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Magnetorefectivity study of type I - type II transition in CdTe/(Cd, Mn)Te quantum wells

A. RIBAYROL, D. COQUILLAT, A.V. KAVOKIN⁽¹⁾, J.P. LASCARAY, H.P. ZHOU*, C.M. SOTOMAYOR TORRES*, B. LUNN** and D.E. ASHENFORD**

Groupe d'Etudes des Semiconducteurs, URA 357 du CNRS, Université Montpellier II, place E. Bataillon, 34095 Montpellier cedex 5, France

* Nanoelectronics Research Centre, Department of Electronics & Electrical Engineering, Rankine Building, University of Glasgow, Glasgow G12 8QQ, U.K.

** Department of Engineering Design and Manufacture, University of Hull, Cottingham Rd., Hull HU6 7RX, U.K.

Abstract: The magnetic field induced type I - type II transition in a 20-Å-thick CdTe/Cd_{0.875}Mn_{0.125}Te single quantum well has been documented by the resonance light reflection measurements. The pronounced splitting of the lower Zeeman-component exciton resonance has been observed to appear at 1.5 T and to increase at higher fields, which manifests the formation of direct and indirect exciton states in the type II quantum well.

1. INTRODUCTION

The semimagnetic semiconductor heterostructures have been intensively studied during the recent decade because of a number of unique phenomena taking place in these systems like the giant Zeeman effect and Faraday rotation, magnetic polaron and spin superlattice formation. One of the intriguing effects in quantum wells (QWs) and superlattices with semimagnetic barriers consists of the possible type I-type II band alignment transition as a result of tuning the barrier heights by an external magnetic field [1-6]. This transition has been observed first in ZnSe/(Zn,Mn)Se and ZnSe/(Zn,Fe)Se multiple quantum well structures by analysing optical transition strength as a function of the applied magnetic field [1-2]. The analysis of exciton Zeeman splitting has permitted to define the critical field of the type I-type II transition in (111)-oriented CdTe/(Cd,Mn)Te QWs [3]. These measurements allowed also to find the value of the valence band offset as percentage of the total band-gap discontinuity to be 15-20%. However, various attempts to identify the band parameters of (001)-oriented CdTe/(Cd,Mn)Te quantum wells using the similar procedure gave different values of this percentage: from 12%[4], 20%[5] up to 40%[6] and 46%[7]. The value reported in Ref. [4] has been obtained by studying the dependence of exciton oscillator strength on the external magnetic field. From the dramatic magnetic-field-induced decrease of the oscillator strength for the lower Zeeman component, the critical magnetic field of type I-type II transition in a 18 Å-thick CdTe/Cd_{0.9}Mn_{0.1}Te quantum well as 1.3 T at pumped liquid helium temperature has been estimated.

The theoretical study [8] shows that, in a type II quantum well, a spacially indirect exciton state with the heavy-hole density shifted to interfaces coexists with the direct exciton state formed by electron and hole wave functions centered in the middle of the well layer. The latter state can be stable due to the Coulomb attraction between the electron and the hole. In this paper we report resonance reflectivity data of CdTe/Cd_{0.875}Mn_{0.125}Te QWs. The composition and thicknesses of the QWs are close to those of the structures studied in Ref. [4]. We have observed the formation of a splitted exciton state in the lower Zeeman component in the 20 Å thick QW which can be considered as the direct evidence of the magnetic field induced type I-type II transition.

⁽¹⁾ Permanent address: A.F. Ioffe Physico-Technical Institute, 26 Polytekhnicheskaya Street, St. Petersburg 1942021, Russia

2. EXPERIMENTAL DETAILS

Magnetoreflectivity measurements of the exciton structure were performed in a standard set-up, in the Faraday configuration with the circular polarizations σ^+ and σ^- , under magnetic fields up to 5.5 T, at 1.8 K. The sample was grown by solid source MBE on InSb substrate and consisted a 1000 Å CdTe buffer layer and four CdTe single wells with widths of 20, 50, 80, 150 Å respectively, separated by $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ ($x = 0.125$) barriers of 2000 Å widths. The wells were grown sequentially from 150 to 20 Å the well 20 Å closest to the surface.

3. RESULTS AND DISCUSSION

Fig. 1 shows the reflectivity spectra taken near the exciton resonance in the 20 Å-thick QW at zero magnetic field and under the fields $B = 1, 2.5, 3.5, 4.5$ and 5.5 T in the circular polarization for the lower Zeeman component.

Fig. 1: Reflectivity spectra near the $e_1\text{-}hh_1$ exciton resonance in the 20 Å-thick $\text{CdTe}/\text{Cd}_{0.875}\text{Mn}_{0.125}\text{Te}$ quantum well in the absence and in the presence of external magnetic field for the lower Zeeman component. The two exciton resonances A and B are shown by arrows.

From the reflectivity spectra one can clearly see the appearance of an additional exciton state in the presence of magnetic field. The analysis of the reflection spectra and their first derivatives allows to trace the variation of the exciton resonance frequency with the magnetic field change, as shown in Fig. 2-a. The points A,C present the usual Zeeman splitting, while the additional exciton state behaviour is shown by the points B. One can see that contrary to the normal lower Zeeman component A, the energy of the additional state B is almost independent on the field.

The model, which interprets the observed effect is illustrated in Fig. 2-b. The heavy hole state in the QW is governed by a potential of the complex form which consists of the net QW potential and an adiabatic Coulomb potential created by an electron in the exciton (for details see Refs.[3,6]). In a type II QW, which is expected to appear for the lower Zeeman-component exciton at fields $H > 1.5$ T [6], there are two bound hole states for this potential : (i) the ground state A which has two maxima associated with both interfaces, and (ii) the symmetrical excited state B with a maximum in the middle of the QW.

Fig. 2: a) Exciton Zeeman splitting in the 20 Å-thick CdTe/(Cd,Mn)Te quantum well (points A and C). The points B show the position of additional exciton resonance. b) Schematic potentials for an electron and a hole in the type II quantum well. Two possible excitonic transitions are shown by arrows.

While the energy of the former is governed by the CdMnTe valence band edge, the latter depends mainly on the Coulomb potential and is, therefore, much less sensitive to the barrier height and the magnetic field. The state B has a substantial oscillator strength because of the high value of electron-hole wave function overlap and, consequently, it can be observed in reflectivity.

Thus, the reflection spectra taken from the heterostructure under study clearly show the doublet structure in the magnetic field range where the type II band alignment is expected. We conclude that the main peak (points A in Fig.2) is associated with the exciton ground state formed by the hole A, the splitted state (points B in Fig.2) is associated with the exciton formed by the hole B. Since the energy of the latter state is almost independent on the field, we can make a simple estimation for the definition of the valence band offset.

Let us assume the hole energy to be equal to the valence band edge in CdTe. In this case the energy of the exciton transition will be a sum of the electron confinement energy, E , and energy gap E_g in CdTe minus the exciton binding energy, E_{exc} . Taking $E_g = 1,605$ eV and $E_{exc} = 10$ meV, we have $\bar{E} = 0.128$ eV. For 20 Å-thick QW the corresponding barrier height for an electron should be $V = 0.176$ eV. The total band gap discontinuity is given by formula $\Delta E_g = 1.576 \times [3]$. Dividing V over ΔE_g , for $x = 0.125$ we obtain a value of 12 % for the valence band offset ratio.

The relative intensities of the spectral peculiarities connected with the two exciton features discussed above show a strong dependence on the QW width, so that an additional exciton state is hardly observable for thick QWs. The details will be presented and discussed elsewhere.

In conclusion, we have studied the magnetic field induced type I - type II transition in CdTe/Cd_{0.875}Mn_{0.125}Te QWs. We have observed the splitting of the lower Zeeman exciton component state in a 20 Å QW at a field of $B=1.5$ T, which manifests the transition. From the energy of the split line we have determined the valence band offset to be $12 \pm 5\%$ from the total band gap discontinuity.

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