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Charged and neutral excitons in natural quantum dots in the InAs/GaAs wetting layer

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Abstract

Magnetospectroscopic studies of the InAs/GaAs wetting layer (WL) accompanying self-organized quantum dots (QDs) grown in Stranski–Krastanow mode are presented. Sharp emission lines from ''natural'' QDs formed in the WL are observed and their evolution in magnetic field is investigated. A quadruplet or a doublet splitting of the emission lines has been observed in magnetic field, which is attributed to a charged and a neutral exciton in a single dot. The metastable transformation of the spectrum from the former to the latter configuration has been observed and explained in terms of the charging of a single dot.

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Keywords: Magnetospectroscopy; Quantum dots

1. Introduction

The interest in semiconductor quantum dots (QDs) is driven by both fundamental physics and potential for applications [1]. The three-dimensional localization of carriers can be obtained in several systems using e.g self-assembled growth or lithographic methods. Localization of excitons can also be achieved in thin quantum wells (QWs) due to monoatomic interface fluctuations in such systems as GaAs/AlGaAs [2] or CdTe/CdMgTe [3]. It has also been observed in the wetting layer (WL) accompanying the InAlAs/AlGaAs QDs [4] and InAs/GaAs QDs [5]. The latter system has been previously investigated in magnetic field [5]. The attribution of emission lines with a quadruplet splitting in magnetic field to charged exciton in its singlet and triplet configuration has been proposed. In this communication we present results which confirm the attribution. In particular, we show that a metastable transformation from the previously studied configuration to a configuration with a doublet splitting in magnetic field can take place, which in our opinion results from the transformation of the investigated dot into its neutral configuration.

2. Experimental technique

The structure with a single layer of InAs/GaAs QDs grown on the n^+-doped GaAs substrate by molecular beam epitaxy has been investigated in this work. The indium flush technique [6] has been applied and the sample has been annealed (850° for 30 s) after the growth. Investigated size of the sample was limited using mesa-patterning. The results of photoluminescence (PL) studies of the self-assembled QDs from the investigated structure have been presented elsewhere [7]. In this report, we focus on results of PL measurements of emission from the WL performed at liquid helium temperature in magnetic field up to 23 T (Faraday configuration) [8].

3. Experimental results

Typical spectrum from a mesa of 0.5 μm × 0.5 μm size is shown in Fig. 1. It consists of a broad band around

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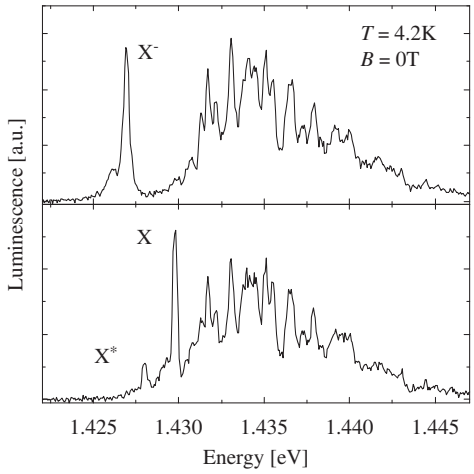

Fig. 1. The wetting layer-related photoluminescence before (upper panel) and after (lower panel) a high power illumination. Both spectra were excited recorded with the same power density.

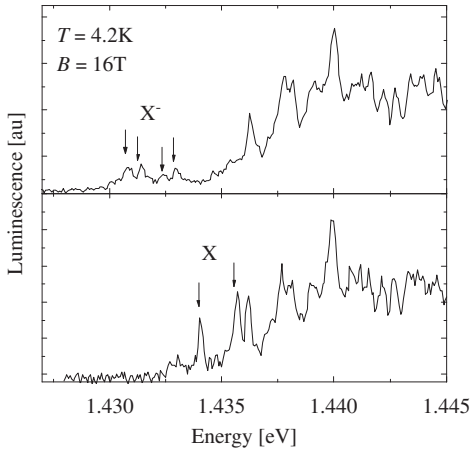

Fig. 2. The wetting layer-related photoluminescence before (upper panel) and after (lower panel) a high power illumination in magnetic field 16 T. Quadruplet (upper panel) and doublet lines (lower panel) are marked with arrows.

1.435 eV, which comprises several sharp excitonic features and a few emission lines at lower energy. The spectrum is similar to spectra previously observed in as-grown sample [5] (except for a blue-shift of ~5 meV due to In/Ga interdiffusion during the annealing procedure) [9].

It has been found that the spectrum from the investigated mesa changed its lineshape after excitation with high-intensity laser light (~1 kW/cm^2). The features observed below the broad band (see upper and lower panels in Fig. 1) have been affected by the illumination. The X^- emission line disappears and two other emission lines X and X^* emerge at lower energy. Different character of the two configurations has also been confirmed by their evolution in magnetic field. While the X emission line splits into two components (a weak X^* line, presumably due to a biexciton disappears at relatively low field) the X^- line splits into four components (see Fig. 2).

4. Discussion

Magnetic field evolution of the emission lines observed in both configurations, relative to the center of mass of the split-off components of the X line are shown in Fig. 3.

It can be seen that both the X and X^- emission lines have the same diamagnetic shift and the effective g^* factor ($g^* = 1.95$). The doublet splitting of the emission line X suggests its attribution to a neutral exciton. Neglecting an exchange-interaction splitting, two bright excitons of total momenta $M = \pm 1$ should split in perpendicular magnetic field. The splitting should be linear in magnetic field and it should depend on electron and hole g-factors.

The quadruplet splitting of the emission line from a natural InAs/GaAs QD, previously observed in the as-grown structure, has been attributed to a charged exciton [5]. Explanation of the splitting involves the negatively charged exciton in a dot, in which the excess carrier density blocks the spin relaxation. Although the triplet configuration cannot be observed in the zero-magnetic field, it becomes visible in magnetic field, which explains the apparent quadruplet splitting. Such a model has previously been proposed to explain the quadruplet splitting of emission lines from a single InAs/AlGaAs QD [10].

The attribution of the X and X^- to a neutral and singly charged exciton is further supported by our present study. The observed metastability can be explained in terms of ionization of the dot charged with an extra electron.

In such a picture the binding energy of the charged (singlet) exciton, defined as the energy needed to remove the second electron equals 2.7 meV at zero-magnetic field. As it can be seen in Fig. 3, the energy does not seem to depend on the magnetic field in the investigated field range. The value of binding energy is in a reasonable agreement with the values for excitons in self-assembled QDs [11] and quantum rings [12].

In conclusion, we have observed the metastable transformation of a PL spectrum related to natural QDs in

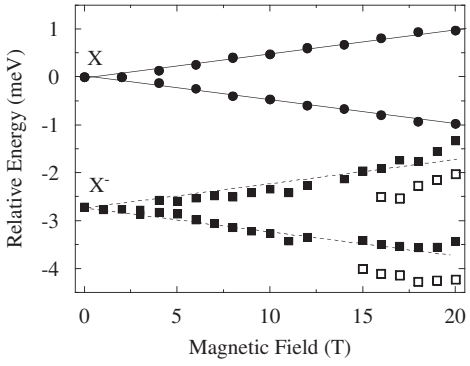

Fig. 3. Energies of emission lines from a natural QD in the InAs/GaAs wetting layers relative to the center-of-gravity of the split X components. Continuous lines reflect the Zeeman splitting of the neutral exciton X. Dashed lines are obtained by shifting the continuous lines by 2.7 meV and serve as guides to the eye.

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InAs/GaAs wetting layer. The quadruplet and doublet splitting of the emission lines observed before and after the transformation have been explained in terms of a negatively charged and a neutral exciton and the transformation has been attributed to the ionization of the investigated dot.

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