Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 318–319

D-6-5

Structural and Optical Properties of 10 nm-Class InGaAs Ridge Quantum Wire Arrays with Sub-Micron Pitches Grown by Selective MBE on Patterned InP Substrate

Chao Jiang, Tsutomu Muranaka and Hideki Hasegawa

Research Center for Integrated Quantum Electronics and Graduate School of Electronics and Information Engineering, Hokkaido University, N-13, W-8, Kita-ku, Sapporo 060-8628, Japan
Phone:+81-11-706-7176 Fax:+81-11-716-6004 E-mail: chjiang@rciqe.hokudai.ac.jp

1. Introduction

Selective MBE/MOVPE growth on pre-patterned substrates is the most powerful approach to realize position- and size-controlled, defect-free quantum wire (QWR) arrays [1-3] that are potentially useful for high density integration of quantum devices[4,5]. Recently, we have been making intensive efforts to realize high-density linear arrays of 10 nm-class InGaAs ridge QWRs with submicron wire pitches by selective MBE on InP pre-patterned substrates.

The purpose of the present study is to carry out systematic micro-structural and optical characterization of the growth process and grown wires for such InGaAs QWR arrays by SEM, TEM, AFM, CL and PL measurements in order to confirm 10 nm-class wire formation and further to improve the growth process for further miniaturization.

2. Experimental

Figure 1 shows the structure of InGaAs QWR arrays used in this study. They were grown by selective MBE on the patterned InP substrates. The growth process was described in detail previously[6,7] where the pitch length of wire arrays, L_p, was reduced from 4 μm down into submicron region by gradually scaling down the mesa patterns.

The structural and optical characterization was made by SEM (HITACHI S-4100), cross-sectional TEM (JEOL JEM-2010X), AFM (Digital Instruments Nanoscope IIIa), PL and CL (JEOL JSM5410 + Oxford monoCL) techniques. PL measurements were performed from 20 to 240 K using an Ar^+ ion laser at 514 nm. Spectrally and spatially resolved CL measurements were performed at 8 K at an electron acceleration energy of 15 keV.

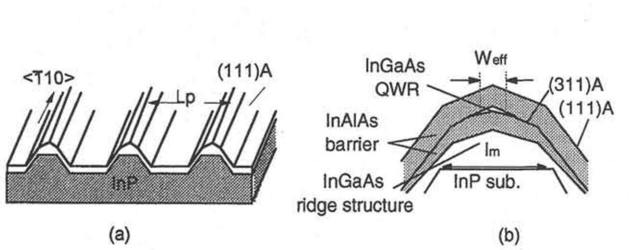

Fig. 1 (a) InGaAs QWR array and (b) cross section.

3. Results and Discussion

In order to realize 10 nm-class wires with acceptable uniformity in the wire direction, high geometrical uniformity of the initial InGaAs ridge structure before QWR growth was found to be extremely important. By aids of pre-growth etching, native oxide removal using atomic hydrogen cleaning of InP pattern below 400 °C without As_4 pressure and use of the optimum V/III ratio, a highly uniform InGaAs ridge structure could be obtained as shown in **Fig. 2** by the result of AFM measurements.

A SEM micrograph and a cross-sectional TEM image of a grown QWR array having a pitch of L_p = 0.8 μm are shown in **Fig. 3 (a)** and **(b)**, respectively. Well-defined InGaAs ridge

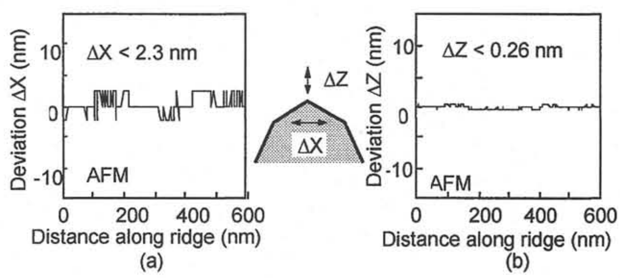

Fig. 2 Structural deviations of the InGaAs ridge structure.

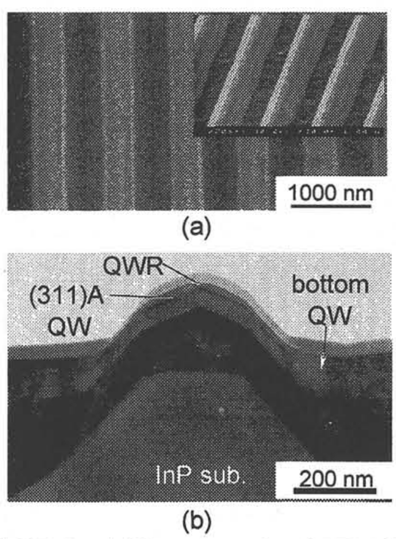

Fig. 3 (a) SEM and (b) cross sectional TEM images of 0.8 μm-pitch InGaAs QWR.

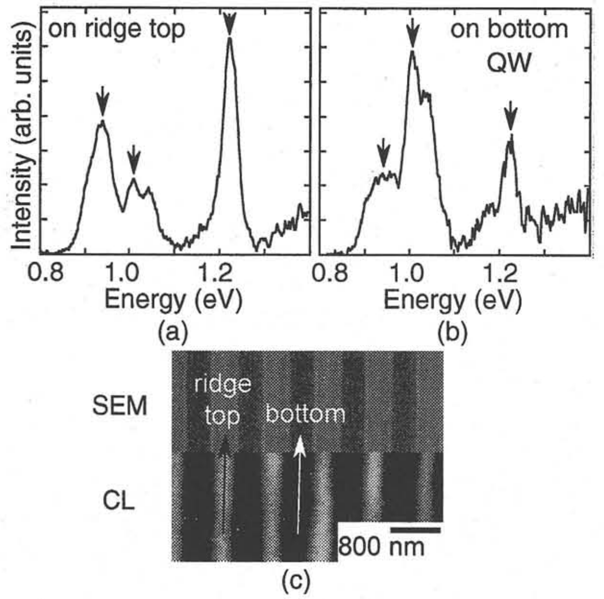

Fig. 4 CL spectra of (a) the ridge top and (b) bottom QW. (c) Plan-view SEM image and its CL image.

structure is formed on the 250 nm-wide InP mesa top, and an arrow-head shaped QWR can be clearly identified on the well-defined two (311)A facets. The lateral extension of QWR increased with increase of the lower InAlAs layer thickness and quickly became equal to the width of stripe mesa of the InP substrate, l_m, being independent of the value of L_p and thickness of buffer ridge. In contrast to the QWR region, the bottom quantum well (QW) region as well as the (111)A sidewall region show structural fluctuations.

Spectrally resolved CL measurements were performed by focusing the electron beam on different spots on the QWR sample. The result is shown in **Fig. 4 (a)** and **(b)** for the cases of the spot being on the QWR ridge top and on the bottom QW, respectively. For the spot on the ridge top, the peaks situated at 1.22 and at 0.92 eV had much higher intensity than the peak at 1.0 eV. An opposite situation took place for the spot on the bottom QW. This led to assignments of 1.22, 0.92 and 1.0 eV peaks being from QWR, (111)A QW and bottom QW, respectively. The assignment of QWR was further confirmed by a spatially resolved monochromatic CL imaging (1.22 eV) as shown in **Fig. 4 (c)**.

The PL measurement is shown in **Fig. 5** for a QWR array with $L_p = 0.8$ μm. As a reference, the PL response at 20 K of a planar QW sample simultaneously grown is shown by a dotted curve. A narrow single peak with FWHM = 23 meV was seen at 20 K together with very small peaks from the bottom/side QWs. From a theoretical analysis, the effective wire width corresponding to the peak position of 1.22 eV was found to be $W_{eff} = 10$ nm. Difference in relative peak heights between PL and CL spectra is due to the fact that, at highly localized strong excitations in CL measurements, the main QWR peak is saturated and bottom and side QW peaks are emphasized.

The excitation power dependence of the integrated PL

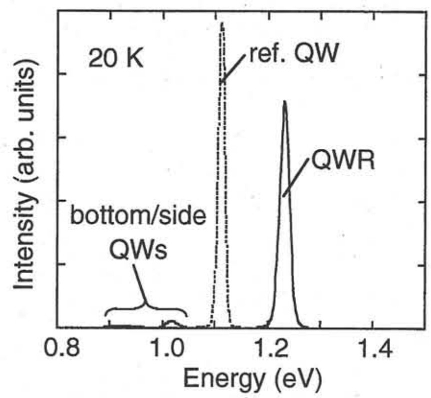

Fig. 5 PL spectra of QWR sample.

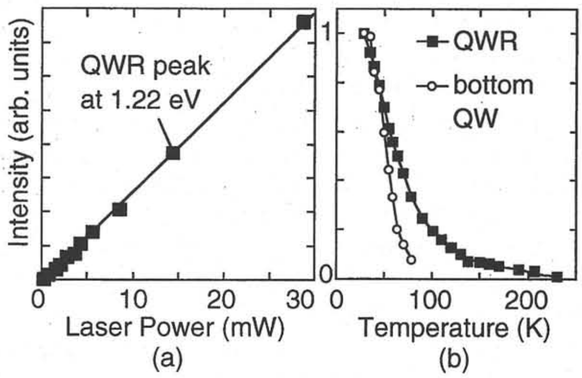

Fig.6 (a) Excitation laser power and (b) temperature dependences of PL intensity.

intensity of the main QWR peak was linear and well-behaved as shown in **Fig. 6 (a)**. The temperature-dependence of the normalized PL intensity of QWR peak is compared with that of the bottom QW in **Fig. 6 (b)**. The QWR had a high PL efficiency, and luminescence persisted up to 250 K in the linear scale intensity as seen in **Fig. 6 (b)**.

In conclusion, detailed systematic study has demonstrated that the present submicron-pitch InGaAs QWR arrays has excellent structural and optical properties after growth characterization and optimization, giving a good prospect for further miniaturization.

References

[1] H. Hasegawa, H. Fujikura and H. Okada, MRS Bull. **24**(8), 25 (1999).

[2] E. Kapon, D. M. Hwang, and R. Bhat, Phys. Rev. Lett. **63**, 430 (1989).

[3] X. L. Wang, M. Ogura and H. Matsuhata, Appl. Phys. Lett. **67**, 3629 (1995).

[4] H. Okada, H. Fujikura, T. Hashizume, H. Hasegawa, Jpn. J. Appl. Phys. **36**, 1672 (1997)

[5] S. Kasai, Y. Amemiya and H. Hasegawa, Tech. Digest. of IEDM 2000, 585 (2000).

[6] C. Jiang, T. Muranaka and H. Hasegawa, Jpn. J. Appl. Phys. **40**, 4B-355 (2001).

[7] C. Jiang, T. Muranaka and H. Hasegawa, Proceeding of IPRM'01, Nara, Japan (2001).