Wavelength shifting of adjacent quantum wells in V-groove quantum wire structure by selective implantation and annealing

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Intermixing induced by selective implantation was used to modify the two-dimensional (2D) quantum wells in the V-grooved quantum wire structure. Photoluminescence measurement of the implanted samples shows the obvious blueshift of the interband transition energy while quantum wire is not influenced by implantation. So the selective implantation method has been demonstrated in this article as a useful technique to isolate the energy levels of quantum wire structure from its neighbor 2D structures, which is preferred for the optoelectronic device application of quantum wire. [S0021-8979(00)02703-1]

Quantum wire structure has attracted much attention[1–4] because of many advantages compared with two-dimensional (2D) quantum well (QW) structures. However, fabrication of quantum wire (QWR) structures is more difficult than 2D structures because of limitation of related technologies. Among all the methods for QWR fabrication, growth on a V-grooved substrate is more promising for device application. Generally for a V-grooved QWR structure, the energy levels of QWR might overlap with the energy levels from adjacent sidewall QWs, top QW, and necking regions (ref). This situation is not preferred for device application since carriers in QWR will be strongly influenced by the neighboring 2D QWs. In this case it is interesting to enhance the separation between the energy levels of the QWR and its neighboring 2D QWs. Ion implantation induced intermixing has been shown to be an effective method to shift spectral response of QW structures.[5–7] In this article, a self-aligned dual implantation scheme was used to enhance the separation of the energy levels in QWR from those of the QWs.

Semi-insulating GaAs (001) substrate was patterned using contact lithography techniques. The pattern consisted of 50 2 μm wide stripes spaced 2 μm apart. After pattern transfer, a sawtooth-type (V-groove) surface profile was formed by wet etching in H_3PO_4:H_2O_2:H_2O solution (1:1:3) at 0 °C. The V-groove substrate was then cleaned with warm trichloroethylene, acetone, methanol, and then in HCl to remove any native oxide. Finally, before being loaded into the growth chamber, the substrate was trimly etched with H_2SO_4:H_2O_2:H_2O. (20:1:1). A GaAs (0.1 μm) buffer was first grown before a 1 μm $Al_{0.5}Ga_{0.5}As$ layer followed by a coupled-QW structure of a 2 nm GaAs/2 nm $Al_{0.2}Ga_{0.8}As$/3 nm GaAs, and 50 nm $Al_{0.5}Ga_{0.5}As$ top barrier layer. Growth was ended with a 20 nm GaAs cap layer. All layers were undoped and grown at 700 °C. Self-aligned dual implantation technique was used to selectively intermix the sidewall QW as illustrated in Fig. 1. Two sets of ion implantation were carried out at an angle almost parallel to both the angled-top surfaces. By utilizing the natural geometry of the V-grooves and selecting the right ion range (ion energy), the bottom of the V-grooves could be masked from the ions. Arsenic ions of 350 keV were used at two different doses; 10^{11} cm^{-2} (sample A) and 4×10^{12} cm^{-2} (sample B). Implantation was carried out at room temperature. After implantation the samples were annealed in a rapid thermal annealer at 900 °C for 30 s under Ar ambient. The optical properties of the QWR were studied by low temperature (8 K) and temperature dependent photoluminescence (PL) measurement with a He–Ne (543 nm) laser as the excitation source. Si charge coupled device was used as detector through a 0.25 m monochromator.

Due to the difference in growth rates on the (111) and (100) surfaces, the thicknesses of the QW on the sidewall, top region, and bottom of the V-grooves are unequal. Furthermore, preferential Ga diffusion into the bottom of the V-grooves will result in the formation of a crescent-like QWR at the bottom of the V-grooves. This is schematically shown in Fig. 2. A cross-sectional transmission electron microscopy (TEM) image of the QWR sample is shown in Fig. 3. Due to the low Al mole fraction and the thin layer of the middle barrier in the coupled QW structure, the TEM image did not reveal distinctly the two QWs. The total thickness at

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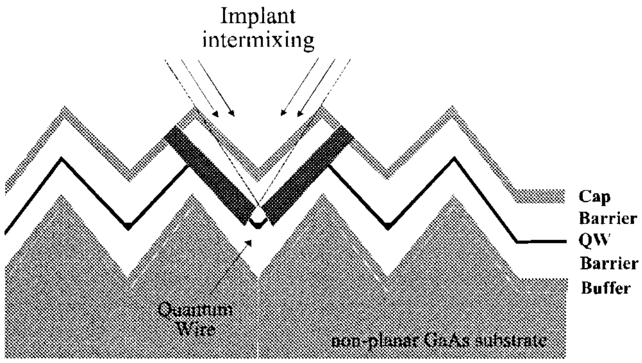
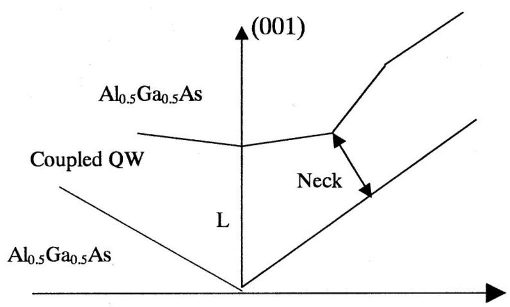


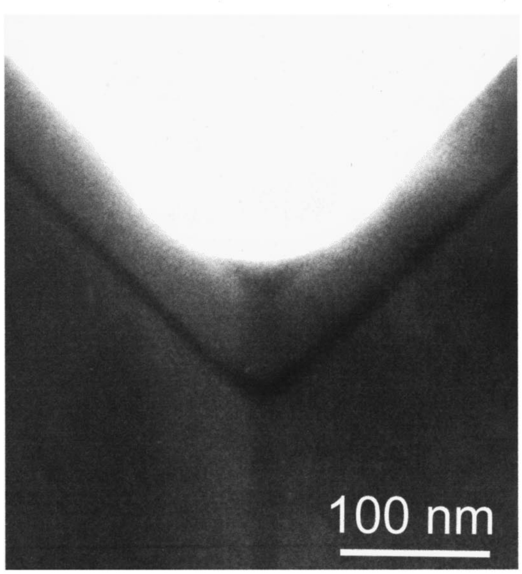
FIG. 1. Schematic of the self-aligned dual implantation technique. The natural geometry of the V-groove substrate was utilized to selectively intermix the sidewall regions and not the bottom of the V grooves (QWR regions).

the sidewall of the coupled QWs and the middle barrier was 7.6 nm, whereas this thickness increased to 8.6 nm at the bottom of the V-groove.

Figure 3 shows the PL spectra for implanted and annealed samples at 8 K. Also shown is the spectrum the as-grown sample for reference. For the as-grown sample the PL signals of QWs from different regions [V-groove top region, (001) planar QW, and sidewall QW] were clearly separated at 778, 763, and 748 nm, respectively. GaAs signal was relatively weak because of the thick AlGaAs layer. Due to the small volume of the QWR at the bottom of the V grooves and the spectrally overlapping signal with that of the top region, the PL signal from the QWR was not clearly observed. After arsenic implantation and annealing, intermixing shifted the spectral responses of the QWs to higher energies. For sample A, the wavelengths of the top region,



(a)



(b)

FIG. 2. (a) Schematic of the V-groove QWR structure showing the various regions and (b) cross-sectional transmission electron microscope image of the as-grown QWR.

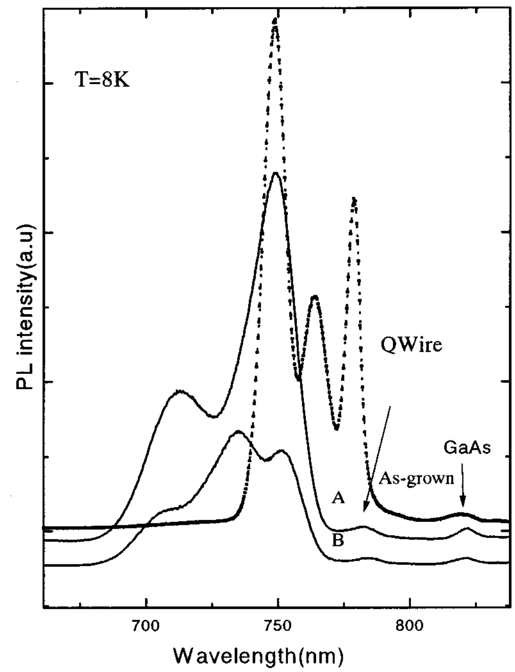


FIG. 3. PL spectra of the as-grown and implanted samples at 8 K. The implantation dose of A was 10^{11} cm^{-2} and B was 4×10^{12} cm^{-2}.

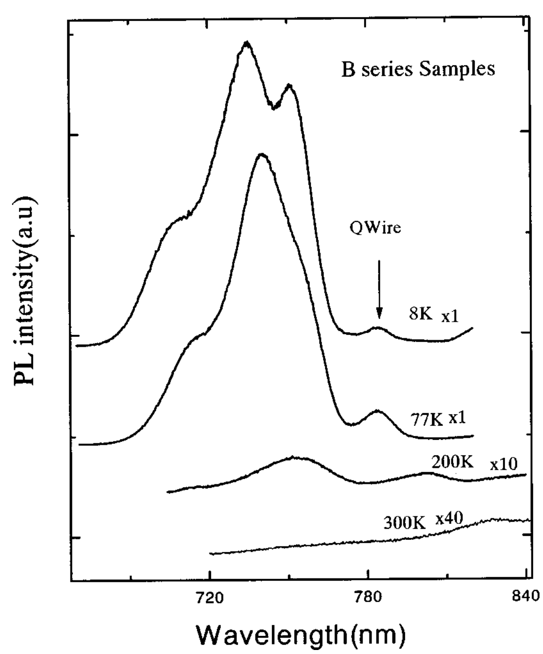


FIG. 4. Temperature dependent PL spectra of sample B.

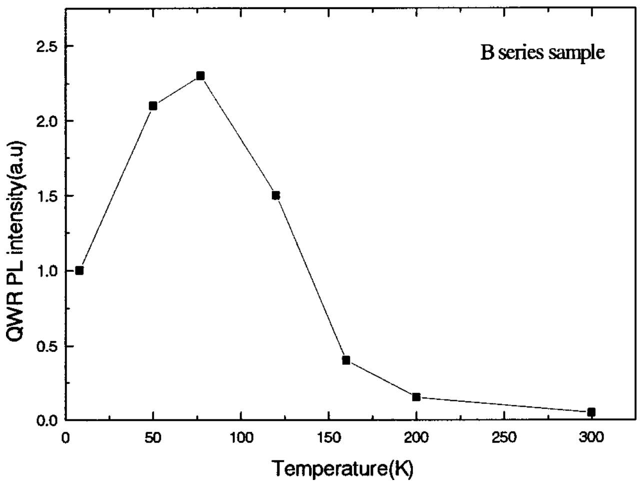


FIG. 5. The temperature dependence of relative PL intensity of the QWR.

(001) planar, QW, and sidewall were 756, 749, and 713 nm, respectively. The signal from the top region merged with that from the planar QW to form a shoulder. For sample B at higher implantation dose, the wavelengths of the top region, planar QW, and sidewall were further blueshifted to 752, 735, and 707 nm, respectively. No wavelength shift in the PL signal of the QWR region was observed as expected from this implantation geometry. Thus, after implantation and annealing, the QWR signal was quite separated from the other QWs signals. This result shows the possibility of increasing the lateral confinement potential of V-grooved QWRs. The increased confining potential may result in the enhancement of subband energy splitting as discussed by Sallese *et al.*[8]

The temperature dependent PL spectra of sample B was shown in Fig. 4. The QWRs PL signal can still be observed at room temperature while the PL signals of QWs were very weak. The QWRs relative intensity normalized by the PL intensity at 8 K was shown in Fig. 5 versus the measurement temperature. As temperature was increased, the QWR PL intensity was increased until about 100 K. This effect was due to carrier thermalization from the sidewall region with increasing temperature, resulting in these carriers being trapped into the QWR region. Hence, this additional carrier recombination in the QWR region increased the PL signal. This behavior is typical of QWR structures grown on V-groove substrates.[9] However, at higher temperatures (above 100 K), carrier thermalization also becomes efficient in the QWR region, thereby resulting in an overall decrease of the normalized PL intensity.

In conclusion, a self-aligned dual implantation scheme was used to selectively intermix the sidewall QW region in order to increase the lateral confining potential of the QWR region of V-grooved QWR structures. This resulted in the enhanced separation of the QWR signal from those of the QWs [from top region, (001) planar QW, and sidewall] as monitored by low temperature PL. Temperature dependent measurements showed an enhancement in the QWR PL intensity with increasing temperature (up to ~100 K) as mediated by carrier transfer from the sidewall to the QWR region.

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