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Fabrication of GaAs Arrowhead-Like Quantum Wires by MOCVD Selective Growth and Their Optical Properties

S. Tsukamoto, Y. Nagamune, *M. Nishioka, and Y. Arakawa

Research Center for Advanced Science and Technology, University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153, Japan
**Institute of Industrial Science, University of Tokyo*
7-22-1 Roppongi, Minato-ku, Tokyo 106, Japan

We fabricated arrowhead-shaped quantum wires utilizing both the selective growth technique and the difference in the stabilized crystal facet between GaAs and AlGaAs. An systematic change in the size of the quantum wire exhibits consistent blue shifts of the photoluminescence peak from 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 these quantum microstructures, selective growth on patterned substrates is one of the most attractive techniques[3-5]. Recently, we fabricated thin GaAs quantum wires 12nmx20nm by the selective growth technique using metal organic chemical vapor deposition (MOCVD)[6]. The measurement of photoluminescence[6], photoluminescence excitation spectra with polarization dependence[6], magneto-photoluminescence[7] demonstrated the existence of the quantized state in the quantum wires. However, at present stage, it is still requested to develop other various fabrication techniques to obtain the quantum wires of high quality.

In this paper, we report an novel fabrication technique for the quantum wires with arrowhead-shaped cross section utilizing both the selective growth technique and the difference in the stabilized crystal facet between GaAs and AlGaAs. An systematic change in the size of the quantum wire exhibits consistent blue shifts of the photoluminescence (PL) peak from the quantum wires.

2.Sample preparation and growth condition

Sample preparation process before MOCVD growth is as follows. First, a SiO_2 layer with the thickness of 40nm was formed by plasma deposition method on a semi-insulating (100) GaAs substrate. Next, PMMA masks with 100nm line and spaces which were parallel to the mesa $<0\bar{1}1>$ 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 masked substrate by MOCVD growth. Further continuation of the growth which leads to smooth (111)A facet sidewalls makes the dimension of the triangular prisms uniform. Then, by switching the growth layer from GaAs to $Al_{0.4}Ga_{0.6}As$, $Al_{0.4}Ga_{0.6}As$ layer was laterally grown on the (111)A facet sidewall of the GaAs triangular prisms. Since the stabilized facet of the $Al_{0.4}Ga_{0.6}As$ layers is not (111)A but (311)A under this growth condition, (311)A facets appear on the top of $Al_{0.4}Ga_{0.6}As$ layers. Then, again, by switching the growth layer from $Al_{0.4}Ga_{0.6}As$ to GaAs, GaAs quantum wires were grown on the top without being exposed to air because the growth rate of (311)A plane is faster than that of (111)A facet for GaAs.

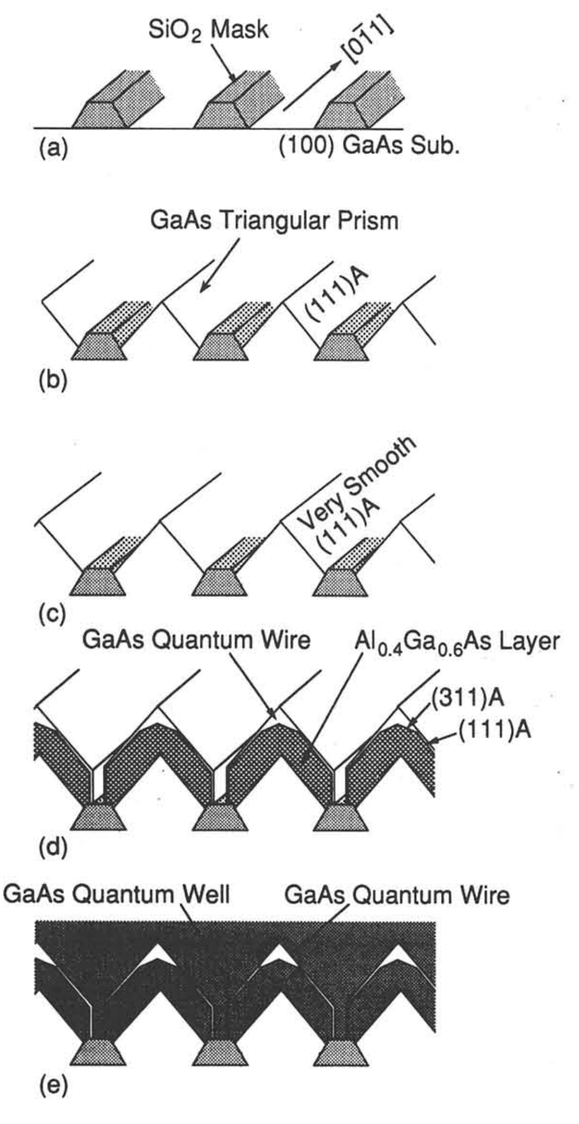

Figure 1 Schematic fabrication sequence of arrowhead-shaped quantum wires.

4.Results and Discussion

Figure 2 shows a high-resolution scanning electron micrograph of the arrowhead-shaped quantum wires and its illustration. As shown in this figure, the quantum wires are on the top of triangular prisms which were selectively grown on SiO_2 patterned substrates and quantum wire here connects smoothly with quantum well layers with the thickness of 10nm. The dimension of the quantum wire is 28nmx50nm. This quantum wires are surrounded by (111)A and (311)B planes, making arrowhead-shaped shape. Noted that the size of the quantum wire can be controlled by changing the thickness of AlGaAs layer on the (111)A facet sidewall of the GaAs triangular prisms. The thinner AlGaAs layer reduces the area of (311)A plane on the top, resulting in the thin quantum wires by supplying small amount of GaAs. Figure 3 shows a high-resolution scanning electron micrograph of the arrowhead-shaped quantum wires with the thinnest size(14nmx25nm) obtained in our experiment.

PL measurements at 8.5K was performed in the samples with different dimensions. Figure 4 shows PL spectra of the arrowhead-shaped quantum wires with the lateral dimension of 14nm shown in Fig.3. The luminescence peak at 1.58eV is corresponding to the quantum wire. The sharp luminescence peaks at 1.51eV and 1.49eV are coming from the bulk of the undoped GaAs bulk region. The broad luminescence band peak around 1.68eV originates from the quantum wells regions (Lz~55Å) on the (111)A facet sidewall of the AlGaAs layers. The PL peaks around 1.99eV and 1.85 are from AlGaAs regions.

Figure 5 exhibits the energy shift of the PL peak of the arrowhead-shaped quantum wires versus the wire width which is determined by using the scanning electron micrograph. As shown in this figure, the blue shifts are enhanced with decreasing the wire width, which is qualitatively consistent with the enhancement of the two-dimensional quantum confinement effect.

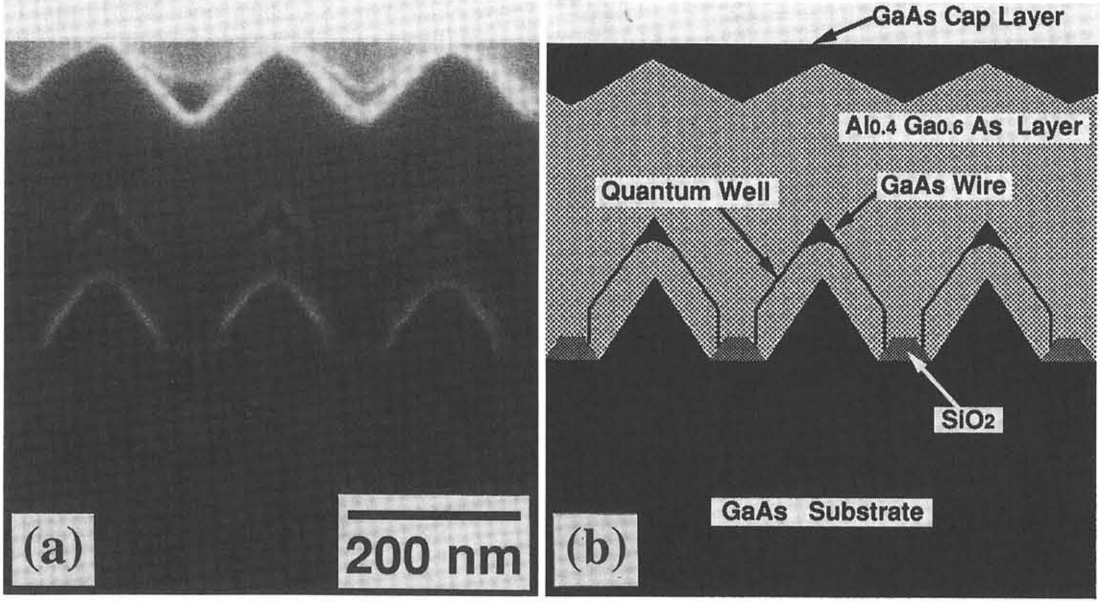

Figure 2 (a) A high-resolution scanning electron micrograph of arrowhead-shaped quantum wires and (b) its illustration.

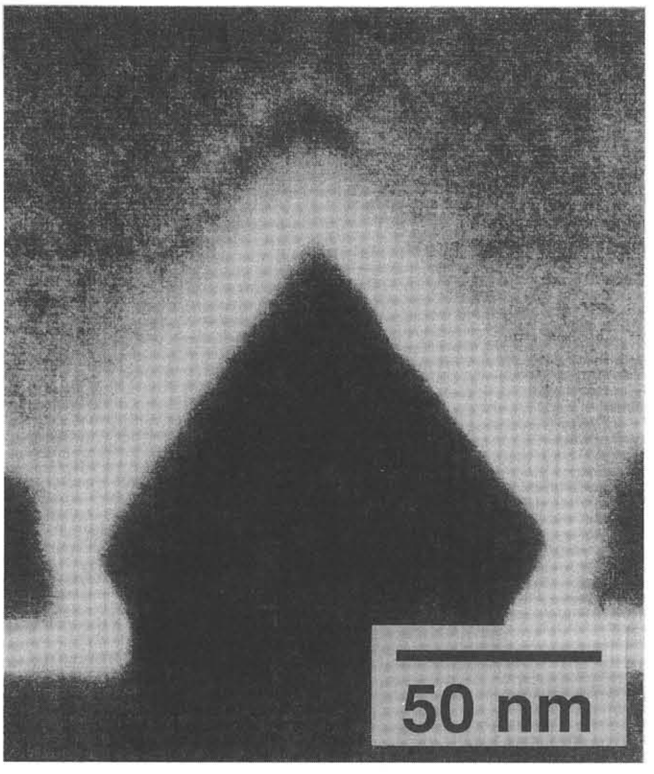

Figure.3 A high-resolution scanning electron micrograph of the arrowhead-shaped quantum wires with the thinnest size (14nmx25nm) obtained in the experiment.

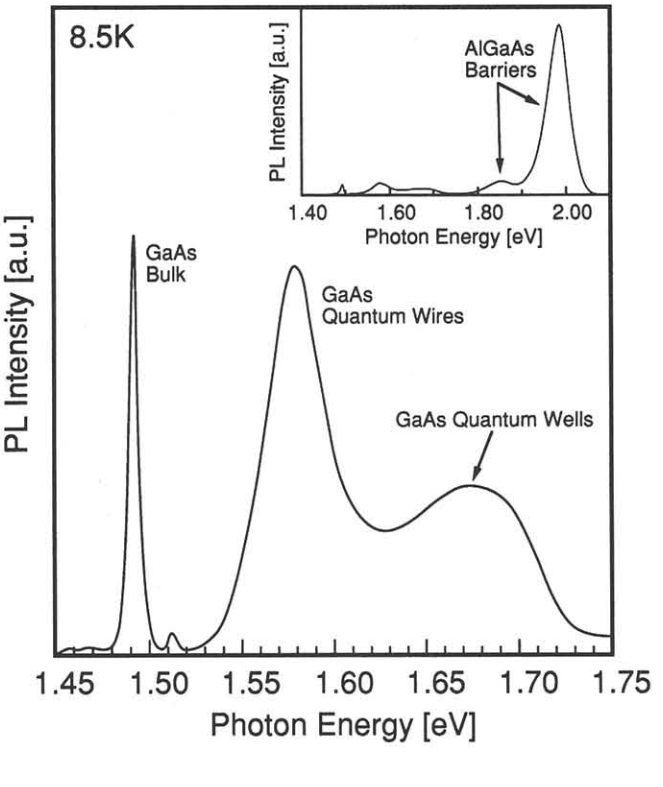

Figure 4 Photoluminescence spectra of the quantum wires shown in Fig.3.

5.Conclusions

We successfully fabricated the arrowhead-shaped quantum wires utilizing the selective growth technique and the difference in the stabilized facet between GaAs and AlGaAs. The quantum wires are surrounded by (111)A and (311)B planes. The measured PL spectra of the the quantum wires demonstrated the two-dimensional quantum confinement effect.

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References

[1] Y. Arakawa and H. Sakaki, Appl. Phys. Lett. 40(1982) 939.

[2] Y. Arakawa, K. Vahala, and A. Yariv, Appl. Phys. Lett. 45(1984) 950.

[3] T. Fukui, S. Ando, and Y. K. Fukai, Appl. Phys. Lett. 57(1990) 1209.

[4] C. S. Tsai, J. A. Lebens, C. C. Ahn, A. Nouhi, and K. J. Vahala, Appl. Phys. Lett. 60(1992) 240.

[5] R. Bhat, E. Kapon, D. M. Hwang, M. A. Koza, and C. P. Yun, J. Cryst. Growth 93(1988) 850.

[6] S.Tsukamoto, Y.Nagamune, M.Nishioka, and Y.Arakawa, J. Appl. Phys. 71(1992) 533.

[7] Y.Nagamune, Y.Arakawa, S.Tsukamoto, M.Nishioka, S.Sasaki and N.Miura, Int. Symp. Sci. and Tech. of Mesoscopic Structures, (1991,Nara).

[8] Y.Nagamune, S.Tsukamoto, M.Nishioka, and Y.Arakawa, Ext. Abs. 23rd SSDM, (1991) 689.

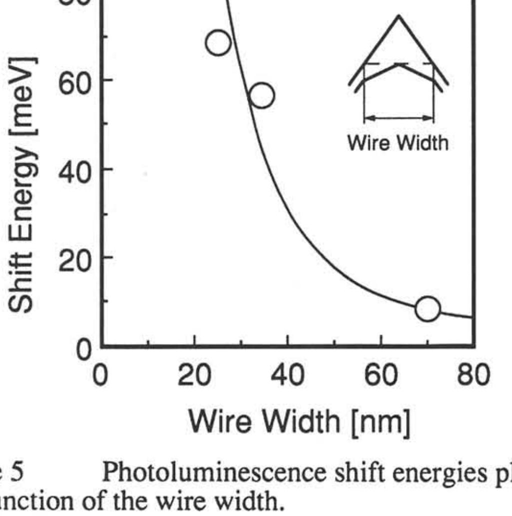

Figure 5 Photoluminescence shift energies plotted as a function of the wire width.