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Near-Field Scanning Optical Microscopy of Quantum Dot Arrays

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1. Introduction

A near-field scanning optical microscope (NSOM) measurement of *n*-type GaAs quantum dot arrays is reported. Monochromatic PL images clearly reveal periodical photoluminescence (PL) intensity distribution, showing the PL intensity is high in the high electron density region. This indicates that a quantum dot array is formed in a field-induced quantum dot array structure, showing that a NSOM-PL measurement is a powerful tool to study the electric states in semiconductor nanostructures.

Field-effect lateral quantum dot structures have been investigated such as by far-infrared spectroscopy [1]. They have advantages that the confinement potential is tunable by changing the bias voltage and that they are less affected by imperfections due to the interfaces. A far-field magneto-PL measurement was reported previously [2] depending on the negative bias voltage applied between a surface nanostructured gate and a backgate. Although the bias voltage dependent PL spectra indicate the spatial modulation of electron density distribution by the nano-structured gate, there has been no direct evidence for a detection of quantum dot array formation by a PL measurement. In this paper, we will show a direct evidence for the formation of a quantum dot array in a field-effect lateral quantum dot structure by a NSOM-PL measurement.

2. Experiments

The sample studied was a molecular-beam epitaxy grown GaAs-AlGaAs *n*-type modulation-doped quantum well (MDQW) structure on a *n*-type GaAs substrate used as a backgate. The electron density was estimated to be 6×10^{11} cm^{-2}. Ti/Au semi-transparent surface Schottky gate structures were fabricated with a square mesh of a period of 1000 nm by the electron beam lithography as shown in Fig. 1. NSOM PL measurements were performed at 7.5 K with the spatial resolution of about 150 nm. The sample was illuminated at 532 nm through the aperture of a high sensitive double-tapered fiber probe [3] at the excitation power density of 700 mW/cm^2 and the PL was collected through the same probe.

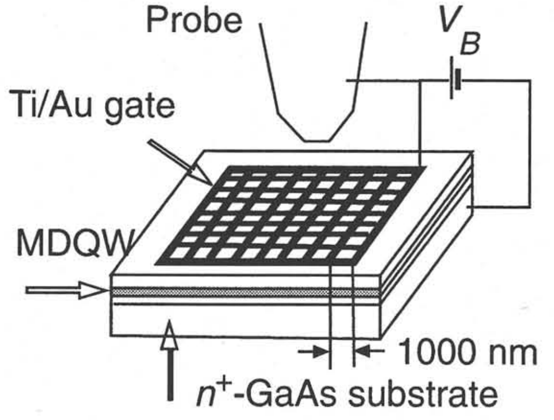

Fig. 1 Aschematic sample structure. A square mesh with a period of 1000 nm is prepared by the electron beam lithography.

3. Results and Discussions

Figures 2 (a) and 2 (b) show a shear-force image of the sample surface and a PL image detected at 1.511 eV with a spectral window of 3 meV at the bias voltage V_B = -0.65 V, respectively. The center of the detected photon energy corresponds to the optical transition energy from the lowest state in the quantum dots. At V_B = -0.65 V, the electron density was shown to be well isolated by self-consistently solving a Schrödinger and Poisson's coupled equation [2], forming a quantum dot array. The PL image shows that the PL intensity has a maximum value at the center of the square mesh structures, where the electron density is highest. This is a direct evidence that the quantum dots are formed in our field-effect structure and that the quantum confined states are detected by the PL measurement.

(a)

(b)

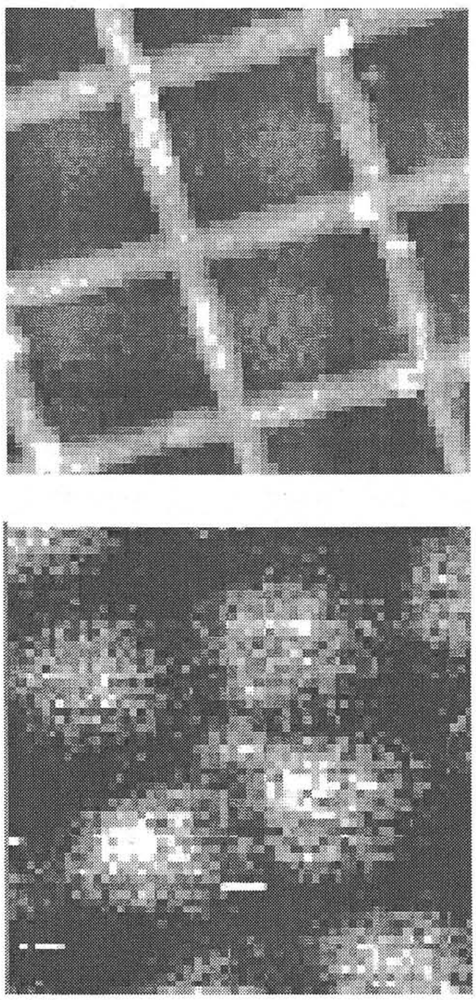

Fig. 2 (a) Shear-force image of sample surface, (b) PL image detected at 1.511 eV with a spectral window of 3 meV.

In a field-effect lateral quantum dot structure, the potential confinement acts differently to an electron and a hole. At a negative bias voltage, the potential minimum for an electron is located at the center of the square mesh, while the potential minimum for a hole is located beneath the surface gate electrode. The observed PL image at a negative bias voltage is not due to the recombination of the electrons and a hole both in the equilibrium states. A self-consistent calculation shows that the lateral potential profile at the center of a quantum dot is nearly flat because of a screening effect, while that in-between quantum dots is steep. The hole diffusion velocity is rather slow at the center of a quantum dot, while the electron diffusion velocity is fast in-between quantum dots. The observed PL image is thus due to the recombination of the electrons defined by the field-induced confinement potential and a hole diffusing around the center of a quantum dot.

4. Conclusions

We have shown by a NSOM measurement that the PL intensity is high in the high electron density region, which indicates that a quantum dot array is formed in a field-induced quantum dot array structure.

References

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