Excitonic Fock-Darwin Spectrum Of A Single Quantum Dot

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Abstract. Optical spectroscopy of a highly-excited single InAs/GaAs self-assembled quantum dot (QD) has been performed. The multiexcitonic emission from the *s*-, *p*-, and *d*-shells of the dot is observed and investigated in magnetic field up to 14T. Effects of interaction between the multiexcitonic configurations and the asymmetry of localizing potential are clearly visible when single-particle states become nearly degenerate: at B=0 and at a field-induced level-crossing. It is shown that the Fock-Darwin pattern modified with phenomenological parameters related to the effects explains the field-evolution of the emission.

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INTRODUCTION

Semiconductor quantum dots (QDs) offer a unique opportunity to study electron-electron interactions in strongly confined systems. So far, these studies were mainly limited to investigations of the emission related to the ground states in QDs [1]. More input may be expected from the analysis of excited states in QDs. To this end optical recombination due to multiexcitonic configurations can be studied. The optical emission from a highly-excited single QDs and its evolution in magnetic field are investigated in this work.

EXPERIMENTAL RESULTS

The sample investigated in this work was grown by molecular beam epitaxy on an n^+-GaAs substrate. It contains a single layer of InAs/GaAs QDs In-flushed at 5 nm [2]. The structure was annealed after growth (30 s at 850° C) to shift the emission into the sensitivity range of a CCD camera and to decrease the confining potential in the QDs [3]. A set of mesa structures was prepared on the sample to limit the number of dots addressed optically. The details of experimental setup have been presented elsewhere [4].

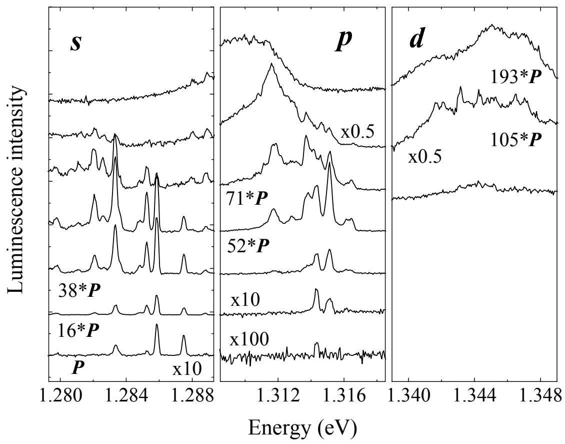

FIGURE 1. Power-dependence of the luminescence from a single InAs/GaAs dot. The lowest excitation power density P=~1 W/cm^2.

The evolution of the photoluminescence (PL) spectra from a submicron-size mesa as a function of the excitation power is shown in Fig. 1. The spectrum obtained at the lowest excitation power (~1 W/cm^2) is dominated by two emission lines, attributed to single excitons in a dot of different charge states. Their weak satellites are most likely due to respective biexcitons. At higher energy a weak emission line can also be observed, which is related to the *p*-shell. With increasing excitation power new *s*-shell-related and *p*-

shell-related emission lines emerge. These involve *NX* excitonic complexes with $N \geq 3$, giving rise to emission associated with the *s*- as well as the *p*-shell [5]. Further increase of excitation power results in new emission lines in both *s*-related and *p*-related energy-range. The highest excitation results in further change of the *s*-related and *p*-related emission, as well as in a new emission band at higher energy, which is due to the *d*-shell of the dot.

The attribution of the emission lines to particular shells of the dot is unambiguously supported by their evolution in magnetic field, which is shown in Fig.2. The *s*-related emission lines shift diamagnetically in magnetic field. The *p*-related lines either red-shift either blue-shift in magnetic field, and the *d*-related emission splits into three components.

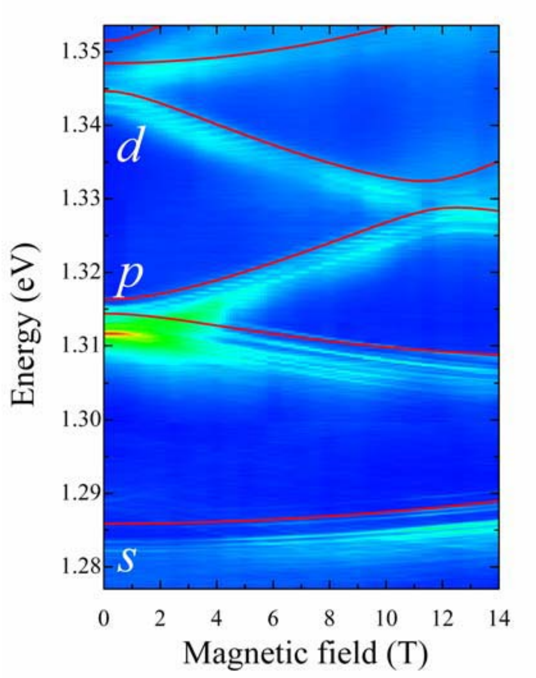

FIGURE 2. Luminescence from the *s*-, *p*-, and *d*-shells of a single InAs/GaAs dot in magnetic field up to 14T. The simulation based on the FD model modified by the zero-field splitting of the *p*- and *d*-shells and *p-d* interaction in high magnetic field is shown with red lines.

DISSCUSSION

The overall pattern of the PL-evolution in magnetic field resembles the Fock-Darwin (FD) spectrum [6], previously observed in PL experiments on large numbers of dots [7]. The observation of discreet emission lines uncovers new details of the dependence. These are the zero-field splitting between the *p*-related emission lines, which in magnetic field red- and blue-shift and the interaction between the *p*-, and *d*-related emission lines induced by magnetic field. The zero-field splitting of the *p*- (and *d*-) related lines is due to electron-electron interaction [8] and to a possible asymmetry of localizing potential [9]. The splitting can be reproduced in a simple perturbation theory by the introduction of a phenomenological interaction parameter to the single-particle FD model. In a similar way, the interaction between the *p*- and *d*-related emission lines can be described. Those parameters, as well as the reduced electron-hole mass found from experiment ($\mu=0.057m_0$) can be used to construct the modified FD pattern (see continuous lines in Fig. 2), which surprisingly well describes our experimental data.

CONCLUSIONS

Spectroscopic measurements of a highly excited single InAs/GaAs QD are presented. Sharp emission lines due to multiexcitonic complexes related to the *s*-, *p*-, and *d*-shells of the dot have been identified and investigated in magnetic field. The orbital Zeeman splitting of the emission from *p*- and *d*-shells and the effects of the electron-electron interaction and/or the asymmetry of the lateral potential have been observed. It has been shown that the magnetic field evolution of the emission from the highly-excited QD can be well described by a modified single-particle excitonic FD model.

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