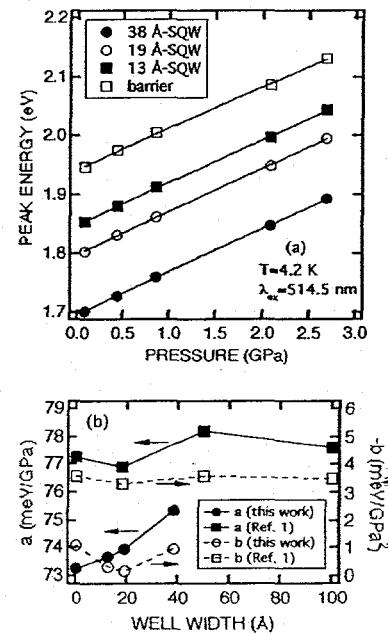


Fig. 1(a): Pressure dependence of the PL peak energies in the CdTe/Cd<sub>0.76</sub>Mn<sub>0.24</sub>Te SQW structure. The solid lines are least-squares fits to Eq. 1. (b): The pressure coefficients obtained are plotted vs. well width together with the results of Meyer *et al.* Barriers are regarded as zero well width. The lines are guides for the eyes.

*et al.* They reported that no well width dependence was observed in the *a*, whereas we found that it became larger with increasing the well width. These results could be explained by much larger effect of pressure on the exciton binding energy due to the barrier height variation in our higher Mn concentration system.

We measured magneto-PL of the exciton up to 30 T at 4.2 K under various pressures. The magnetic field was generated by a water cooled resistive magnet with a 32 mm bore. The results are shown in Fig. 2. We fitted the observed Zeeman shift ( $\Delta E$ ) to the function taking the linear magnetization term,<sup>2,3</sup>

$$\Delta E = \frac{1}{2}(\beta - \alpha)N_0(x\langle S_z \rangle_{Mn} + M_l H), \quad (2)$$

$$\langle S_z \rangle_{Mn} = S_0 \cdot B_{5/2}(H, T + T_0), \quad (3)$$

where  $B_{5/2}$ ,  $x$ ,  $H$ ,  $\alpha$ ,  $\beta$ ,  $N_0$ ,  $S_0$ ,  $T_0$  and  $M_l$  are a modified Brillouin function for spin of 5/2, Mn content, an external field, s-d, p-d interaction constant, cation site density and fitting parameters for the saturation of spins, the antiferromagnetic coupling and a linear magnetization factor, respectively.

Pressure dependence of  $N_0(\alpha - \beta)$  and that of  $T_0$  and  $M_l$  were obtained after a careful fitting in Fig. 2. The results were summarized for the barriers and the widest well (well A) together with the results of Meyer *et al.* in Fig. 3(a) and (b).  $M_l$  was almost zero in the well A. In the fitting procedure of these parameters, we assumed that both  $S_0$  and  $x$  are unaffected by the pressure.<sup>1</sup>

$N_0(\alpha - \beta)$  was found to decrease in the barriers (Fig. 3(a)). Its pressure dependence can be considered to change from positive to negative with increasing Mn concentration. One can see the similar decreasing tendency also in the results of Meyer *et al.* It can not be explained only by the existing theory for the p-d interaction<sup>4</sup> and might suggest the necessity of considering pressure variation of s-d interaction (direct interaction).

As for  $T_0$  of the well A, we observed nonlinear pressure dependence in higher pressure region (Fig. 3(b)). This behavior was not found in our result for the barriers and in the results of Meyer *et al.*  $M_l$  arises from changes in the

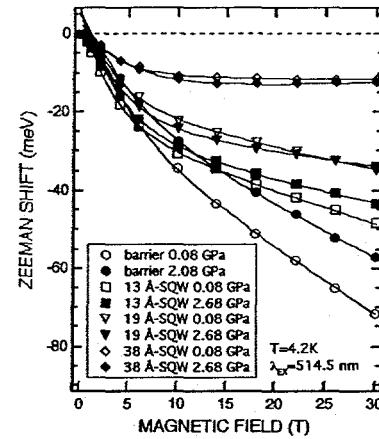


Fig. 2: The Zeeman shifts vs. magnetic fields of the band-edge excitons in CdTe/Cd<sub>0.76</sub>Mn<sub>0.24</sub>Te SQW structure. The solid lines are least-squares fits to Eq. 2 and 3.

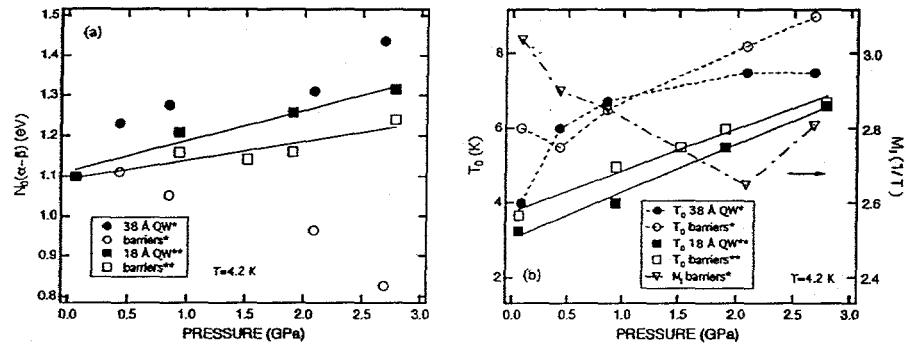


Fig.3: Pressure dependence of (a)  $N_0(\alpha - \beta)$  and (b)  $T_0$  and  $M_l$  in  $\text{CdTe}/\text{Cd}_{1-x}\text{Mn}_x\text{Te}$  ( $x=0.24^*$  and  $0.09^{**} 1$ ) SQW structures. The solid lines are least-squares fits to the linear function for the latter. The broken lines are guides for the eyes.

internal magnetic moment of large clusters.<sup>3</sup> We found a tendency that  $M_l$  and  $T_0$  for the barriers decreased and increased, respectively, with increasing the pressure (Fig. 3(b)). This tendency reflects enhancement of the antiferro-coupling between Mn ions by the pressure.

In conclusion, we could reveal peculiar magnetic properties in a  $\text{CdTe}/\text{Cd}_{0.76}\text{Mn}_{0.24}\text{Te}$  SQW structure through PL measurements under the high hydrostatic pressure up to 2.68 GPa and high DC magnetic fields up to 30 T. Negative pressure dependence of  $N_0(\alpha - \beta)$  in the barrier and the saturation of  $T_0$  in the QW of 38 Å width by the pressure were newly found.

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