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The in Situ Growth of Lateral Confinement Enhanced Rectangular AlGaAs/AlAs Quantum Wires by Utilizing the Spontaneous Vertical Quantum Wells

Wugen Pan, Hiroyuki Yaguchi, Kentaro Onabe, Ryoichi Ito

Department of Applied Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan

Noritaka Usami, Yasuhiro Shiraki

Research Center for Advanced Science and Technology (RCAST), The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153, Japan

A proposal for the *in situ* growth of a lateral confinement enhanced AlGaAs/AlAs quantum wire (QWR) structure, which utilizes the Ga-rich AlGaAs spontaneous vertical quantum wells (SVQWs) formed in the growth of the AlGaAs epilayer in the V-grooves, has been put forward. The actual AlGaAs/AlAs QWR structures have been grown on the V-grooved substrates by low-pressure metalorganic vapor phase epitaxy (MOVPE), and been studied by transmission electron microscope (TEM) observations, photoluminescence (PL) and cathodoluminescence (CL) measurements.

1. Introduction

Low-dimensional semiconductor structures have been proposed to further improve laser performances.[1] The *in situ* growth of the crescent-shaped GaAs/AlGaAs quantum wires (QWRs) on the V-grooved substrates has been demonstrated to be an effective method to achieve very low threshold current density QWR lasers.[2-4] However, the lateral confinement by the tapering in the crescent-shaped QWRs (lateral width of 30 nm ~ 80 nm) is expected to be somewhat too weak. A further improvement of lateral confinement should be made to improve the QWR laser performances. A spontaneous Ga-rich AlGaAs vertical quantum well structure (lateral width of 30 ~ 50 nm) formed in the growth of the AlGaAs layer on a patterned substrate by atmospheric pressure metalorganic vapor phase epitaxy (MOVPE), due to the different migration properties of the Ga and Al atoms, has been reported recently.[5-7] We have studied the growth temperature dependence of the width of the AlGaAs spontaneous vertical quantum wells (SVQWs) grown on the V-grooved substrates by low-pressure MOVPE, in which the SVQW width varies from 14 nm to 27 nm with increasing the growth temperature from 600 °C to 700 °C. The Al content in the SVQWs is 30% lower than that in the sidewalls.[8] The application of the SVQWs to the growth of AlGaAs/AlAs quantum wire structures on the V-grooved substrates, as shown in Fig. 1, may lead to an effective lateral QWR confinement not only by the reduced lateral width (14 nm to 27 nm), but also by the AlGaAs composition difference between the SVQWs and the sidewalls. Moreover, the spontaneous vertical quantum well wire (SVQWR) structure shown in Fig. 1 may also have the following fascinating advantages: (1) well-defined rectangular cross-section with size homogeneity because of the lateral QWR width determined by the SVQW width; (2) light emission in the visible range (red) at room temperature by properly selecting the AlGaAs composition in the SVQWs.[7]

In this paper, we report the proposal and the exploratory studies of the lateral confinement enhanced rectangular AlGaAs/AlAs QWR structures grown on the V-grooved substrates by low-pressure MOVPE.

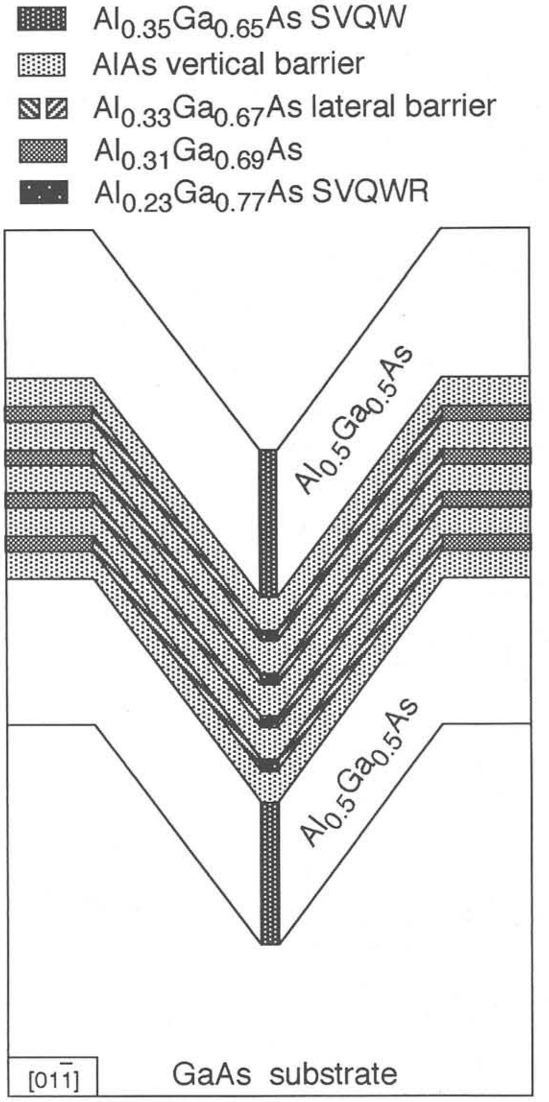

Fig.1 Schematic illustration of the lateral confinement enhanced AlGaAs/AlAs quantum wire structure.

2. MOVPE Growth

The $[01\bar{1}]$-oriented V-grooves used in this study were fabricated on semi-insulating GaAs (100) substrates using conventional photolithography and chemical wet etching (8 H_2SO_4 : 1 H_2O_2 : 1 H_2O solution). The etched V-grooves with a period of 3 μm in the substrate are approximately 2.1 μm wide at the top and 1.5 μm in depth. Prior to the growth, the V-grooved substrate was treated with a 10 NH_4OH : 5 H_2O_2 : 480 H_2O solution for 30 seconds. The substrate was then rinsed in deionized water, dried and finally loaded into the reactor.

The AlGaAs/AlAs QWR structure was grown by low-pressure (100 Torr) MOVPE with a RF-heated horizontal reactor. Trimethylgallium (TMG), Trimethylaluminum (TMA), and 10% arsine (AsH_3) were used as the Ga, Al, and As sources, respectively. The growth temperature was 650 °C and 700 °C. The V/III ratio was about 150 for the growth of $Al_{0.33}Ga_{0.67}As$. A typical structure consists of a 20 nm GaAs buffer layer (grown at 650 °C), a 500 nm $Al_{0.5}Ga_{0.5}As$ cladding layer (650 °C), four 90-nm-$Al_{0.33}Ga_{0.67}As$/10-nm-AlAs heterostructures (700 °C), a 500 nm $Al_{0.5}Ga_{0.5}As$ cladding layer (650 °C), and then 10 nm GaAs cap layer (650 °C). All the layers were undoped. No growth interruption was introduced in the $Al_{0.33}Ga_{0.67}As$/AlAs heterostructures.

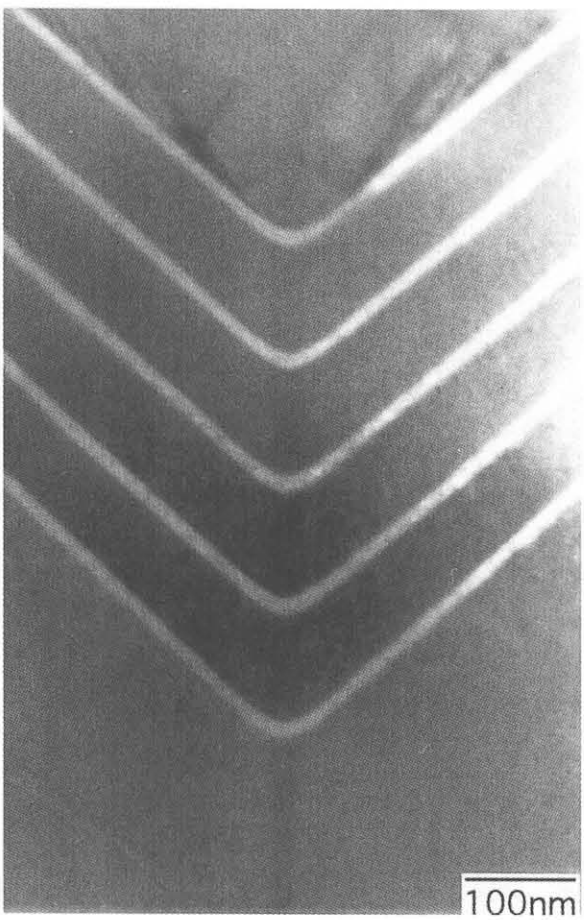

Fig.2 TEM cross-sectional image of the quadruple AlGaAs/AlAs SVQWR structures cladded by two $Al_{0.5}Ga_{0.5}As$ layers.

The $Al_xGa_{1-x}As$ compositions stated above are the nominal compositions corresponding to the growth on (100) planar substrates.

Figure 2 shows a transmission electron microscopy (TEM) cross-sectional image of the AlGaAs/AlAs QWR structure. As shown in Fig. 2, quadruple $Al_{0.23}Ga_{0.77}As$ SVQWs, 90 nm in vertical and 27 nm in lateral, which are separated by 10 nm AlAs layers in the bottom intersection of the V-groove, are clearly observed. The quadruple AlGaAs/AlAs QWR structure is sandwiched by the two 500 nm AlGaAs cladding layers. A 20 nm SVQW with Al content about 0.35 in the cladding layer is also observed. This 0.35-SVQW in the cladding layer may play a very important role in the carrier capture into the 0.23-SVQWR (only 0.35-SVQW regions in the cladding layer are of direct band gap). Although the vertical size of the SVQWR structure is too large in the structure shown in Fig.2, we can grow a smaller vertical size SVQWR by reducing the growth time of $Al_{0.33}Ga_{0.67}As$ layers.

3.Photoluminescence and Cathodoluminescence

Figure 3 shows the low temperature cross-sectional photoluminescence (PL) spectra of the grown SVQWR structures pumped by a 488-nm-Ar^+-ion laser. There are three distinct peaks centered at 1.856 eV, 1.924 eV and 1.995 eV. To make clear the origins of the above three luminescence lines, we performed a low temperature (6K) cross-sectional spectrally and spatially resolved CL study. As revealed in the CL images shown in Fig.4, the peak at 1.856 eV, 1.924 eV and 1.995 eV originates from the SVQWR structures, the top (100) $Al_{0.31}Ga_{0.69}As$/AlAs heterostructures and the 0.35-SVQWs in cladding layers, respectively. The full width at half maximum (FWHM) of the SVQWR structure peak is about 5 meV.

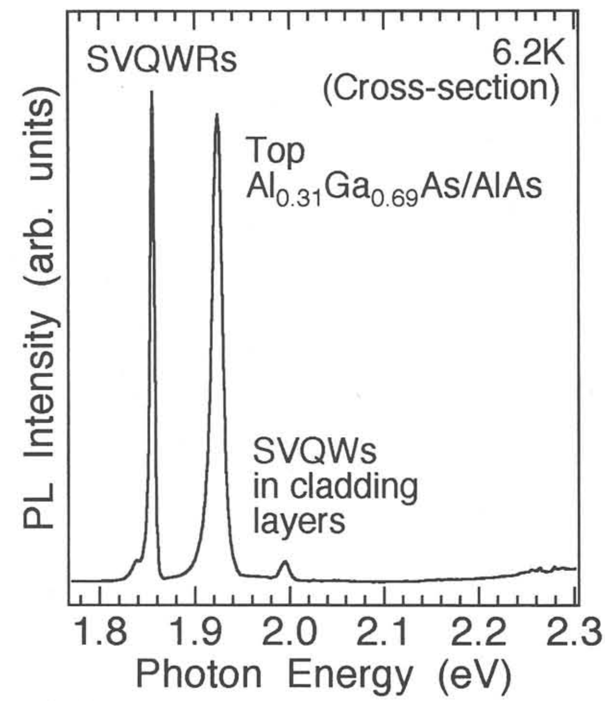

Fig.3 Low temperature cross-sectional PL spectrum of the SVQWR structure shown in Fig.2.

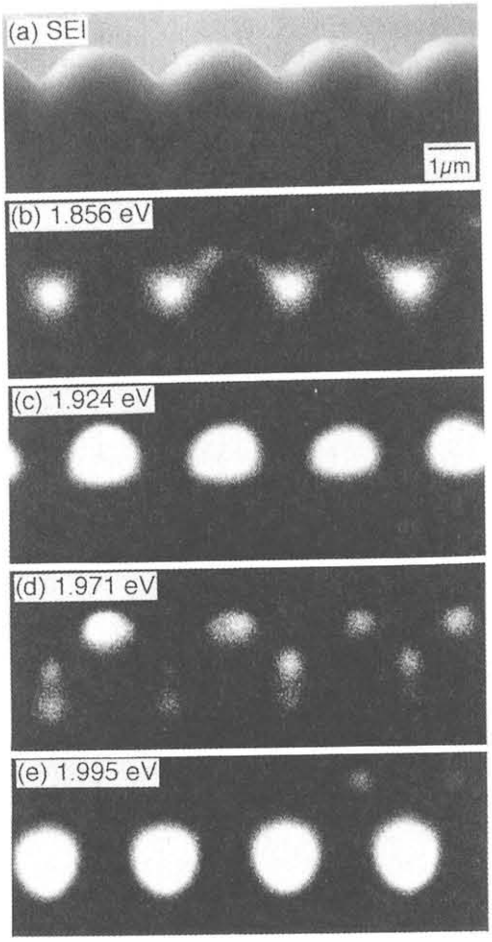

Fig.4 Low temperature cross-sectional CL images of the SVQWR structure shown in Fig.2. (a)secondary electron image (SEI); (b) 1.856 eV (SVQWRs); (c) 1.924 eV (top AlGaAs/AlAs heterostructures); (d) 1.971 eV (by widely opening the slits, the top $Al_{0.31}Ga_{0.69}As$/AlAs heterostructures and SVQWs in cladding layers); (e) 1.995 eV (SVQWs in cladding layers).

4. Conclusions

In conclusion, a new method to grow AlGaAs/AlAs QWR structures by using the Ga-rich AlGaAs SVQWs formed in the growth of the AlGaAs epilayer in the V-grooves, has been proposed, and been demonstrated by MOVPE. TEM studies show that the lateral width of SVQWR is about 27 nm. The SVQWR structures have been revealed by PL and CL measurements.

Acknowledgements

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