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Photoluminescence of Field-Effect Quantum Dot Arrays Based on a Be-Delta Doped Single Heterojunction

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1. Introduction

Field-effect lateral quantum dot (QD) structures have been attracting interests [1]. One of the advantages of them is that the confinement potential is tunable and transition from 2 dimensional (D) to 0 D electron systems can be studied in single sample by changing the bias voltage.

A magneto-photoluminescence (PL) measurement was reported previously for a sample based on a GaAs modulation-doped quantum well (MDQW) structure [2]. It was shown that the Fermi-edge singularity depends on the applied bias voltage. Because an optically created hole is mobile in a MDQW, both the motions of electrons and a hole are modulated by the bias voltage. This obscured direct identification of 0 D electron system in the PL spectra.

Field-effect lateral quantum dot structures based on a Be-delta doped single heterojunction (SHJ) are one of the candidates to overcome the above difficulty. The PL spectra of Be-delta doped SHJ due to the radiative recombination of electrons with a hole are known to directly reflect the electron density of states [3]. Because of the strong localization, a hole bound to an acceptor can recombine with any electrons with momentum **k** with nearly equal optical transition probabilities. Thus the PL spectrum gives a direct method to investigate the electron systems.

The purpose of the present paper is to show that the electron density of states can be in fact tunable from 2 D to 0 D by the bias voltage in the field-effect lateral QD structure by PL measurements.

2. Experiments

The sample studied was a molecular-beam epitaxy grown GaAs-AlGaAs Be-delta doped SHJ structure on a *n*-type GaAs substrate used as a backgate. The electron density was estimated to be 5.6×10^{11} cm^{-2}. A Ti/Au semi-transparent surface Schottky gate structures was fabricated with a square mesh of a period of 200 nm by the electron beam lithography. A sample with unpatterned surface Schottky gate structure was also studied for comparison. The sample was illuminated at 532 or 785 nm at the excitation power density of less than 2 mW/cm^2.

3. Results and Discussions

3.1 Unpatterned surface gate case

A sample with an unpatterned surface gate structure is studied before proceeding to a lateral QD structure. Figure 1 shows bias voltage dependent PL spectra depending on the applied bias voltage between the backgate and the unpatterned surface gate structure at 1.8 K illuminated at 532 nm. The band gap (E_g) and the Fermi energy (E_F) are located at around 1.478 and 1.495 eV, respectively, at $V_B = 0$ V. The electrons are slightly depeleted due to the metal deposition on the surface. The PL intensity between E_g and E_F are seen to be nearly flat, reflecting the 2 D density of states. E_g and E_F shift to higher and lower energies, respectively, with decrease in V_B. This shows that the electron density below the unpatterned surface gate structure decreases with decrease in V_B. At $V_B \leq -1.8$ V, the PL from the electron system becomes very weak, showing that the electrons below the surface gate structure are

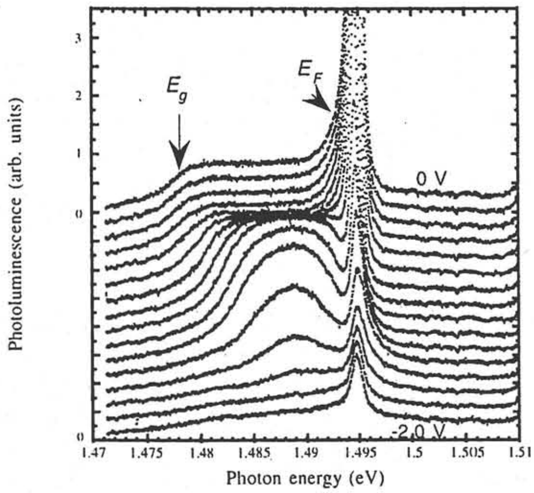

Fig. 1 Bias voltage dependent PL spectra of a sample with an unpatterned surface Schottky gate structure at 1.7 K. The bias voltage are varied as 0, -0.1, -0.2, -0.3, -0.4, -0.5, -0.6, -0.7, -0.8, -0.9, -1.0, -1.2, -1.4, -1.6, -1.8, and -2.0 V. Zero points of the y axis are shifted.

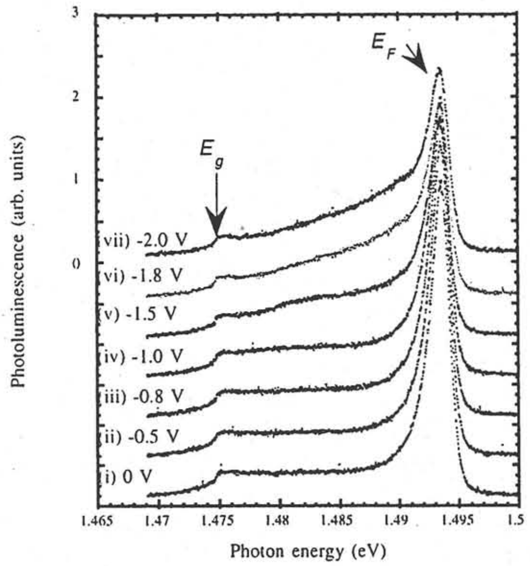

Fig. 2 Bias voltage dependent PL spectra of a sample with a square mesh of a period of 200 nm Schottky gate structure at 3.3 K. The bias voltage are varied as (i) 0, (ii) -0.5, (iii) -0.8, (iv) -1.0, (v) -1.5, (vi) -1.8, and (vii) -2.0 V. Zero points of the y axis are shifted.

completely depleted.

3.2 Square mesh surface gate case

Contrasting with the PL of the unpatterned sample, the bias voltage dependent PL spectra of a sample with a square mesh of a period of 200 nm as shown in Fig. 2 show two distinct behaviors. First, the band gap shown by the arrow is constant between V_B = 0 and -2.0 V. This indicates that the electron density is constant in the area contributing to the observed PL. Second, the PL lineshape changes with V_B. The PL intensity increases almost linearly with energy between E_g and E_F at V_B = -2.0 V, which contrasts with the flat PL intensity between E_g and E_F at V_B = 0 V. This almost linear increase of the PL intensity with the energy shows that the density of states of the electrons in the sample at V_B = -2.0 V is approximately described by that of the 2 D harmonic oscillator. In the 2 D harmonic oscillator, the degeneracy of the states increases linearly with the increase in the principal quantum number.

The above result shows that confined electron states are created at V_B = -2.0 V with nearly the same aerial electron density in the center of the QD as that in 2D at V_B = 0 V.

4. Conclusions

We have shown that the bias voltage dependent PL spectra of the Be-delta-doped sample indicate a 0 D density of states of electrons at negative bias voltages. This shows that quantum dots are formed in our field-induced quantum dot array structure.

References

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