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Field Effect Control of Photoluminescence from InGaAs Ridge Quantum Wires Grown by Selective MBE on Patterned InP Substrates

Chao Jiang and Hideki Hasegawa

Research Center for Integrated Quantum Electronics and Graduate School of Electronics and Information Engineering, Hokkaido University, Sapporo 060-8628, Japan

Telephone: +81-11-706-7176, FAX: +81-11-716-6004, E-mail: chjiang@reciqe.hokudai.ac.jp

1. Introduction

Field effect control of optical properties of nanostructures, if it is possible, provides an interesting possibility for understanding physics as well as for creating novel gated photonic devices. Recently, we have observed a strong gate voltage dependence of photoluminescence intensity in an InP metal-insulator-semiconductor (MIS) structure well-passivated by a silicon interface control layer[1]. We could show that gating controls the surface potential for majority carriers in spite of presence of photo-excitation. This indicates feasibility of very fast optical switching by sweeping of majority carrier depletion edge with gate-controlled surface potential.

The purpose of this paper is to investigate field effect control capabilities of photoluminescence (PL) from InGaAs ridge quantum wires (QWRs) grown by our selective MBE growth method[2,3] on patterned (001) InP substrates. This method has recently achieved highly uniform wire arrays having wire widths below 10 nm.

2. Experiment

The cross-sectional structure of the InGaAs ridge QWR array sample used in this study is shown in **Fig.1 (a)**. An arrow-head shaped QWR was formed in a self-organized fashion during MBE growth of an InAlAs/InGaAs/InAlAs layer structure on the InGaAs ridge structure pre-grown on the patterned n^+-InP substrate. The effective width of the wire was about 30 nm, and the wire pitch was Lp = 4 μm. For the purpose of comparison, a planar double-quantum well (QW) sample shown in **Fig.1 (b)** was also prepared as a reference. Both samples had a thin 10-nm thick InGaAs cap layer as the Schottky-assist layer.

In order to investigate field-effect control capabilities under optical excitation, a semi-transparent Au Schottky contact was deposited in vacuum. A GeAuNi ohmic back contact was also formed. The set-up for the measurements is shown in **Fig. 2**. The PL measurements were performed at 25 K using an Ar^+ ion laser having an emission wave length of 514 nm. The excitation power for PL was 70 mW.

3. Results and Discussion

3.1 Gate-controlled PL from planar double-QW Samples

The gated PL behavior observed at 25 K on a planar double-QWs reference sample under the negative bias is summarized in **Fig. 3**. Four major peaks existed when no gate bias was applied. From the theoretical calculation of QW emission wavelengths, the peaks from 1.14 eV and 0.86 eV are assigned to QW1 (2.5 nm) and QW2 (10 nm), respectively. The peak at 1.41 eV is from the n^+-InP substrate and that at 1.58 eV is from the InAlAs layers.

The gate voltage dependence of various PL peak heights is summarized in **Fig. 3(b)**. When a negative bias, $-V_g$, was increased, intensity of all peaks generally decreased except that the intensity of QW2 peak first showed a small increase before showing decrease. All the gated PL behavior can be, not only qualitatively, but also quantitatively, explained in terms of sweep of majority carrier depletion layer edge together with exponential decay of absorption of excitation light[1]. This results in extremely sharp V_g-dependences for QW peaks. The initial increase of QW2 intensity is due to sharp V_g-induced decrease of radiative recombination at QW1. As shown in **Fig. 3(c)**, the QW2 peak showed a redshift with bias, and this can be explained quantitatively in terms of the Stark effect in a wide QW.

3.2 Gated PL emission from Ridge QWR arrays

The PL spectrum of the ridge QWR array sample before gate deposition is shown in **Fig. 4**. Besides two bulk peaks at 1.4 eV and 0.8 eV from the n-InP substrate and n-InGaAs ridge layer, three other peaks are typical PL spectra of our ridge QWR[4], originating from the bottom QW (b-QW at 1.03 eV), QWR (1.12 eV) and sidewall QWs (s-QW at 1.19 eV), respectively, shown in Fig. 1(a).

The gated PL behavior observed at 25 K on the QWR sample with Au gate under the negative bias is summarized in **Fig. 5(a)**. The peaks showed different voltage dependences as summarized in **Fig. 5(b)**. The QWR sample showed the steepest response. Although the quantitative analysis of V_g-dependence requires a numerical simulation on computer due to the complicated QWR geometry, it can be qualitatively explained again in terms of sweep of majority carrier depletion layer edge. This seems to provide a great promise for extremely high speed gated switching of our sharp and narrow QWR PL peak.

References

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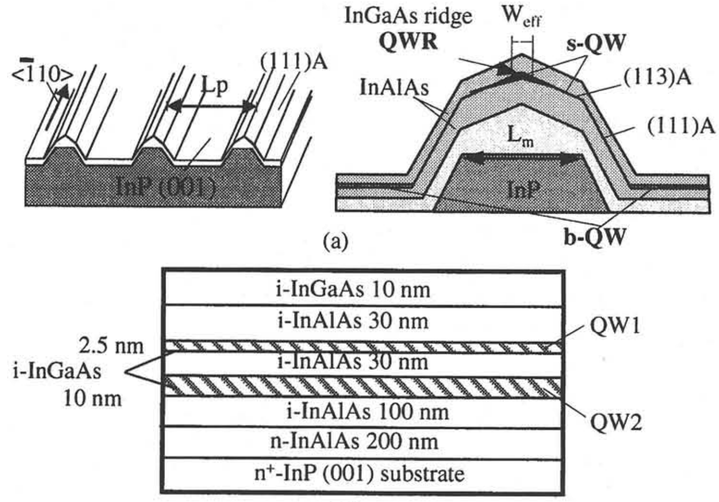

Fig. 1 (a) Schematic of ridge QWR (b) structure of double QW.

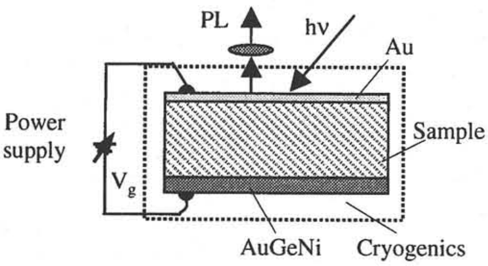

Fig. 2 Setup of gate-controlled PL measurement.

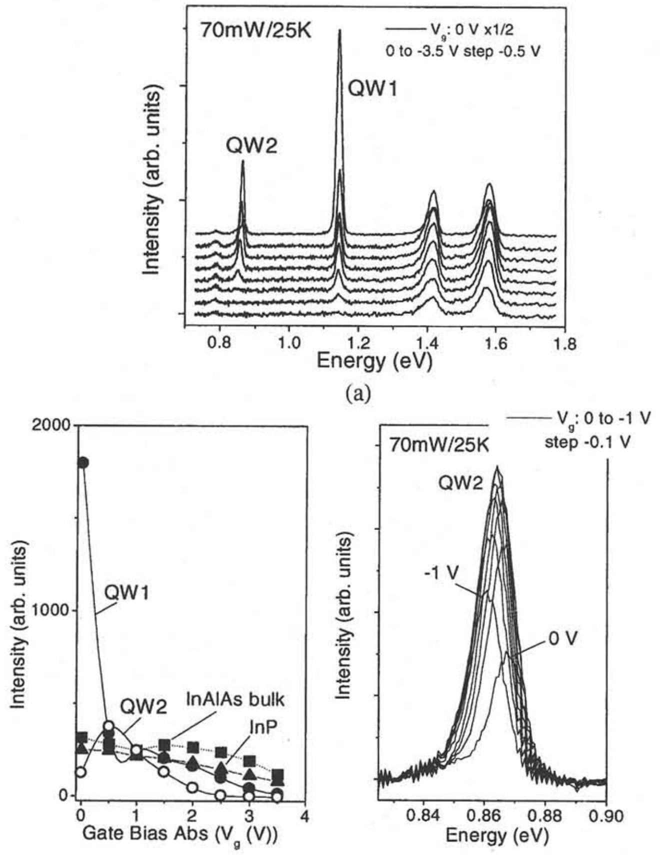

Fig. 3 (a) Gated PL spectra for the planar double-QWs under the negative bias. (b) Comparison of peak intensity and (c) Negative bias-dependent PL spectra for the QW2 (10 nm).

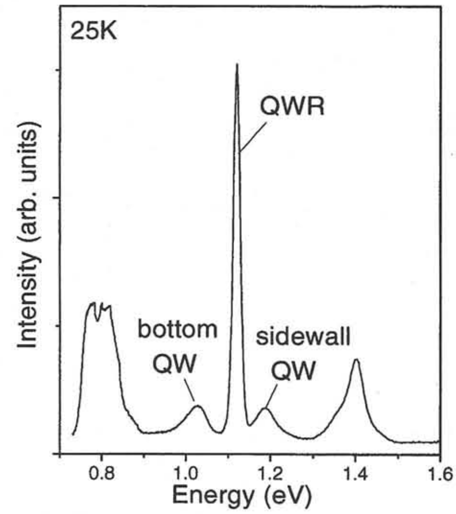

Fig. 4 PL spectra for the ridge QWR without Au film coating.

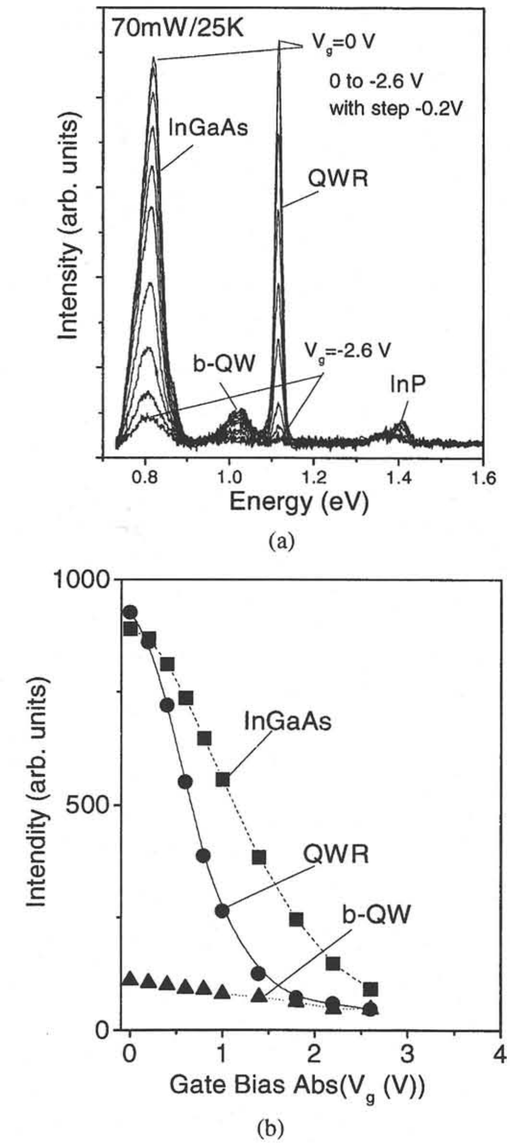

Fig. 5 (a) Gated PL spectra for the ridge QWR under the negative bias. (b) comparison among InGaAs bulk, bottom QW and QWR.