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Fabrication of InGaAs Strained Quantum Wire Structures Using Selective Area MOCVD Growth

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We report on fabrication of $In_xGa_{1-x}As$ strained quantum wire structures with various In compositions using a selective area metal organic chemical vapor deposition growth technique. Photoluminescence (PL) measurements at 14 K demonstrated that strained quantum wires of high quality were obtained when x is less than 0.35. Change of the full width with half maximum of the PL peaks indicates that the structural dimension of the quantum wires exceeded the critical thickness around x = 0.4. Finally, a laser structure is fabricated.

Low dimensional semiconductor structures such as quantum wires have recently received great attentions because new physical phenomena with possible applications to semiconductor lasers and other functional optical devices are expected[1,2)]. To fabricate these microstructures, selective area growth on patterned substrates is one of the most attractive techniques[3-7)]. Recently, we fabricated GaAs triangular-shaped quantum wires with the lateral width less than 10 nm by a selective area growth technique using metal organic chemical vapor deposition (MOCVD) technique[8)]. Photoluminescence (PL) measurements demonstrated enhanced two-dimensional quantum confinement with the material of high quality. The uniqueness of our technique is to form dense V-groove structures by using the selective area growth of GaAs triangular prisms on SiO_2 patterned substrates, instead of chemical etching techniques.

On the other hand, in the search for new materials useful in semiconductor lasers, interest was recently extended to strained InGaAs/GaAs system. In fact, low threshold current and high modulation frequency have been achieved in those lasers. In addition, recent theoretical studies have shown that the strain effects in quantum wire structures lead to additional improvements of the lasing characteristics compared with unstrained GaAs/AlGaAs quantum wire lasers[9,10)]. Thus it is important to fabricate such strained quantum wire structures.

In this paper, we report the fabrication of $In_xGa_{1-x}As$ strained quantum wires with the lateral width of about 10 nm utilizing the selective area MOCVD growth technique. PL spectra measured at 14 K for various In compositions indicate red shifts of the PL peak due to the increase of In composition in the quantum wires. Measurement of the full width at half maximum (FWHM) of the PL suggests that relaxation of the strain occurs when x is in the range between 0.35 and 0.4.

The fabrication of InGaAs quantum wires is the same as that for the GaAs quantum wires because the growth behavior of InGaAs is quite similar to GaAs[11)]. Figure 1 shows the fabrication process for the InGaAs quantum wires. First, the GaAs triangular prisms with (111)A facet sidewalls are selectively grown on a SiO_2 masked substrate. Further continuation of the growth that leads to smooth (111)A facet sidewalls, making the dimension of the triangular prism uniform. As a result, a sharp V-groove's corner between the triangular prisms is obtained. The space between the triangular prisms is filled up with an $Al_{0.4}Ga_{0.6}As$ layer by switching the growth layer from GaAs to AlGaAs. Thus, *in situ* growth of the InGaAs quantum wires which are connected to thin quantum wells are

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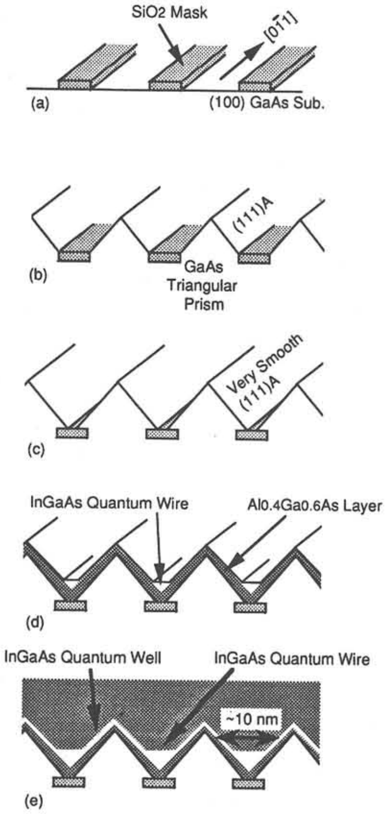

Fig.1 Schematic fabrication sequence of InGaAs Quantum wires.

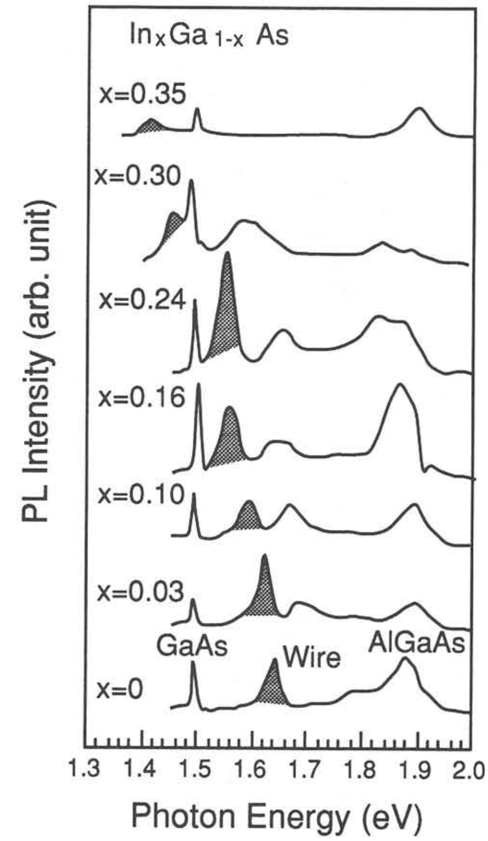

Fig.2 Photoluminescence spectra of the sample including InGaAs quantum wires, where In composition x is indicated on the left side of each spectrum.

formed between the triangular prisms without being exposed to the air. The growth temperature and pressure are 700°C and 100 torr, respectively. V/III ratio is about 100.

Figure 2 shows the PL spectra of the sample at 14 K. The sample was pumped by an Ar^+ laser. In this figure, the hatched spectral region is corresponding to PL from the quantum wires. When In composition x=0.24, for example, the PL peak at 1.53 eV corresponds to that of the quantum wires. The PL peaks at 1.51 eV and 1.49 eV come from the GaAs bulk transition, probably (Do, X). and the transition at carbon impurities, respec-tively. The peak around 1.57 eV originates from the quantum well regions on the (111)A facet sidewalls of the AlGaAs layers. The PL peak around 1.9 eV is from AlGaAs regions. As shown in this figure, the PL peak positions of the quantum wires are systematically shifted to lower energy side with increasing In composition. Here, we assume that In composition of these quantum wire structures is the same as that of InGaAs bulk grown under the same conditions. On the basis of the fact that the growth behavior of InGaAs is quite similar to that of GaAs[11)], the lateral width of the quantum wire is estimated to be in the range of 10 and 13nm. It should be noted that the quantized energy of electrons in the triangular-shaped quantum wires with the lateral width of Lw is almost equal to that in the rectangular-shaped quantum wires with the lateral width of 0.6Lw

This suggests that the strain is relaxed with the increase of In composition owing to approach of the structural dimension to the critical thickness conditions.

Figure 3 is the relationship between In composition of the quantum wires and the FWHM of the PL spectral line. As shown in this figure, the FWHM suddenly increases at x = 0.4. This result indicates that the structural dimensions of the quantum wires exceed the critical thickness around x=0.3-0.4. Almost the same value of x, on the other hand, gives the critical thickness condition for the quantum wells with the thickness of 5nm. These results suggest that the strain effects of the our quantum wires can be modeled by the biaxially strain effects in the same same way for conventional strained quantum wells, which is consistent with the fact that the present quantum wires are connected to the quantum well regions.

In addition, we also fabricated a laser structure with these InGaAs strained quan-

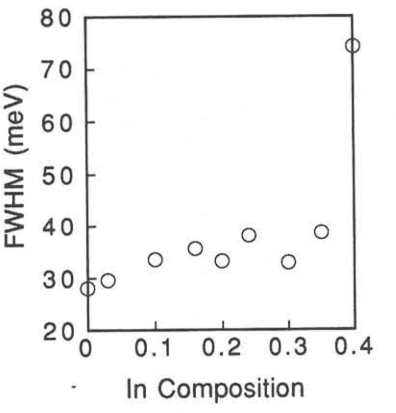

Fig.3 FWHM of PL spectral lines vs In composition.

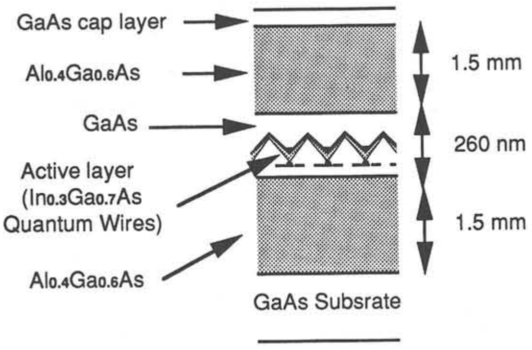

Fig.4 Schematic illustration of the cross section of the laser structure.

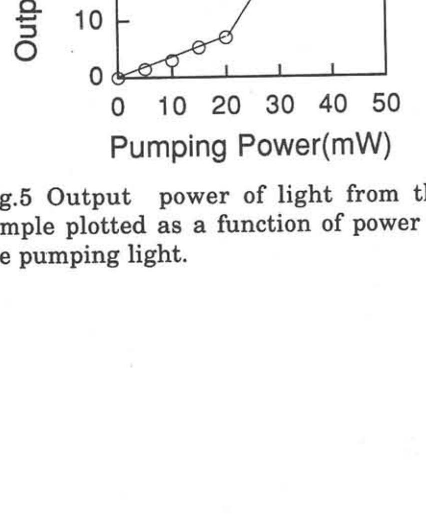

Fig.5 Output power of light from the sample plotted as a function of power of the pumping light.

tum wires. Figure 4 shows a schematic illustration of the cross section of the structure. Before the deposition of SiO_2, an $Al_{0.4}Ga_{0.6}As$ cladding layer was grown. After the InGaAs quantum wire structures were grown with the above-mentioned tech-nique, they were buried and flatted with GaAs. Then finally an Al0.4Ga0.6As cladding layer was formed again. The wafer were cleaved into 800 μm-long cavity chip. The lasing property of this sample was measured at 10 K, using optical pumping method with a mode-locked Nd^{3+} :YAG laser. Figure 5 shows the output power of light from the sample plotted as a function of power of the pumping light .

In conclusion, we successfully fabricated $In_xGa_{1-x}As$ strained quantum wire structures with the lateral width of about 10 nm with various In compositions, using the selective area MOCVD growth technique. PL measurements demonstrate that the strained quantum wires of high quality are fabricated when x is less than 0.35. A clear change of the FWHM's of PL peaks indicates that the dimensions of the quantum wires exceed the critical thickness around x = 0.4. In addition, a laser structure is fabricated.

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