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Composition Modulation in Quantum Wire Structures on Vicinal (110) GaAs Studied by Photoluminescence

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Quantum wires are fabricated by the growth of AlGaAs system on vicinal (110) GaAs substrates misoriented 6° toward (111)A. It is concluded that during the growth of AlGaAs the composition modulation occurs on the large-step structure almost independently of the temperature while the large-step structure is formed by the growth only blow a critical temperature. The photoluminescence (PL) from a single quantum wire is observed with a much narrow spectral width as compared with the usual PL from quantum wires.

1. Introduction

Fabrication of quantum wire structures has become a matter of great concern in recent semiconductor physics because of their unique optical and electrical properties. It has been reported that quantum wires are formed on vicinal (110) GaAs substrates misoriented 6° toward (111)A through following two growth-stages by use of molecular beam epitaxy (MBE)[1]. In the first stage, as schematically shown in Fig. 1, a GaAs-$Al_{0.5}Ga_{0.5}As$ superlattice is grown in order to get regularly aligned large-growth-step structures. In the succeeding second stage, an AlAs - $Al_xGa_{1-x}As$(x=0.2-0.5) - AlAs quantum well is grown on the large-step structures. Quantum wires are formed in the $Al_xGa_{1-x}As$ layer at the large-step edges, where AlAs composition becomes smaller than that on the terraces. Essential points are the formation of coherently aligned large-steps and adequate composition modulation of $Al_xGa_{1-x}As$ at the large-step edges and on the terraces. These effects are closely related to each other in the MBE growth.

In this paper, the composition modulation as well as the large-step formation is studied by photoluminescence (PL), since PL peak positions are sensitive to both the composition and the confinement sizes.

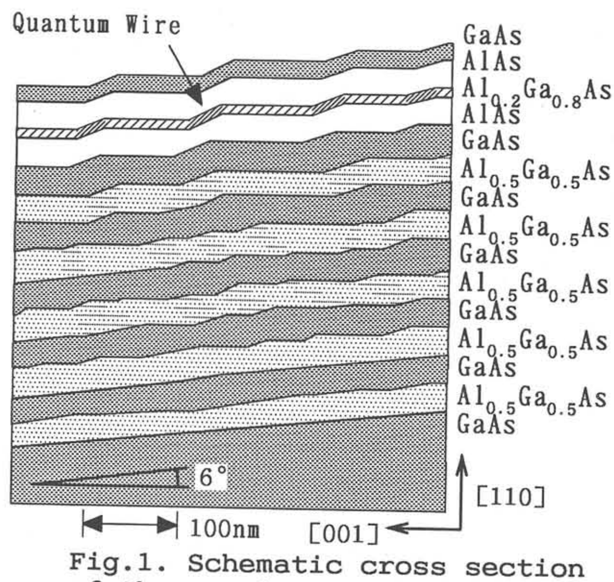

Fig.1. Schematic cross section of the samples. A quantum well AlAs-AlGaAs-AlAs is grown on a GaAs-AlGaAs superlattice. Quantum wires are formed at the large-step edges. The wire length is longer than a few μm.

2. Experimental

Samples were grown by MBE using AsH_3 on a vicinal (110) GaAs substrate misoriented 6° toward (111)A. As a reference sample, a (100) GaAs substrate was set beside the (110) substrate on the same sample holder in the MBE process. PL spectra were taken at 2K with 514.5nm Ar ion laser line.

3.Results and Discussion

Figure 2 shows the PL spectra of two samples (a) and (b) on the vicinal (110) GaAs and a reference sample (c) on a (100) GaAs. Substrate temperatures were changed between in the first and in the second stages in the growth of these samples. The GaAs(10nm)-$Al_{0.5}Ga_{0.5}As$(60nm) superlattices were grown for 8 periods at 540°C in the first growth-stage, while the AlAs(60nm)-$Al_{0.2}Ga_{0.8}As$(10nm)-AlAs(60nm) quantum wells were grown on the superlattices at 540°C (b) and at 620°C (a) and (c) in the second growth-stage.

The large-step structures are observed on the surfaces of samples (a) and (b) by scanning electron microscopy. Such large-step structure does not appear by the whole growth at high temperatures such as 620°C. The large-step structure is formed during the growth of the superlattices at 540°C. It is consistent with the result of reflection- high-energy-electron- diffraction observations that large-step formation occurs only below a critical temperature (580 - 610°C) in AlGaAs growth.[2)]

In Fig. 2, the PL peaks, (a) and (b), of the quantum wells on the large-step structure is remarkably red-shifted as compared with that of a reference sample grown on a (100) GaAs (c). This red-shift is mainly due to the decrease in the AlAs-composition in the quantum well at the large-step edges. It should be stressed that the red-shift is observed in the similar amount for both samples (a) and (b) in which the quantum wells were grown above (a) and below (b) the critical temperature of the large-step formation. The composition modulation is almost independent of the growth temperature and probably mainly depends on the surface orientations of the large-step edges and of the terraces. The AlAs composition modulation has been recently confirmed also by energy dispersive X-ray spectroscopy combined with transmission electron microscopy.[3)]

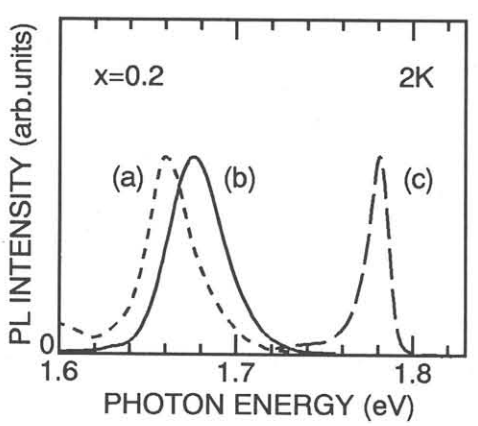

Fig.2. PL spectra of samples (a) and (b) grown on vicinal (110) GaAs, and (c) on a (100) GaAs. Growth temperatures are described in the text. The PL peak (c) at about 1.78 eV is assigned to the $Al_{x=0.2}Ga_{0.8}As$ quantum well. The PL peaks (a) and (b) are remarkably red-shifted owing to the composition modulation on the large-step structure.

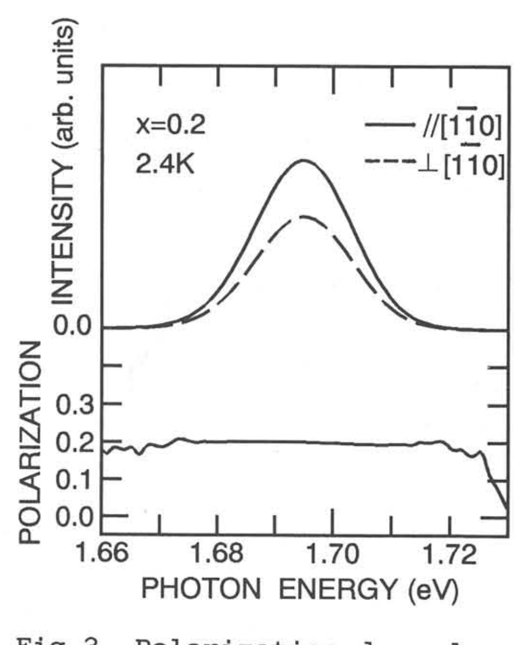

Fig.3. Polarization dependence of the PL. In the upper spectra, the PL component E // wire direction $[1\bar{1}0]$ (solid line) is much stronger than the perpendicular component (dashed line). Degree of polarization $(I_{/\!/}-I_{\perp})/(I_{/\!/}+I_{\perp})$ is also shown.

Figure 3 shows the polarization dependence of the PL of the quantum wires grown below 580°C. The strong polarization parallel to the wire gives a clear evidence for the carrier confinement to the quantum wires.[4] The degree of polarization is almost constant, about 0.2, within the spectral width of the PL peak. It means that the broadening of the PL can not be explained by the higher subband component relating to the light holes.

We try to put an Al mask on the sample surface by a standard electron beam lithography. The mask has 300 nm width slit through which we can observe the PL from only one or two quantum wires. Figure 4 shows the PL spectra of the samples with and without the mask. Two peaks of the spectrum with the mask are probably due to two quantum wires under the slit. The spectral width of the PL from the single quantum wire is about 5 meV, which is much narrower than that without the mask (about 23 meV). The broadening of the PL without the mask is due to fluctuations in the wire size and in the degree of the composition modulation. In a rough estimation, the broadening of 23 meV corresponds to ± 10 % wire-size fluctuation in this sample, though it is inseparable from the composition fluctuation.

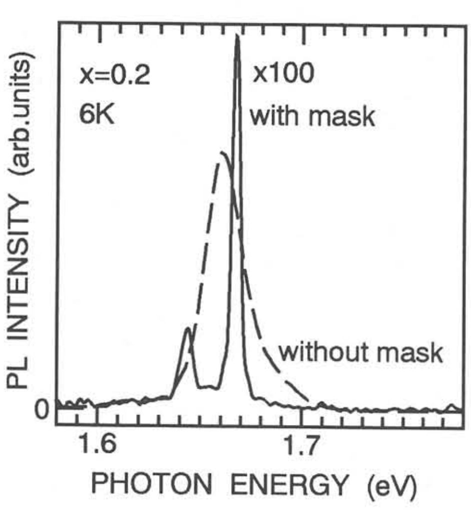

Fig.4. PL spectra of the sample with the mask (solid line) and without the mask (dashed line).

4. Conclusions

During the MBE growth of AlGaAs on vicinal (110) GaAs substrates misoriented 6° toward (111)A, the large-step structure is formed and the AlAs composition is reduced on the large-step edges. The composition modulation occurs on the large-step structure almost independently of the temperature while the large-step structure is formed by the growth only blow a critical temperature. Quantum wires are fabricated by the two growth-stages. The photoluminescence (PL) from single quantum wire is observed with a much narrow spectral width as compared with the usual PL from quantum wires.

Acknowledgments

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