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Quantum Nanostructure of InGaAs on Submicron Gratings by Constant Growth Technique

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Abstract

A new constant growth technique to conserve an initial grating height of V-groove AlGaAs/InGaAs quantum nanostructures above 1.0 μm thickness has been successfully embodied on submicron gratings using low pressure metalorganic chemical vapor deposition. A GaAs buffer prior to an AlGaAs barrier layer on submicron gratings plays an important role in overcoming mass transport effects and improving the uniformity of gratings. Transmission electron microscopy (TEM) image shows that high-density V-groove InGaAs quantum wires (QWRs) are well confined at the bottom of gratings. The photoluminescence (PL) peak of the InGaAs QWRs is observed in the temperature range from 10 to 280 K with a relatively narrow full width at half maximum less than 40 meV at room temperature PL. The constant growth technique is an important step to realize complex optoelectronic devices such as one-step grown distributed feedback lasers and two-dimensional photonic crystal.

Key Words : quantum wire, InGaAs, submicron grating, MOCVD, PL

1. INTRODUCTION

Recently, the study of semiconductor nanostructures has drawn much attention because of their potential for applications in new functional devices [1-6]. In particular, strained V-groove InGaAs quantum wires (QWRs) have many unique properties, such as enhanced optical non-linearity due to the quantum confined stark effect [4] and an increase in the exciton binding energy due to the enhanced electron-hole Coulomb correlations [5,6]. Selective metalorganic chemical vapor deposition (MOCVD) on nonplanar substrates has been widely developed, because high-quality QWRs are realized beyond the limitation of lithographic resolution. However, the volume of active region of QWRs grown on gratings with a period of several microns tends to be too small compared with that of the quantum wells (QWs). This figure deteriorates the efficiency of optical devices. In order to overcome this problem, high-density QWR array structures have been fabricated on submicron gratings [7]. Recently, a constant MOCVD growth technique has been developed on submicron gratings to fabricate high-density V-groove GaAs/AlGaAs QWRs structures [8]. The constant growth technique is a new growing method that enables the grating height of AlGaAs/GaAs epilayers grown on submicron grating to conserve above 1.0 μm thickness along the vertical direction of epilayer by one-step MOCVD growth. Especially, the constant growth technique for fabricating distributed feedback (DFB) laser hold many advantages including the elimination of *ex situ* etching and regrowth, and the stable single

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longitudinal mode operation via gain-coupling, as compared to conventional DFB laser which generally requires at least two-step growth and other critical processing for single-mode operation [9,10].

Strained InGaAs structures are very important for practical applications since the range of emission wavelength will extend toward the optical telecommunication windows [11]. It also favors high temperature excitons because of strong confinement between InGaAs and AlGaAs. Especially, the establishment of high-density InGaAs quantum wires on submicron grating is undoubtedly important for the fabrication of one-step grown DFB lasers [9,10]. The potential advantage of the constant growth technique is the fact that such complex structures can be grown by one-step growth without interface defects due to the elimination of *ex situ* etching and the regrowth of buried heterostructures. In this work, high-density InGaAs/AlGaAs QWRs are realized by the constant MOCVD growth technique on submicron gratings.

2. EXPERIMENTAL

Epitaxial growth was carried out in a horizontal quartz reactor by low pressure MOCVD. The submicron gratings with the periods of 380 and 430 nm and the grating height of 200 nm were fabricated by conventional hololithography and wet chemical etching. A hololithography, a maskless technique that records the interference fringes of two collimated interfering laser beams, is a well-known technique suitable for defining submicron gratings. A wet chemical etching technique was employed to produce V-shaped submicron gratings on the exact (100) n^+-GaAs substrates. GaAs substrates were patterned with a symmetric saw-tooth shape along the $[0\bar{1}1]$ direction on the GaAs substrates. More details on the pattering of submicron gratings by hololithography are described elsewhere [8,12].

After the patterned GaAs substrates were etched by HCl to remove a surface oxide, rinsed thoroughly in deionized water, and dried with pure nitrogen, those were loaded into a low pressure MOCVD reactor. Palladium-diffused H_2 gas was used as a carrier gas. The total flow rate was 4,000 sccm. The V/III ratio was 200. Triethylgallium (TEG), trimethylaluminum (TMA), trimethylindium (TMI), and AsH_3 were utilized as source reagents. The cross sections of samples were observed with a high-resolution scanning electron microscope (SEM) and a transmission electron microscope (TEM). Photoluminescence (PL) measurement was carried out over the temperature range from 10 to 280 K using the 514.5 nm line of an Ar^+ laser as an excitation light.

3. RESULTS AND DISCUSSION

The submicron gratings on GaAs substrates tend to be thermally deformed during a thermal cleaning. This is due to mass transport near the crystal surface, and the driving force is the variation in the surface free energy accompanying the variation in surface curvature [13]. The mass transport process is significantly affected by the surface diffusion of Ga atoms from a convex surface to a concave surface, since the periods of gratings are in the range of the group III atoms [13]. In this work, the grating profile changes from saw-toothed to sinusoidal after a thermal cleaning in pure H_2 ambient with addition of AsH_3 gas at 720 °C for 7 min, prior to epitaxial growth. To obtain the optimum growth condition for conserving an initial grating height, the growth temperature was varied from 610 to 720 °C. High-density V-groove GaAs quantum nanostructure with an initial grating height over 1.0 μm thickness has been successfully embodied on submicron gratings by the constant growth technique as shown in Fig. 1. A rounded initial submicron grating height due to mass transport effects is recovered by growing a GaAs buffer at an optimum growth temperature, 680 °C[8]. The

GaAs buffer on submicron gratings plays an important role in overcoming mass transport effects and improving the uniformity of gratings. More details on the growth condition and mechanism are described elsewhere [8].

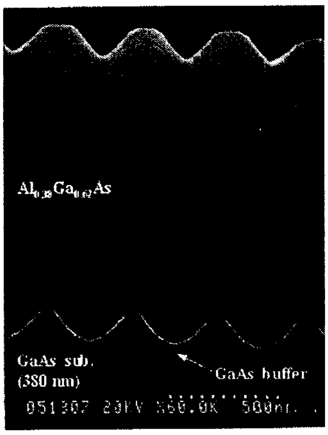

Fig. 1. Cross-sectional SEM image of $Al_{0.38}Ga_{0.62}As/GaAs$ QWRs with 20 periods grown on a V-groove GaAs buffer grown at 680 °C.

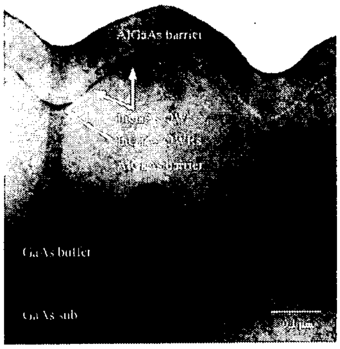

Fig. 2. Cross-sectional TEM image of $In_{0.2}Ga_{0.8}As/Al_{0.38}Ga_{0.62}As$ QWRs on a V-groove GaAs buffer grown at 680 °C.

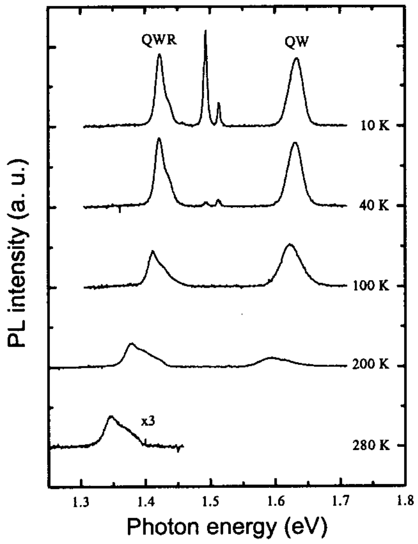

Fig. 3. Temperature-dependent PL spectra of $In_{0.2}Ga_{0.8}As/Al_{0.38}Ga_{0.62}As$ QWRs from 10 to 300 K.

By the constant growth technique, high-density V-groove $In_{0.2}Ga_{0.8}As$/AlGaAs QWRs on the V-groove GaAs buffer have been successfully grown on submicron gratings at the optimum growth temperature of 680 °C. Figure 2 shows the cross-sectional TEM image of $In_{0.2}Ga_{0.8}As$ QWRs. The InGaAs QWRs are well confined at the bottom of gratings. The observed In enrichment in the core of the QWRs is similar to the Ga enrichment in the case of self-assembled GaAs QWRs [14]. Self-assembled crescent-shaped InGaAs QWRs of 70 nm width connected by InGaAs sidewall and top QWs exhibit high structural quality and uniformity, as depicted in the TEM image. When QWRs are grown on V-groove substrates with a period of several microns, luminescence from the QWRs is very difficult to detect, probably because the photogenerated carriers diffuse from the (111)A AlGaAs barrier layer to the (100) AlGaAs barrier layer which has lower Al composition than the (111)A barrier layer before they are captured by the (111)A sidewall QWs and QWRs region. To improve the carrier capture efficiency of the QWR region, the (100) top QWs should be selectively removed by self-aligned wet chemical etching [14]. When the well-defined V-shaped GaAs buffer is grown prior to the AlGaAs barrier layer to establish constant growth, the (100) top InGaAs QWs following the AlGaAs layer with a very small area can be achieved as revealed in Fig. 2. It results in well-separated luminescence from InGaAs QWRs and the top QWs. Thus, it is not necessary to carry out additional self-aligned wet chemical etching to remove the (100) top InGaAs QWs.

Figure 3 represents the temperature-dependent PL spectra of InGaAs QWRs. At 10 K, four PL peaks at 1.42, 1.49, 1.51, 1.63 eV are attributed to the luminescence from the InGaAs QWRs, GaAs substrates, impurities, and InGaAs QWs, respectively. Since the PL peak energy of InGaAs QWRs is separated from that of the QWs by 210 meV, the PL peak of the QWRs is independently analyzed. As temperature increases, the PL intensity of the parasite InGaAs QWs rapidly decreases, and then vanishes above 200 K. In contrast, at room temperature, only luminescence from QWRs remains with a relatively small full width at half maximum less than 40 meV.

4. CONCLUSIONS

High-density InGaAs QWRs were successfully grown on submicron gratings by the constant MOCVD growth technique. Self-ordered crescent-shaped InGaAs QWRs of about 70 nm width exhibit high structural quality and uniformity in the TEM image. Since the PL peak energy of the InGaAs QWRs is well separated from that of the QWs, the PL peak of the QWRs is independently analyzed. The potential advantage of this technique is the fact that the complex optical devices such as the gain-coupled DFB laser can be fabricated on submicron gratings by one-step MOCVD growth.

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