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# Characteristics of Nitrogen δ-doped AlGaAs/GaAs Quantum Wells grown by Molecular Beam Epitaxy

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## 1. Introduction

Nitrogen δ-doping for GaAs, one-dimensional introduction of nitrogen into the material,[1] has been studied focusing on the observable discrete emission lines having acutely narrow line width.[2] That is expected to be a defined photon energy light source. The extremely limited spatial dimension of the elements provides a dynamic control of material properties, especially for the carrier density and wave function, while the modification of eigenstates in a quantum well (QW) by the substitution of sub-monolayer isoelectronic elements has been studied until now.[3] Besides, the substitution of several percent group-V atoms with nitrogen rapidly decreases the energy gap. This behavior is markedly different from that of conventional compound semiconductors, and is of interest for over the past decades.[4] Based on the above, we here focus on one-dimensionally arranged nitrogen in a quantum well (QW) structure for the band engineering of semiconductors, in contrast to the random distribution of the nitrogen within the dilute nitrides so far studied.

In this report, we grow and investigate nitrogen δ-doped AlGaAs/GaAs QW. Photoluminescence (PL) obtained from the samples show clear red-shift of spectral peak positions depending on the amount of nitrogen. That indicates the band-gap shrinkage of the system.

## 2. Experimental

Figure 1 shows the sample structure. Samples were grown on a semi-insulating GaAs (001) substrate by plasma-assisted solid-source molecular beam epitaxy.[5] The substrate temperature was kept at 560°C during the growth. Nitrogen δ-doping was performed by the irradiation of nitrogen plasma during growth interruption at the middle of $Al_{0.18}Ga_{0.82}As$/GaAs QW under $As_2$ beam pressure. The partial pressure of $As_2$ was $8.0\times10^{-6}$ Torr. The amount of introduced nitrogen was controlled by the irradiation time. The coverage of nitrogen was between 0 and 0.50 ML. Structural characteristics of the samples were investigated with X-ray diffraction (XRD) and transmission electron microscope (TEM). Optical characteristics were investigated with PL measured at room temperature (RT).

## 3. Result and Discussion

Figure 2 (a) shows the XRD curve obtained for the samples having their δ-doped nitrogen coverage of 0, 0.12, and 0.50 ML. Figure 2 (b) shows the simulated XRD curve.

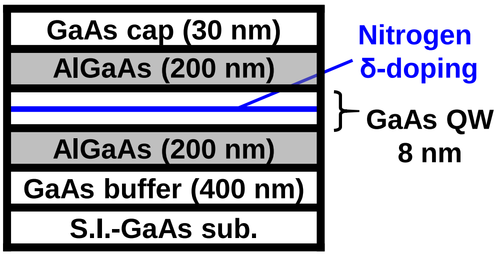


Fig. 1. Sample structure.

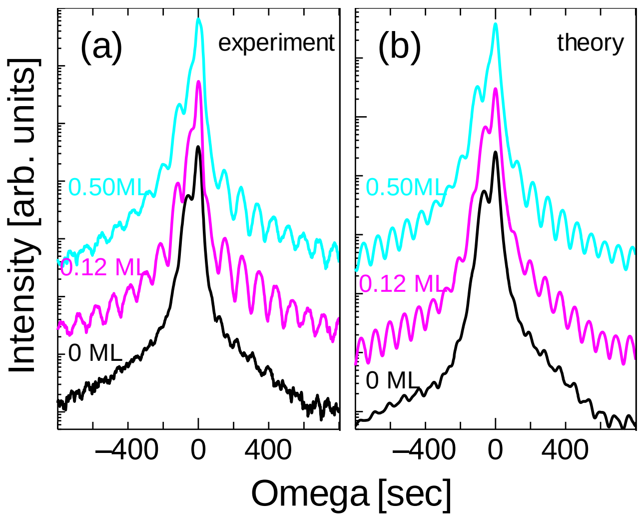


Fig. 2. (a) Experimental and (b) simulated XRD spectra around GaAs (004) diffraction obtained from the samples having δ-doped layer with their nitrogen coverage of 0, 0.12, and 0.50 ML.

The simulation was carried out for the structure there is δ-doped nitrogen at the middle of the QW. Though the precise dispersion can not determined, we can deduce from this simulation that the nitrogen is intoruced into the QW with the amount expected from the growth interruption time.

Figure 3 shows the cross-sectional TEM micrographs for the samples without and with δ-doped layer. The nitrgen coverage is 0.1 ML for the δ-doped sample. Specifically, we observe a dark line at the middle of the QW for the δ-doped sample, indicating its existence.

To examine the impact of the growth sequence, we inves-

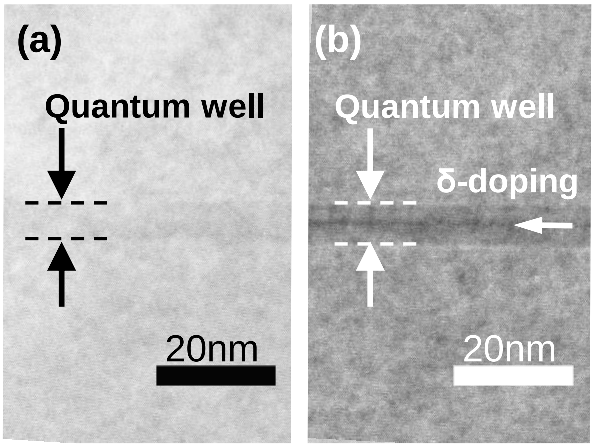


Fig. 3. Cross-sectional TEM images of the samples (a) without δ-doping and (b) with δ-doping having 0.1 ML nitrogen at the middle of $Al_{0.18}Ga_{0.82}As$/GaAs QW.

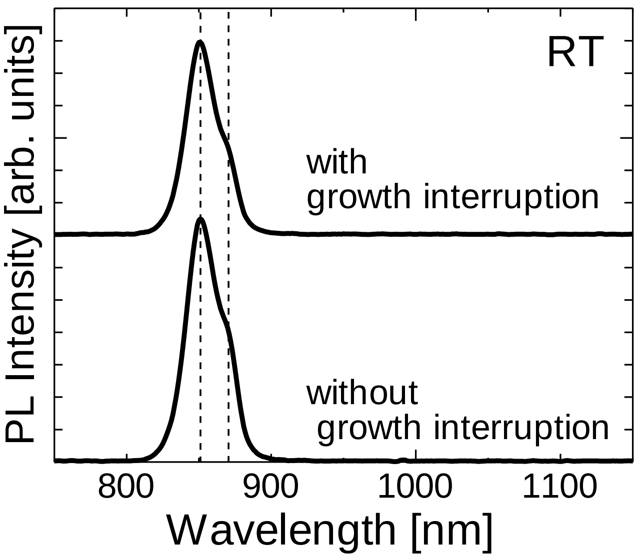


Fig. 4. PL spectra of $Al_{0.18}Ga_{0.82}As$/GaAs QW grown with or without growth interruption.

tigate PL spectra of the QW samples grown with or without growth interruption at the middle of the QW. Figure 4 shows the PL spectra for the samples. The plasma was not ignited throughout the growth of those samples. For both the samples, peaks stemmed from GaAs band edge and quantized states from the QW were observed at the wavelengths 870 nm and 851 nm, respectively. Those spectra did not show significant difference. Hence, the effect of growth interruption on the optical characteristics is negligible. Then we can hereafter proceed the investigation of the effect of δ-doping without affected by that.

Figure 5 shows RT PL spectra for the series of δ-doped samples having different nitrogen coverage between 0 and 0.5 ML. The series of δ-doped samples show an emission at

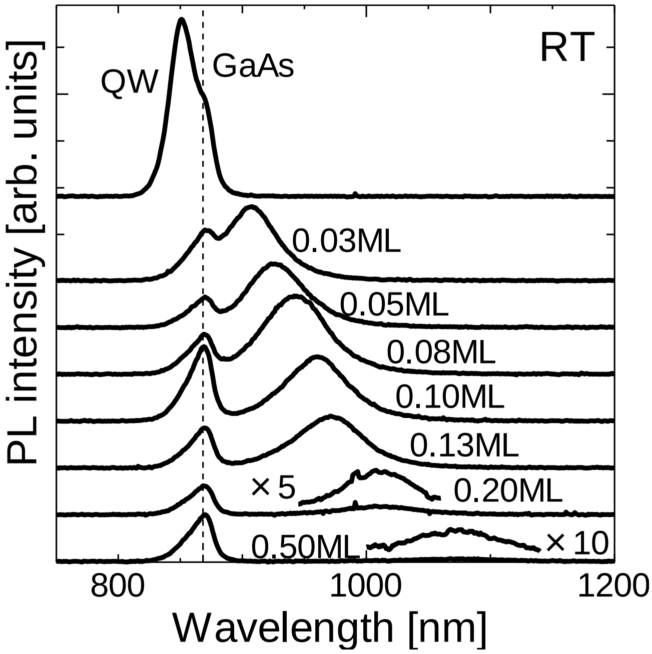


Fig. 5. PL spectra for the series of δ-doped samples having their nitrogen coverage between 0 and 0.5 ML.

the lower energy side of GaAs in the range between 920 and 1070 nm. Those emissions show clear red-shift of the spectral peak positions with increasing the nitrogen coverage. These results suggest that the band structure of the QW system can be engineered with the nitrogen δ-doping.

## 4. Summary

In summary, we have studied the nitrogen δ-doping for AlGaAs/GaAs QW. Using molecular beam epitaxy, we grew δ-doped samples varying the coverage of nitrogen. PL obtained from the samples showed clear red-shift of spectral peak positions depending on the nitrogen coverage. That indicated the band-gap shrinkage of the system.


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