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Effect of Capping Layer Growth on Bound Exciton Luminescence in Nitrogen δ-Doped GaAs

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1. Introduction

Impurity centers in semiconductors have been attracting considerable interest for the realization of solid-state photon sources with specific emission wavelengths [1, 2]. The emission wavelength is uniquely determined by a combination of the host material and the impurity element. On the other hand, electrically driven single-photon sources are required from the viewpoint of practical applications. Therefore, III-V semiconductor-based impurity centers can be utilized for potential applications in quantum-information processing based on the solid-state device technology.

The localized electronic states created by nitrogen (N)-related isoelectronic centers in GaAs show extremely narrow bandwidth luminescence lines [3-5]. Recently, we developed a site-controlled N δ-doping technique using molecular beam epitaxy (MBE) [5] and studied the fine structure splitting of excitons bound to the N-pair centers in GaAs [6, 7]. However, the broad background luminescence, which prevents us demonstrating a single-photon emission, was observed below 1.5 eV in dilute-N δ-doped GaAs [7]. This background luminescence is considered to result from defect levels in the GaAs capping layer grown after the N δ-doping. In this work, we studied the capping layer dependence of bound exciton luminescence in N δ-doped GaAs.

2. Experimental

N δ-doping was performed on the (2×4)α surface of GaAs(001) by MBE using As_2 molecular beams. We used active N species created in a radio-frequency plasma source from ultrapure N_2 gas. The details of the site-controlled N-doping technique are described elsewhere [5]. The 100-nm active layer of GaAs:N was sandwiched between $Al_{0.3}Ga_{0.7}As$ barrier layers to achieve efficient carrier capture into the N-pair centers [7]. A GaAs capping layer was deposited on the N δ-doped surface after confirming the (2×4)α or (2×4)β reconstructed surface. The N δ-doping layer was located at the center of the active layer.

PL measurements were carried out by using a continuous-wave laser beam (λ = 484 nm). The PL was dispersed in a 550-mm single monochromator for observing signals in a wide energy range and an 850-mm double monochromator for linearly-polarized measurements. The signal was detected using a liquid-N_2-cooled Si-charge coupled device array. The resolution limit of our spectroscopy system for the linearly-polarized PL measurements was approximately 12 μeV.

2. Results and Discussion

Figures 1(a) and 1(b) show PL spectra of GaAs:N capped on the (2×4)α and (2×4)β surfaces, respectively, for different excitation intensity at T = 5.4 K. The dotted lines are the baselines for each spectrum. As shown in Fig. 1(a), sharp emission lines were observed at 1.444 and 1.493 eV for GaAs:N capped on the (2×4)α surface [5-7]. On the other hand, emission lines for GaAs:N capped on the (2×4)β surface appeared at 1.479 and 1.494 eV. The sheet density of the emission centers examined by observing the two-dimensional PL image for both the 1.444- [Fig. 1(a)]

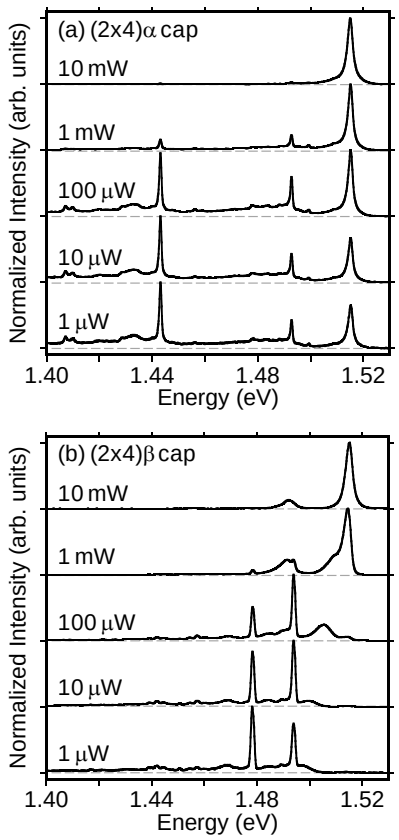

Fig. 1 Normalized PL spectra of GaAs:N at T = 5.4 K for different excitation intensity. (a) and (b) are the results for the GaAs:N capped on the (2×4)α and (2×4)β surfaces, respectively.

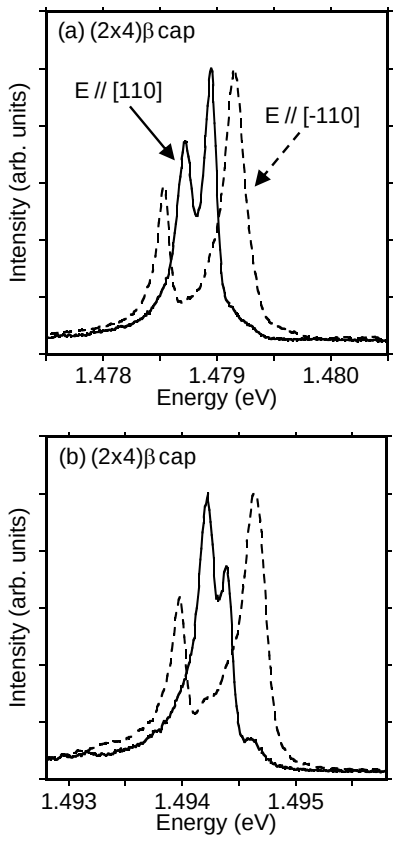

Fig. 2 Linearly polarized PL spectra at T = 4.4 K and P_{exc} = 0.36 W/cm^2. (a) 1.479- and (b) 1.494-eV lines are the results for the GaAs:N capped on the (2×4)β surface. The solid and dotted lines are the results for the [110] and [-110] polarizations, respectively.

and 1.479-eV [Fig. 1(b)] lines were approximately 0.2 μm^{-2}. The origin of the 1.444- and 1.493-eV lines for GaAs:N capped on the (2×4)α surface have been attributed to be the first- and fourth-nearest N pairs, respectively [7, 8]. The origin of the 1.479- and 1.494-eV lines for GaAs:N capped on the (2×4)β surface are expected to be the N pairs, because the sheet densities of the luminescence centers were comparable for both the samples.

Since the exciton fine structure reflects the origin of the bound exciton lines [9], we have measured the linearly polarized PL characteristics. Figure 2 shows linearly polarized PL spectra at 4.4 K measured under the excitation power density of 0.36 W/cm^2 for GaAs:N capped on the (2×4)β surface. Figures 2(a) and 2(b) are the results for the 1.479- and 1.494-eV lines, respectively. The solid and dotted lines represent the [110] and [-110] polarization components, respectively. Both the lines clearly show linearly polarized exciton fine structure, which is explained by the electron-hole exchange interaction and local-strain field [6, 9]. In the case of the C_{2v} symmetry, the $\Gamma_6 \times \Gamma_8$ excitonic states split into eight levels with the mixing of the bright- and dark-exciton components; six levels become optically active and other two levels remain optically forbidden. We can expect to observe four exciton levels when the N pair is formed in the growth plane (001). Thus, the origins of these lines are N pairs aligned along the [110] or [-110].

On the other hand, the broad background luminescence observed in Fig. 1(a) was suppressed in Fig. 1(b) under the weak excitation intensity less than 10 μW. The suppression of the background luminescence for GaAs:N capped on the (2×4)β surface would results from the optimized growth of the GaAs capping layer after the N δ-doping. This result suggests that the GaAs:N capped on the (2×4)β surface have an advantage for the demonstration of a single-photon emission in the N δ-doped GaAs.

4. Conclusions

We studied the bound exciton luminescence in N δ-doped GaAs whose GaAs capping layer after N δ-doping was deposited on the (2×4)α and (2×4)β reconstructed surfaces. It is found that GaAs:N capped on the (2×4)β surface exhibits a suppressed background luminescence, which will be an advantage for the demonstration of a single-photon emission.

Acknowledgements

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