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Photoluminescence of CdTe/CdMgTe Double Quantum Wells with a Two-Dimensional Electron Gas

M. Deresz[a], M. Wiater[b], G. Karczewski[b], T. Wojtowicz[b,c] and J. Łusakowski[a,*]
[a]Faculty of Physics, University of Warsaw, L. Pasteura 5, PL-02-093 Warsaw, Poland
[b]Institute of Physics, PAS, Aleja Lotnikow 32/46, PL-02668 Warsaw, Poland
[c]International Research Centre MagTop, Aleja Lotników 32/46, PL-02668 Warsaw, Poland

Magnetophotoluminescence measurements at liquid helium temperatures were carried out on asymmetric double quantum wells based on CdTe/CdMgTe heterostructures. Due to doping with shallow iodine donors, a two-dimensional electron gas was present in the quantum wells. The samples studied differed with the quantum well widths and doping level. We show a resemblance of the luminescence to results obtained on single quantum wells which suggests that in samples studied the quantum wells are not strongly coupled.

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1. Introduction

Previous magnetoluminescence research on asymmetric double quantum wells (ADQW) based on CdTe concerned only undoped samples with the barrier or one of the wells formed by a diluted magnetic semiconductor, mainly CdMnTe. This type of material allows to manipulate the shape of the barrier and observe magnetically tuned interwell coupling [1] or exciton transfer [2]. In the present paper we show results of magnetophotoluminescence experiments done on a new type of structures: CdTe/CdMgTe ADQW with a two-dimensional electron gas (2DEG).

The motivation of this research was to optically characterize structures in which one could observe magnetoplasmons in coupled quantum wells by optically detected resonance (ODR) method. Magnetoplasmons in CdTe were previously studied in less complicated structures — single CdTe/CdMgTe quantum well doped with iodine donors in a quantum point contact or grid-gate geometry [3–5]. A photoluminescence characterization of samples is one of necessary steps towards measurements in which a coupling of two types of excitations — a visible one and a THz one — are active. The present paper presents preliminary characterization of a set of samples which will be subsequently used in ODR experiments.

2. Samples and experiment

The samples under investigation were CdTe/CdMgTe double quantum wells grown by a molecular beam epitaxy. Active layers in all samples studied were grown on a 2 inch, (100)-oriented semi-insulating GaAs substrates, with a thick CdTe buffer layer, followed by a CdTe/CdMgTe superlattice and a CdMgTe spacer (Fig. 1C). In the present paper we focus on representative data obtained on only two samples which differed in the structure of active layers and in the concentration of a 2DEG.

The sample A was composed of two CdTe quantum wells, the deeper one (closer to the substrate) with the thickness of 80 Å, and the upper one with the thickness of 120 Å, separated by a MgTe barrier with a nominal thickness of 10 Å. The structure was modulation doped with iodine donors into CdMgTe barrier on both sides, a 50 Å-thick doping area was introduced at 535 Å below the deeper wells and two doping areas were introduced at 200 Å above the upper well: the first one, a 32 Å thick and the second one, a 10 Å thick, separated by a 500 Å thick CdMgTe spacer (Fig. 1A).

The sample B had a similar design as sample A with two main differences: a 50 Å thick doping area was introduced now at 200 Å below the deeper QW and two QWs are now separated by a 10 Å wide CdMgTe barrier, instead of being separated by a MgTe barrier. The reason for decreasing spacer thickness was to increase the 2DEG concentration in the deeper QW, while replacing MgTe barrier in-between QWs for the narrower energy gap CdMgTe aimed at increase of a coupling between 2DEG residing in two QWs (Fig. 1B).

The measurements were carried out in a liquid helium optical cryostat supplied with a split coil; the magnetic field was perpendicular to the surface of the sample. The cryostat provides temperatures from 1.6 K to 300 K and magnetic fields up to 6 T. The luminescence was excited with a 514 nm line of a multiline Ar+ laser which provides power up to 1.35 mW and it was analyzed with a spectrometer supplied with a CCD camera. Three types of measurements were carried out. The first one with a constant excitation power matched accordingly to sample properties, at temperature of 1.6 K and magnetic field changing from 0 T to 6 T with a 0.5 T step. The second one with a constant temperature 1.6 K, zero magnetic

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[*] corresponding author; e-mail: Jerzy.Lusakowski@fuw.edu.pl

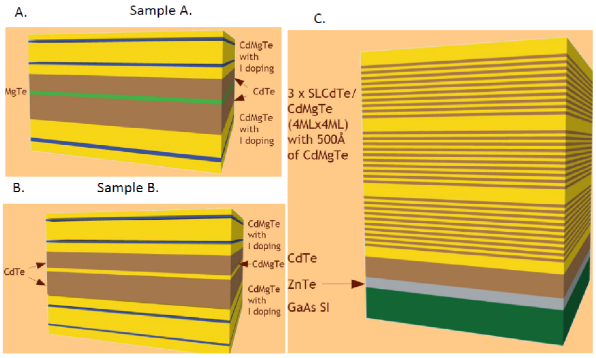

Fig. 1. The structure of investigated samples (not to scale): sample A (part A), sample B (part B). The substrate part of structures, the same for each sample, is shown in part C. An iodine doped CdMgTe layer is marked with a dark continuous line, the wells are shown with dark areas with marks for barriers: lighter area for CdMgTe, darker area for MgTe.

field and with changing the excitation power from 5 μW to 1.35 mW. The third one with changing temperature from 1.6 K to 220 K at a constant excitation power and zero magnetic field. In all measurements both $\sigma-$ and $\sigma+$ polarizations of the luminescence were registered.

3. Results and discussion

In both samples, (see Fig. 2) PL spectra at energies below the PL of the barrier (at 2.12 eV, which gives Mg content in the CdMgTe barrier of 32%) and of superlattice (at 1.83 eV) are composed of two broad lines (at about 1.650 eV and 1.625 eV in sample A and 1.59 eV and 1.615 eV in sample B) which we attribute to the emission from two quantum wells, the lower energy line in each sample is related to the recombination in 120 Å wide QW, while the higher energy line is related to the recombination in 80 Å wide QW. In sample A, the line at the lower energy is composed of two peaks which we attribute to the exciton (X, a higher energy component) and a negatively charged trion (X^-, a lower energy component). At much lower excitation power (not shown) the PL is dominated by X^- line while for power stronger than that shown in Fig. 2, the X line starts to dominate. This is the result of low electron concentration in 120 Å QW for 535 Å thick spacer and removal of carriers from the QW via over the barrier illumination, used for PL excitation. The band to band recombination of the 80 Å wide QW with a higher 2DEG concentration results in a single broad line, which only slightly shifts to higher energy with increasing excitation power. The low energy part of the spectrum of sample B is different from that of the sample A due to a higher concentration of 2DEG inside of the 120 Å QW. For this sample, the excitation power that was used was not strong enough to introduce any sizable change in the 2DEG concentration, and hence both the position of line and its shape remained unchanged.

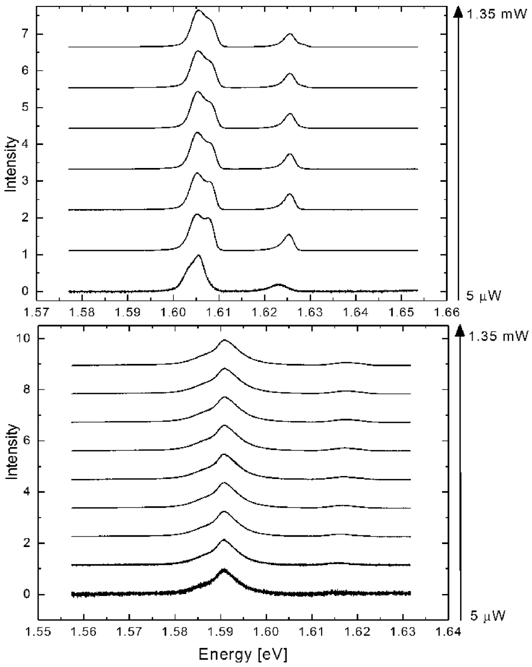

Fig. 2. Evolution of luminescence spectra with the power of excitation for the sample A (top) and B (bottom) at 1.6 K and zero magnetic field.

Polarization-resolved spectra collected at the magnetic field of 6 T are shown in Fig. 3. The stronger signal was observed in the σ^+ polarization. The sample A, shows an X^- emission much stronger than that of X. This is similar to observations on a single QW (Ref. [6]). For the sample B, with a higher 2DEG concentration in the 120 Å QW, we observe a Landau quantization of the luminescence which proves that in this case, the luminescence is in fact related to the recombination of a 2DEG with photoexcited holes.

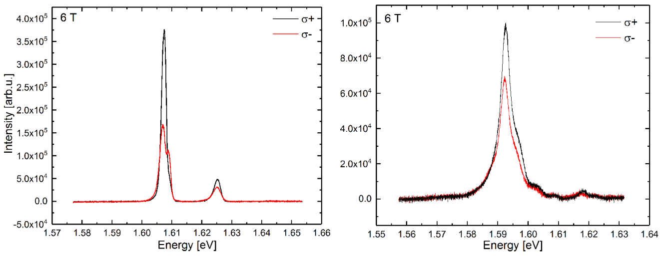

Fig. 3. Polarization-resolved PL spectra of samples A (left) and B (right) collected at magnetic field of 6 T.

4. Conclusions

We carried out photoluminescence characterization of a new type of structures — CdTe/CdMgTe double asymmetric quantum wells doped with iodine. The shape and evolution of spectra as a function of magnetic field and excitation power depend on the 2DEG concentration. We observed clearly transitions from both quantum wells in each sample, however the presented results did not allow us to determine how strongly the QW are coupled. The spectra from each of the QWs in the pair show a strong resemblance to results obtained on single quantum wells which suggest that the QWs in studied samples are not strongly coupled. This conclusion, however, must be verified by other type of experiments, e.g., time-resolved studies, which are in progress.

Acknowledgments

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