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Novel Selective Growth of Buried GaAs Quantum Wire Arrays by Metal Organic Chemical Vapor Deposition

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We report successful fabrication of thin GaAs quantum wires (120Å-200Å)x(200Å-300Å), obtained by a novel selective growth technique using metal-organic chemical vapor deposition. The GaAs quantum wire is grown on a V-groove formed by two GaAs triangular prisms which are selectively grown on patterned substrates. The V-groove has a very sharp corner at the bottom, which results in reduction of the effective width of the quantum wire structures. The measurement of photoluminescence and photoluminescence excitation spectra with polarization dependence exhibit existence of the quantized state in the quantum wires.

1. Introduction

Low dimensional semiconductor structures such as quantum wires have recently received great attentions since new physical phenomena with applications to semiconductor lasers and other functional optical devices are expected[1,2]. To fabricate this quantum microstructures, use of wet chemical etchings[3], reactive ion etchings[4], ion beam implantaions[5] and ion beam millings[6,7] have been investigated. These methods, however, suffer from free surface effects, creation of a damage field during implantation, or interface control due to the random nature of the disordering mechanism. To avoid these problems, selective growth techniques on masked substrates[8,9] and nonplanar substrates[10-12] have been also investigated. Recently, Kapon et al. successfully fabricated quantum wire lasers on V-grooved (100) oriented GaAs substrates by the selective metal-organic chemical vapor deposition (MOCVD) [10]. The advantage of these methods is that the size and shape are controlled by the substrate pattern and/or crystal growth conditions and interfaces which are free from damages and contaminations are formed. In addition, vertically - stacked 3 quantum wires on a single V-groove were achieved[11]. Note that the V-grooves are obtained by the chemical wet etching. Therefore, it is slightly difficult to obtain the narrow and smooth V-grooves.

In this paper, we report successful fabrication of thin GaAs quantum wires (120Å-200Å)x(200Å-300Å) by a novel MOCVD selective growth technique. An essential technique different from previously reported MOCVD growth for quantum wires on V-grooves[10,11] or submicron gratings[12] is that the V-grooves is formed by using GaAs triangular prisms which are selectively grown on SiO_2 patterned substrate. The triangular prisms have 55° tilted facet sidewalls corresponding to crystallographic (111)A, forming very narrow and smooth V-grooves between the triangular prisms. Measured photoluminescence (PL) and photoluminescence excitation (PLE) spectra are discussed, which demonstrate existence of the first subband state in the GaAs quantum wires. Moreover, PLE spectra have shown a clear dependence on the polarization of the excitation light. This exhibits existence of the quantized state in the quantum wires[13].

2. Sample preparation and growth condition

Sample preparation process before MOCVD growth is as follows. First, a SiO_2 layer with the thickness of 200 Å was formed by plasma deposition method on a semi-insulating (100) GaAs substrate. Next, PMMA masks with 1000Å line and spaces which were parallel to the mesa <01$\bar{1}$> direction were lithographically defined on SiO_2 layer by electron beam (EB) lithography technique, followed by a wet chemical etching.

The MOCVD growth was performed in a low pressure, horizontal, rf-heated MOCVD reactor, using trimethylgallium (TMG), trimethylaluminum (TMA) and arsine (AsH_3) as group III and V sources, respectively. The TMG bubbler was kept at -10 °C and the TMA bubbler was kept at 20 °C. The partial pressure of TMG, TMA and AsH_3 were kept at 4.4×10^{-6} atm, 1.5×10^{-6} atm and 4.4×10^{-4} atm, respectively. The ratio between V and III was 100. The growth temperature for layers was 700 °C. Purified H_2 with a 6L/min flow rate was used as a carrier gas. The growth pressure was 100 Torr. Under these growth conditions, the GaAs growth rate for unmasked substrates is almost constant at 1.20 μm/hour.

3.MOCVD selective growth

MOCVD growth processes for the quantum wire arrays are illustrated in Figure 1. The GaAs triangular prisms with (111)A facet sidewalls were grown on the substrate. Further continuation of the growth which smoothed (111)A facet sidewalls made the dimension of triangular prisms uniform, forming a sharp corner at the bottom of the V-groove between the triangular prisms. Because of small width of the SiO_2 masking wires, the space between the triangular prisms was filled up by further continuation of the growth of $Al_{0.4}Ga_{0.6}As$ layer. Finally three multiple GaAs quantum wires which were connected to thin quantum wells were grown between the triangular prisms without being exposed to the air.

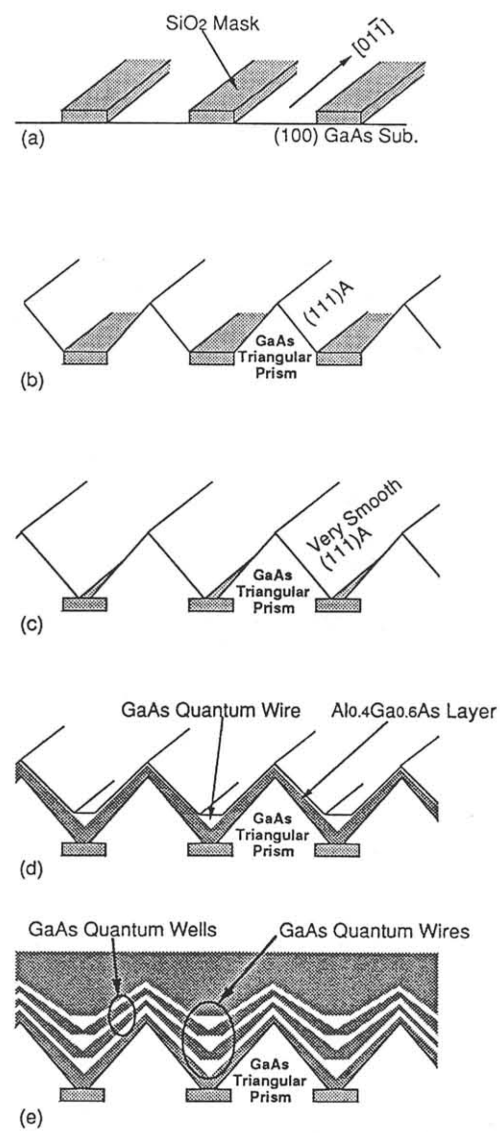

Figure 1 Schematic fabrication sequences of multiple quantum wires.

4.Results and Discussion

Figure 2 shows a high-resolution backscattered electron image of vertically stacked multiple quantum wires (120Å-200Å)x(200Å-300Å) fabricated here and its illustration. As shown in this figure, there are three quantum wires on a very narrow and smooth V-groove structure sandwiched by two GaAs triangular prisms. Each quantum wire is coupled with quantum well layers with the thickness of 40Å.

PL measurements were performed at 46K for the latter samples using Ar lasers. Figure 4 shows PL spectra which indicate two PL peaks coming from the GaAs triangular prism region (8195Å) and the quantum wires (7955Å), respectively. The PL peak from quantum wells which are connected to the quantum wires is also observed near the wavelength of 7500Å. The full width at half-maximum (FWHM) of the PL peak from the quantum wires is 20 meV. The energy difference (45meV) between the PL peaks of the GaAs triangular prisms and the quantum wires agrees well to the calculated energy difference (44meV) assuming the PL from the first subband of 140Åx140Å quantum wires. This estimated dimension of the wires is consistent with the backscattering electron image observation shown in Figure 2.

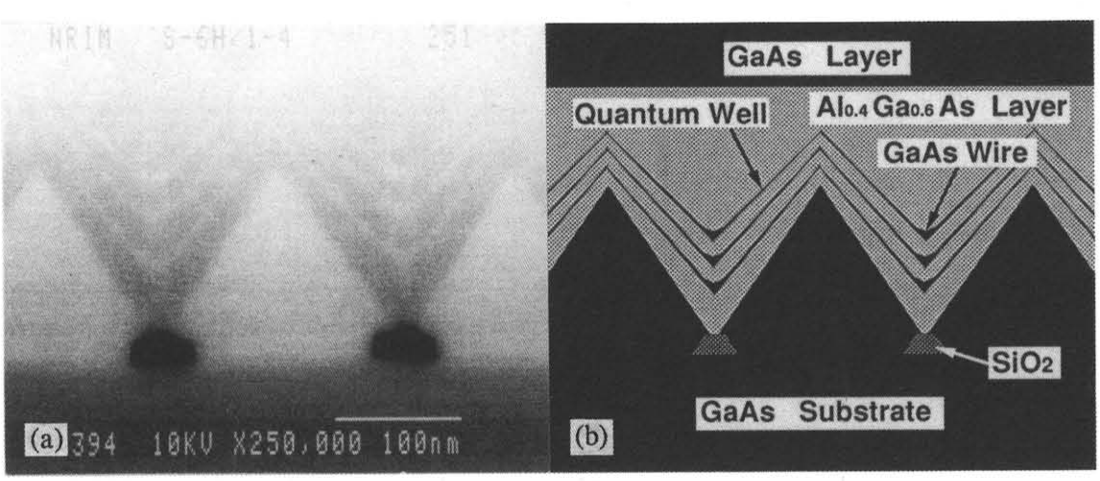

Figure 2 (a) A high-resolution backscattered electron image of multiple quantum wires and (b) its illustration.

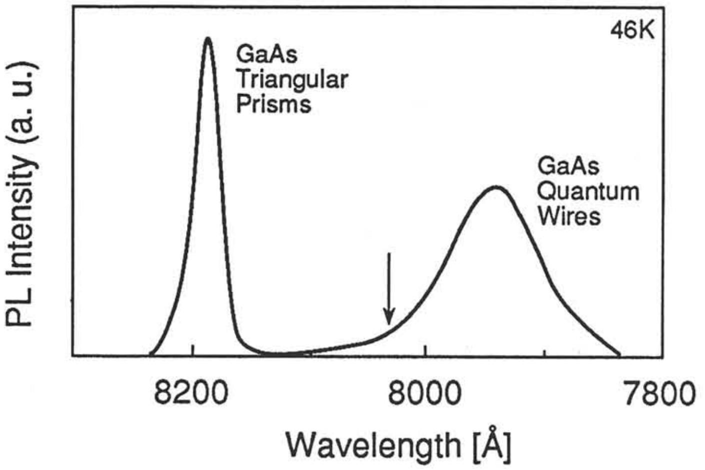

Figure 3 Photoluminescence spectra measured at 46K. An arrow shows the measured wavelength (8030Å) for the photoluminescence excitation measurement discussed in Figure 4.

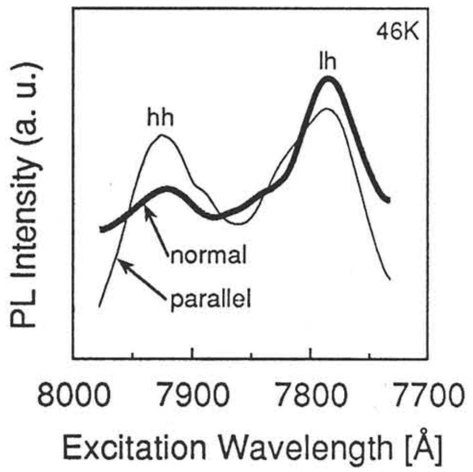

Figure 4 Photoluminescence excitation (PLE) spectra measured at 46K.The light and bold curves show the PLE spectra with E parallel and normal to the quantum wires direction, respectively.

Moreover, we have measured the PLE spectra and their dependence on the polarization of the incident laser light. The polarization is varied by using the a polarizer and a half-wave plate. The measurement was performed at 46K using Ti:Sapphire lasers. The measured wavelength is 8030Å which is corresponding to the tail with longer wavelength side of the PL peak from the quantum wires, as indicated an arrow in Figure 3. In Figure 4, PLE spectra are shown, indicating two absorption peaks which are corresponding to heavy hole(hh)-electron and light hole(lh)-electron excitonic states in the first subband in the quantum wires. When electric field vector E of the incident laser light is nealy paralel to the quantum wire, the ratio of two excitonic peak heights I_{lh}/I_{hh} is 1.1. However, when E is nealy normal to the quantum wire, the ratio of two excitonic peak heights I_{lh}/I_{hh} is changed into 1.5. This shows the polarization dependence of the quantum wires.

5.Conclusions

We fabricated quantum wire arrays which are grown on the V-grooves formed by GaAs triangular prisms. PL and PLE measurement with polarization dependence exhibit existence of the quantized states, which is consistent with observations by the high-resolusion backscattered electron image.

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