Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 312–313

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Optical Investigation of High-Density InGaAs/AlGaAs Quantum Wire by Constant MOCVD Growth

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1. Introduction

Semiconductor nano-structures such as quantum wires (QWRs) have attracted much attention due to their potential applications for photonic devices such as laser diodes and photonic switches. Selective metalorganic chemical vapor deposition (MOCVD) on nonplanar substrates has been widely paid attention, because high quality QWRs are realized without lithographic resolution. For the first time, we have fabricated high quality QWR structures by flow rate modulation epitaxy [1] and realized the grand state lasing operation in V-groove QWR laser [2]. However, the active region volume of the QWRs tends to be too small compared with that of the QWs, and it deteriorates the efficiency of the optical devices. In order to overcome this problem, high-density QWR array structures have been fabricated. Recently we developed the constant MOCVD growth technique on submicron grating to fabricate high-density V-groove GaAs/AlGaAs Quantum wire (QWRs) structure preserving a grating height above 1 μm [3]. By this technique, complex photonic devices such as gain-coupled distributed feedback (DFB) lasers have also fabricated [4]. The potential advantage of the constant growth technique is the fact that such a complex structures can be grown by one-step growth without interface defect due to the elimination of ex-situ etching and regrowth of buried heterostructures.

Strained InGaAs structures are very important for the practical applications since the emission wavelength range increase to the optical telecommunication windows. It also favors high temperature excitons because of strong confinement between InGaAs and AlGaAs. In this study, high-density InGaAs/AlGaAs QWR structures are realized by the constant MOCVD growth technique on submicron grating, and optical properties of these structures have been investigated by photoluminescence spectroscopy (PL), photoluminescence excitation spectroscopy (PLE) and time-resolved PL technique.

2. Experimental Procedure

In order to investigate the structural and optical properties, we grew $In_{0.2}Ga_{0.8}As/Al_{0.38}Ga_{0.62}As$ QWR structures by constant MOCVD growth technique. The submicron gratings were fabricated by a conventional holography and a wet chemical etching on exact (100) GaAs substrates. Epitaxial growth was carried out in a horizontal quartz reactor by a low pressure MOCVD.

The cross section of the samples were observed with a high resolution transmission electron microscopy (TEM). PLE spectra of the sample were measured for a excitation light polarized parallel and perpendicular to the wire axis at 11 K using cw-Ti: sapphire laser. PL spectrum was also measured for a reference using cw-Ti: sapphire laser (λ = 720 nm). Time-resolved PL measurements were performed over the temperature range of 10-200 K using mode-locked Ti:sapphire laser, whose pulse duration is 2 ps and wavelength is 810 nm.

3. Results and Discussions

The cross-sectional TEM image the $In_{0.2}Ga_{0.8}As/Al_{0.38}Ga_{0.62}As$ QWR structure by one-step constant MOCVD growth technique is shown in Fig 1. The InGaAs QWRs are well confined at the bottom of the grating. The vertical thickness of the QWR is about 7 nm. Parasite quantum wells (QWs) are also observed at the side-wall and top of the grating. Although the side-wall and top QWs still exist, its thickness is very thin compared with that of QWRs at the bottom of the gratings, because an indium migration rate is fast due to the larger diffusion coefficient [5]. Therefore, the difference in the quantum ground states between the QWRs and the parasite QWs is expected to be large because the size of these two structures are not the same as shown in Fig. 1.

Figure 2 shows the PLE spectra of the InGaAs QWR structure for an excitation light polarized parallel (solid line) and perpendicular (dashed line) to the wire axis at 11 K. The PL is also shown in Fig. 2 for a reference and the peak is located at 1.420 eV. The PLE spectra of both polarizations are in line with the reported results by Constantin et al. [6]. It is observed that the PLE peak is located at 1.467 eV due to the transition between the first electron state and the first heavy-hole state (1e-1hh). The peak of the PLE spectrum is shifted by 47 meV from the peak of the PL spectrum, which is considerably large Stokes shift.

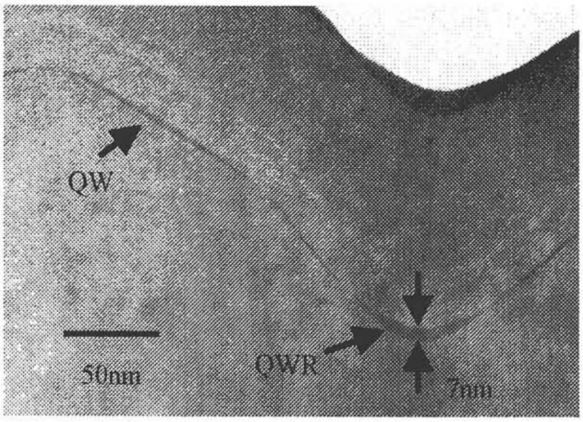

Fig. 1 Cross-sectional TEM image of $In_{0.2}Ga_{0.8}As/Al_{0.38}Ga_{0.62}As$ QWR structure.

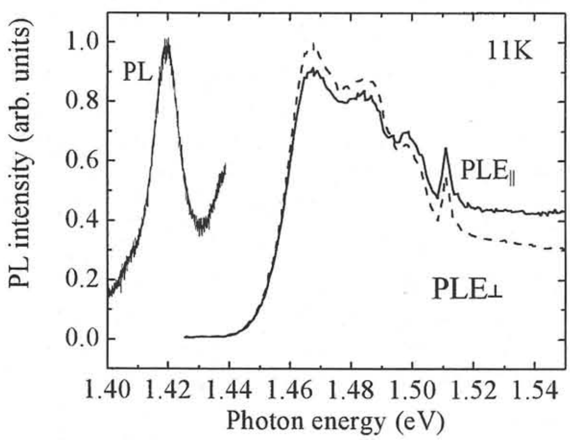

Fig. 2 PLE spectra of InGaAs/AlGaAs QWRs structure at 11 K.

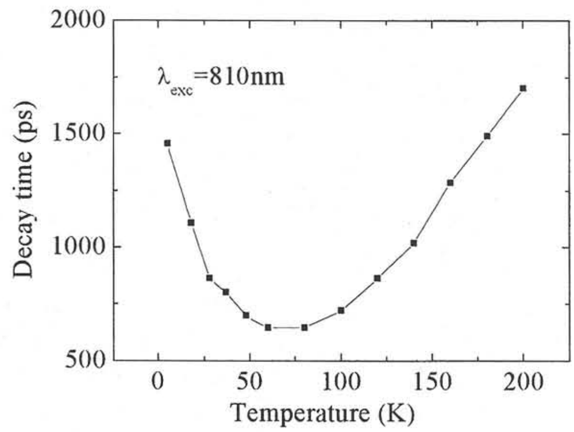

Fig. 3 Temperature dependence of PL lifetimes.

The temperature dependence of the PL lifetimes of the InGaAs QWR structure is shown in Fig. 3. In general, the PL lifetimes of QWRs increases as the temperature increases when the radiative recombination is dominant process [7, 8]. However, we have observed longer lifetime about 1.5 ns for QWRs, and the lifetimes decrease up to 60 K, after that it increases up to 200 K. This anomalous behavior suggests that the excitons in the QWRs are strongly localized like those in the quantum dots (QDs) at 5 K, and are delocalized at high temperature range and the structure behaves like QWRs above the temperature 60 K. The considerably large Stokes shift (shown in Fig. 2) is more evidence of the QD-like behavior at the low temperature range.

4. Conclusions

In conclusion, high-density InGaAs/AlGaAs Quantum wire (QWR) structures were successfully grown on submicron gratings with the period of 430 nm and grating height above 1μm by constant metalorganic chemical vapor deposition (MOCVD) growth technique. The potential advantage of this technique is the fact that the complex optical devices such as gain-coupled DFB laser can be fabricated on the submicron grating by one-step MOCVD growth. The optical properties of high-density InGaAs/AlGaAs quantum wire array structures were investigated by PL, PLE and time-resolved PL. Large Stokes shift was observed by PLE at 11 K. Temperature dependence of PL lifetimes suggested that the structures analogous to QDs behavior at the low temperature region.

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