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Band Offset Analysis of GaNAs/GaAs by X-Ray Photoelectron Spectroscopy

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1. Introduction

Recently, GaInNAs is expected to provide long-wavelength laser diodes with an excellent high-temperature performance for use in optical-fiber communications [1]. This expectation is based on the unique physical properties of this type of material, in which the conduction band edge (Ec) is significantly lowered due to a huge bandgap bowing when nitrogen atoms are added. Band offset analysis of the mixed group-V nitride-alloy semiconductors is, thus, an important step towards realizing high-performance opto-electronic devices based on the application of this type of new material system. We have used X-ray photoelectron spectroscopy (XPS) to evaluate the change in the valence band of GaNAs/GaAs caused by an increase in the nitrogen content and discuss our findings in this paper. We also discuss the change in the conduction band of GaNAs/GaAs in terms of the bandgap bowing in GaNAs.

2. Experimental

Based on XPS measurements of the GaNAs/AlAs system, we estimated the energy discontinuity in the valence band (ΔEv) of GaNAs/GaAs by using AlAs as a reference [2]. In this work, two GaNAs samples and a GaAs sample were compared with an AlAs layer. Figure 1 shows the (400) X-ray diffraction patterns of the two GaNAs layers (denoted as GaNAs 1 and GaNAs 2), in which the estimated nitrogen contents were 1.39% and 3.39%, respectively. The broad peak of GaNAs 2 originated from a layer that was relatively thin (20 nm thick) to avoid the generation of misfit dislocations due to the large strain in the layer.

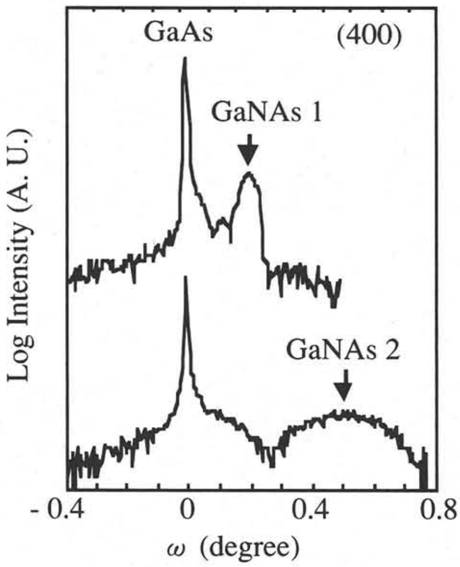

Fig. 1 (400) X-ray diffraction patterns in GaNAs

3. Results and Discussion

The measured nitrogen content dependence of ΔEv in GaNAs/GaAs is shown in Fig.2. The valence band edge (Ev) of GaNAs is lowered by increasing the nitrogen content. This suggests the formation of a type-II band line-up in GaNAs/GaAs. From the slope, ΔEv of GaNAs/GaAs is estimated to be $-(0.019 \pm 0.027)$ eV/%N, which is quantitatively in good agreement with the linear interpolation of ΔEv in GaAs/c-GaN of -1.84 eV

[3], suggesting there is negligible bandgap bowing in Ev. By considering the decrease in the bandgap of GaNAs/GaAs (ΔEg) of −0.156 eV/%N [4], we estimated the energy discontinuity in the conduction band (ΔEc) to be −(0.175±0.027) eV/%N. Thus, the bandgap bowing in Ec is quite large. These experimental results are consistent with the theoretical prediction by Sakai et al., in which the bowing in Ev is small [5].

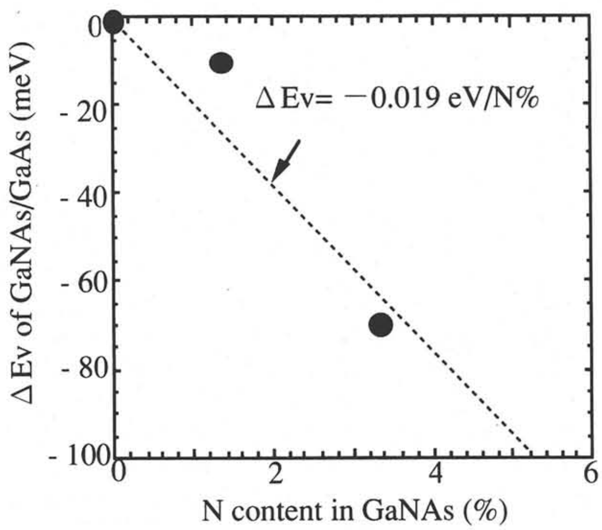

Fig. 2 N-content dependence of ΔEv of GaNAs/GaAs

Figure 3 shows the photoluminescence (PL) spectra of a three quantum well (3QW) layer sample at 77 K. The inset shows the sample structure. We compared the PL of the $GaN_{0.007}As_{0.993}$ QW layer with that of the $Ga_{0.7}In_{0.3}N_{0.007}As_{0.993}$ QW layer; both layers were wet etched to the same thickness of the GaAs cap layer. The PL intensity of the $Ga_{0.7}In_{0.3}N_{0.007}As_{0.993}$ QW layer was about one hundred times larger than that of the $GaN_{0.007}As_{0.993}$ QW layer. This qualitatively supports the XPS result, in which the type-II band line-up is formed in GaNAs/GaAs.

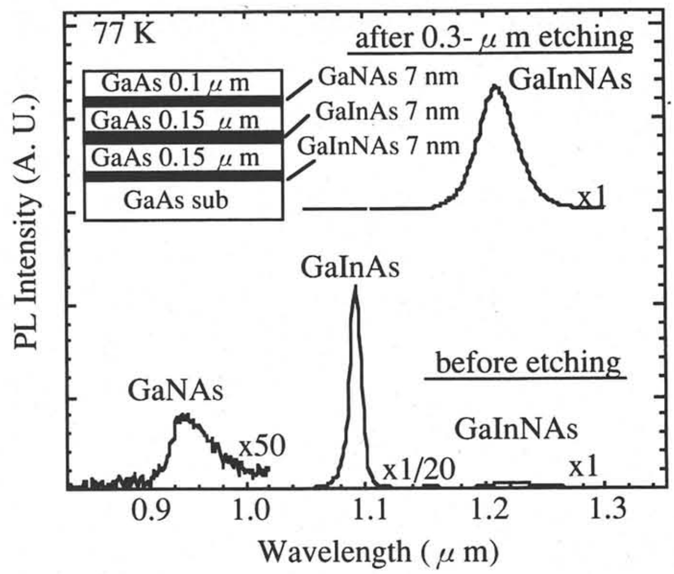

Fig. 3 PL spectra of a 3SQW sample at 77 K

4. Conclusion

From our XPS analysis of the band offset in GaNAs/GaAs, we found that Ec decreases drastically due to bandgap bowing caused by adding nitrogen atoms. The large bowing in Ec should enable the effective confinement of electrons in the wells when GaInNAs is used in the active region of long-wavelength laser diodes.

References

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