Time-resolved optical studies of coupling in CdTe/CdMnTe asymmetric double quantum wells

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Abstract: Tunneling in asymmetric double quantum wells (ADQWs) CdTe/CdMnTe where one of the QWs contains Mn is studied for different tunneling barrier thickness. From time-resolved photoluminescence (TRPL) experiments at various temperature up to 80K, tunneling times and radiative lifetimes are extracted.

1. INTRODUCTION

Semimagnetic semiconductors are of great interest because of their novel properties [1]. In particular, the strong interaction between the spins of carriers and the magnetic ions leads to giant magneto-optical effects such as extremely large Zeeman splittings.

In contrast to previous studies of Mn-based ADQWs where the quantum wells (QWs) were made of CdTe [2-3], in our system the wide well (WW) contains Mn, so as to increase drastically the influence of a magnetic field on the confined levels [4].

The samples were grown by molecular beam epitaxy in the $\langle 100 \rangle$ direction. The structures were deposited on a buffer layer of the same Mn content as the barrier (11%-15% depending on the sample). The wide CdMnTe QW of 150 Å width contains about 4% Mn. The width of the narrow CdTe QW is 55 Å [4,5]. Samples with middle barrier thicknesses L_B of 10 Å, 50 Å, 80 Å, 110 Å, and 530 Å have been studied.

A study of tunneling times versus temperature up to 80K and middle barrier thickness is presented here. It shows strong dependences of the radiative lifetime on temperature and of the tunneling times on middle barrier thickness.

2. TIME-RESOLVED PHOTOLUMINESCENCE DATA

The sample was immersed in a cold finger cryostat, at temperatures ranging between 10K and 80K. The TRPL data were obtained by a two-dimensional synchroscan streak camera. The excitation density was chosen to be low enough ($\sim 10^{10} \text{ cm}^{-2}$ per

pulse) to avoid space charge effects and to assure an excitonic regime. A typical time resolution of the system is 10 ps.

Figure 1: Time resolved PL spectra with an excitation energy above the two QWs versus temperature for the sample with $L_B=80\text{\AA}$: (1a) fundamental excitonic transition in the CdTe QW, (1b) fundamental excitonic transition in the high energy CdMnTe QW. The indicated slopes are guides to the eyes, see text for the definition of τ_1 , τ_1' and τ_2 .

Figure 1 shows the results for the sample with $80\text{\AA}$ thick barrier, a case where the coupling between the two wells is still strong. The luminescence decay of the fundamental excitonic transitions in the narrow CdTe QW ($e_N^1h_N^1$) and in the wide QW ($e_W^1h_W^1$) are depicted at different temperatures ranging between 10K and 50K. The CdTe luminescence decay becomes longer as the temperature increases and at the same time a delay of a few hundred ps is observed before the monoexponential decay starts. The decay of the CdMnTe QW luminescence shows a general change in its shape: from a monoexponential decay at low temperatures (with the characteristic time τ_1) it reaches a biexponential decay at higher temperatures (with the characteristic times τ_2 and τ_1'). By contrast, on the decoupled QW (with a middle barrier thickness of $530\text{\AA}$), neither the delay of the CdTe QW luminescence nor the biexponential decay for the CdMnTe QW luminescence are observed. In a previous work [5] it has been shown that τ_2 is correlated with the delay observed on the CdTe QW luminescence, due to the tunneling of carriers from the high energy CdMnTe QW to the low energy CdTe QW. The decay time τ_1' has the same value as the decay time of the CdTe QW at the same temperature (namely 600 ps at 50K), then it has been attributed to the excitonic recombination when a thermal equilibrium is reached in the occupation of the NW and WW excitonic states.

Figure 2 compiles all characteristic decay times of (2a) the CdTe QW, and (2b) the CdMnTe QW (τ_1' and τ_2), versus temperature for differently coupled samples. A linear increase of the luminescence decay times of the CdTe QW is observed, proving the

dominance of radiative recombination at these temperatures [6]. Notice that this behaviour is also observed for the CdMnTe QW in the sample with $L_B=530\text{\AA}$.

The temperature dependence of the luminescence decay time of the high energy CdMnTe QWs for coupled samples, i.e., for $L_B \leq 110\text{\AA}$ is now presented. Notice that for the sample with $L_B=10\text{\AA}$ the coupling is so strong that the excitonic recombination in the high energy QW is not observed with our 10 ps time resolution. The decay time τ_1 increases linearly at low temperature, for the thicker middle barriers ($80\text{\AA}$, $110\text{\AA}$). At higher temperatures ($T > 30\text{K}$) the measured initial decay time τ_2 has a lower value than τ_1 and is nearly independent on temperature. Finally, the longer decay time τ'_1 follows also a linear behaviour with temperature indicating that it is a purely radiative decay time [6].

Figure 2: Compiled decay times versus temperature for samples having different barrier thicknesses between $10\text{\AA}$ and $530\text{\AA}$.

(2a): decay times of the low energy CdTe QW when exciting only the low energy QW.

(2b): decay times of the high energy CdMnTe QW when exciting both QWs; the full symbols represent the characteristic decays τ'_1 when the thermal equilibrium is reached, whereas the opened symbols and crosses represent τ_2 or τ_1 depending on the temperature. The radiative recombination τ_R time and tunneling time τ_T were deduced from the data at high temperatures (as shown in the right insert) and τ_T is reported as a function of the middle barrier thickness (left insert)

3. DISCUSSION

First the linear increase of the radiative lifetime with temperature for both CdTe and CdMnTe QWs (which reaches for all the samples a value of the order of 700ps at 50K) is larger than that observed on similar systems by Polhmann & al [7] but smaller than

that observed for GaAs/GaAlAs QWs (2.5ns at 50K) [6]. This variation of exciton radiative recombination which depends on the coherence volume of the exciton and is determined by exciton scattering, indicates that the exciton-phonon interaction is weaker in II-VI as compared to III-V QWs.

Secondly the two decay times which are observed at $T > 30\text{K}$ in CdMnTe QWs for the coupled samples can be understood as follows: the observed recombination time (τ) can be expressed as a function of the radiative decay time (τ_R) and of the tunneling time (τ_T) according to the relation $1/\tau = 1/\tau_R + 1/\tau_T$. At low temperatures $\tau_R < \tau_T$ and therefore the linear radiative-like behaviour (τ_1) is observed. As τ_R increases with temperature the tunneling effect becomes dominant as soon as τ_R is larger than τ_T , i.e., at 30K for $L_B = 80\text{\AA}$ and $110\text{\AA}$, and at 20K for the barrier of $50\text{\AA}$. From the data at 50K we extracted tunneling times following the relation $1/\tau_T = 1/\tau_2 - 1/\tau_R$ considering that ($\tau_R = \tau_1$). The calculated values are reported in the insert of figure 2. These results show a substantial decrease of the tunnel transfer efficiency when the middle barrier thickness increases. For the $530\text{\AA}$ thick middle barrier this decrease is such that the dynamical behaviour corresponds to two independant QWs.

To elucidate the nature of the tunneling mechanism, i.e., transfer of hole, electrons, or excitons [8-10], some TRPL measurements have been performed under magnetic field. Under such field resonant tunneling conditions can be tuned, mainly due to the modification of the hole confinement potentials. A resonance-like behaviour of the decay times is observed for both QWs as the field increases. Calculations of excitonic transitions are in progress to explain this magnetically induced resonances.

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