

Cold and Hot Excitons in CdMnTe/CdMgTe Quantum Wells in Strong Excitation Regime and External Magnetic Field

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Systematic studies of neutral heavy-hole excitonic line energy changes in a strong excitation regime were carried out by means of a pump-probe method for quantum wells containing a 2D gas of free holes. Energy shift of X_{e1hh1} line was analyzed for different excitation energies at fixed delay between pump and probe pulses, also under external magnetic field. It was observed that this shift depends not only on the density of created excitons but also directly on the pump energy. In co-polarization configuration for excitation energy below an absorption resonance the energetic *blue shift* rises linearly with the elevated exciton density (localized excitons are created). For energies slightly above the resonance, the *blue shift* diminishes dramatically in spite of high exciton density present (delocalized excitons are created). Model absorption calculations are in qualitative agreement with the experimental data.

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1. Introduction

Optical spectra of highly excited semiconductor structures are determined by the interaction between charged quasi-particles — electrons and holes. Studying the renormalization of the spectra introduced by the many-body effects provides important information from the point of view of basic physics and possible applications. To obtain and control high concentrations of carriers it is convenient to use the pulse-probe technique. In the present work we demonstrate and discuss the influence of high population of excitons and energy of excitation beam on the energy behavior of the excitons (X_{e1hh1} — neutral exciton containing an electron and a heavy hole from the first subbands of the quantum well (QW)). Furthermore, we conduct model theoretical calculations and compare them with our experimental data.

2. Samples and experiment

The reflectivity signal was measured in the pump-probe experiment. The beam from a $Ti^{3+}:Al_2O_3$ tunable 60 fs pulse laser was split into two beams, an intense pump and a weak probe. The pump was shaped in a dispersive set containing a diffraction grating. Time between the pump and the probe pulses was fixed at a

so-called “zero” delay obtained from time-resolved pump-probe experiment. It is defined as a moment when maximum changes in spectra for resonance excitation in X_{e1hh1} line are observed. The reflected signal was recorded by a CCD camera attached to a 300 mm monochromator. The picosecond pump pulse of spectral full width at half maximum (FWHM) of about 1 nm and controlled mean power up to 1 mW. It created a density of excitons (in the resonance) up to a few $\times 10^{10}$ per cm^2 .

A photoluminescence excitation (PLE) experiment performed in the very same conditions allowed us the estimation of density of photocreated excitons for different excitation wavelength. Several (Cd, Mn)Te/(Cd, Mg)Te quantum well samples with different well width (from 80 Å to 140 Å) and a 500 Å cap layer were studied. The samples were intentionally undoped. Due to surface states, QWs showed *p*-type conductivity (positively charged trions). All samples were grown by MBE on a GaAs substrate; therefore only measurements of reflectivity and photoluminescence were available without mechanical interference into sample structure. Manganese doping of about 0.6% allowed us (through the giant Zeeman splitting) to identify excitonic transitions and the sign of charge carriers in 2D gas. Because of barrier width close to 500 Å all the studied samples revealed valley-like reflectance spectra [1]. The samples were mounted strain-free in a cryostat with a superconducting magnet and immersed in pumped liquid helium (bath temperature between 1.5 K and 1.7 K).

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3. Results

The measurements were performed for fixed free carriers density at “zero” delay. For each sample, a set of reflectivity spectra of neutral heavy-hole exciton for different excitation energies was analyzed in co- and cross-polarization configurations. The experiment was performed for different values of excitation beam power, which allowed us to change exciton density using fixed excitation energy. Moreover, set of PLE spectra was measured in the same excitation conditions. 100 and 120 Å QW samples were also studied in external magnetic field (which assured clear excitonic spin situation). In the reflectivity spectra an energy position of X_{e1hh1} was obtained from the fit of a Gaussian profile. Taking into account the parameters of experimental setup we estimated the density of photons per pump pulse. The value of reflection and absorption in the maximum of the line allowed us the estimation of exciton density created at the maximum of PLE spectrum. Thus we obtained the “calibration” of PLE spectrum in terms of exciton density similarly as in Ref. [2]. The best way to analyze obtained results was a relationship between exciton energy shift and its density for different excitation energies (see Fig. 1).

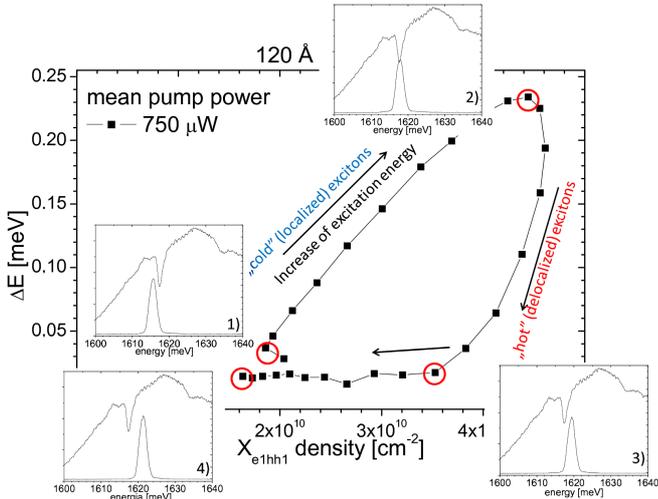


Fig. 1. Changes of energy of X_{e1hh1} transition line for different densities of created excitons for different excitation energies. The insets from 1 to 4 present energy position of the pump (narrow line) according to the exciton transition line (deep line on the broad spectrum). Pump energy rises from inset 1 to 4. Graph obtained for p -type, 120 Å QW, for co-polarization configuration.

4. Discussion and conclusions

In Fig. 1 a relation between energy shift of neutral exciton transition and the density of photocreated e-h pairs is presented for different energies of excitation in co-polarization configuration. The arrows indicate the rising excitation energy.

For both polarization configurations *blue shift* of exciton transition was observed, with a stronger effect for co-polarization. There is systematic increase of the *blue shift* for excitation below the resonance (Fig. 1 from point 1 to 2). It originates from increasing interaction among growing exciton population. The interaction results mainly from the Pauli exclusion principle. Maximum energy shift occurs at the resonance conditions (point 2). In case of excitation slightly above the resonance (from point 2 to 3), a rapid drop of the *blue shift* is observed despite further increase to PLE intensity. In that region, the exciton population is still rising and delocalized (hot) excitons are being created. The creation of hot excitons weakens interaction between excitons.

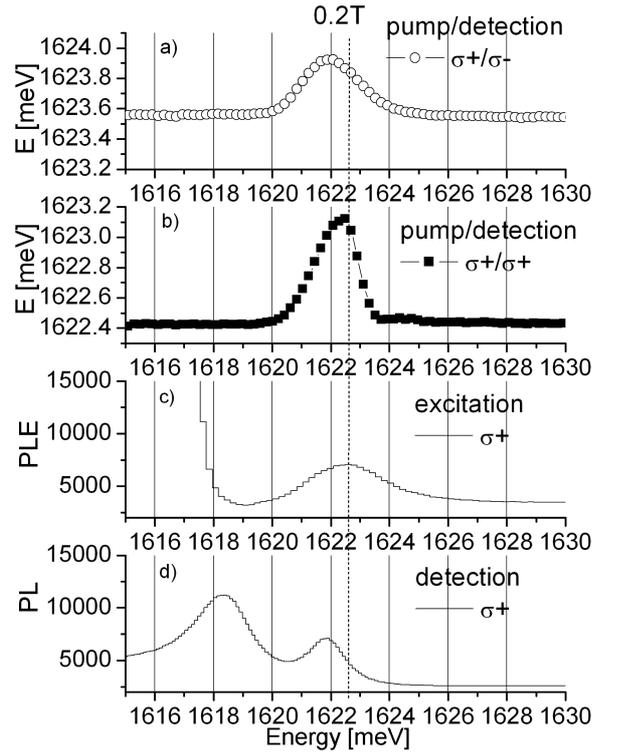


Fig. 2. The pump-probe reflectivity, PL and PLE results for p -type 120 Å QW in external magnetic field (0.2 T). Parts (a) and (b) present fitted X_{e1hh1} peak position for cross- and co-polarization configuration, respectively (σ^+ excitation). Part (c) shows PLE spectrum for σ^+ excitation, and part (d) shows PL spectrum for σ^+ detection.

The theoretical absorption spectra [3] were obtained within the time dependent Hartree-Fock approximation with the static screening of the Coulomb interaction. The multi-subband model was employed which takes into account the mixing between the bands caused by both Coulomb and $\mathbf{k}\cdot\mathbf{p}$ coupling [4]. The absorption coefficient is calculated by diagonalization of the effective Hamiltonian in the momentum space. Theoretical calculations reveal similar tendency of weakening energy shift with increase of temperature.

External magnetic field assured clear spin of excitonic population (which was created in lower σ^+ polarization). In Fig. 2 there are presented fitted energy positions of excitonic line versus excitation energy: (a) cross-polarization, (b) co-polarization, and PLE spectrum (c) for σ^+ excitation and PL spectrum (d) for σ^+ detection. For co-polarization configuration the same energy behavior is observed as in measurements without external magnetic field (a fast decrease of exciton energy line for above-resonance excitation). The maximum of the *blue shift* is almost for the same pump energy as the maximum of PLE. For cross-polarization the *blue shift* decays in a way similar to the disappearing PLE intensity. There is no effect of delocalized excitons. The *blue shift* for cross-polarization is probably caused by screening effects which weakens with falling exciton density.

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