1. Introduction

Recently, the GaNAs alloy have been intensively studied and it is known to very large band-gap bowing factor [1]. In particular, GaNAs has a potential to be used for light-emitting devices of a long wavelength ($\lambda > 1.3\mu m$) with good temperature property because of the large band offset. However, it is reported that a GaNAs on GaAs (001) substrate photoluminescence (PL) intensity decrease with increase of N content [2-3]. For increase PL intensity, many studies have been made which used tilted substrates and various anneal techniques however PL peak energy is blue-shift in the case of anneal [4-6].

So far, during the growth of GaNAs/GaAs quantum well, nitrogen plasma was kept igniting in RF-MBE. We reported novel growth technique for multiple quantum well (MQW), in which plasma is ignited only when the GaNAs layer is grown [7-8]. By this modulated N radical beam source technique, we could control the GaNAs well thickness by atomic layer scale also with fine hetero interface with GaAs barrier.

In this paper, we have investigated the effect of GaNAs well thickness and of N composition on GaNAs/GaAs MQW optical properties.

2. Experiment

The GaNAs/GaAs MQWs were grown on (001) semi-insulating GaAs substrates by MBE using modulated N radical beam source (SVT, RF 4.5). All the samples were un-doped and were grown on a GaAs buffer layer of 1μm, with a GaAs cap layer of 5 nm thick. In this study, we changed GaNAs layer thickness, $L_w$, and surface temperature, $T_{sub}$. The $L_w$ ($T_{sub}$) were designed to be (performed at) 0.85 nm (470 ℃), 1.4 nm (450, 470 and 500 ℃) and 2.8 nm (450, 470, 490, 500 and 510 ℃). In all samples, the GaAs barrier layer thickness of MQW and number of period were fixed to 14.1 nm and 30 times, respectively. The after thermal annealing was performed at 580 ℃ for 10min under a flux of As$_4$ to maintain mirror-like surface morphology.

The MQW structures were examined by XRD measurements. The (00L) scattering profiles in reciprocal space were obtained by $\theta$-2$\theta$ scan at Cu K$_{α}$. In PL measurements at 77K, the samples were excited by second harmonics of Nd:YVO4 laser at 532 nm.

3. Results and Discussion

Figure 1 shows the PL spectra of the MQW structures with designed $L_w$ of 2.8 nm, where the as-grown samples and annealed ones were shown as gray lines and black lines, respectively. The N composition $x$ of all samples except for samples grown at 500 and 510 ℃ were clearly observed by XRD, as shown in Fig. 1. From the PL spectra of the all samples, we have observed two PL peaks from each sample, one is a dominant emission from GaNAs/GaAs MQW and the other is a weak broad PL peak around 0.85 eV. The latter broad emission was observed very weak in the samples grown at 500 and 510 ℃.
510 °C. The origin of this broad emission was related to crystalline defect by Buyanova et al. [3]. The sample of lower $T_{\text{sub}}$ has larger N composition in GaNAs layer. By increase of N composition in GaNAs, the PL peak energies shifts lower, however, the dominant PL emission decreases, as observed in precious literature [2-3][6]. On the other hand, the PL intensities from the after annealed samples are 1.5 times stronger than that from as-grown samples. From these results, we can control the well width $L_W$ and N composition $x$ of GaNAs/GaAs MQW structures for optimization of their optical properties.

Figure 2 shows comparison of the PL spectra of the three annealed MQW samples, the PL peak energies of which are similar, and around 1.3 eV, although designed $L_W$s and growth temperatures $T_{\text{sub}}$s of the samples are quite different. The designed $L_W$ ($T_{\text{sub}}$) are 0.85 nm (470 °C), 1.4 nm (470 °C) and 2.8 nm (490 °C) starting from the top, respectively. All the dominant PL peaks are between 1.30 and 1.35 eV. The dominant peak intensity of narrow $L_W$ (0.85 nm) sample is approximately 100 times as high as that of thick $L_W$ (2.8 nm). This increase of PL intensity is higher in magnification than that reported by in-situ annealing and ex-situ rapid thermal annealing [4-5].

Figures 3 (a) and (b) shows the N composition dependence of the PL peak energy and the integrated PL intensity of dominant emission peak, respectively. In Fig. 3(a) the solid line and dotted line are band-gap of GaNAs alloy and fitted curve, respectively. We confirmed the red-shift of the PL peak energy of the each $L_W$ by increasing N composition. The integrated PL intensities of the MQWs of $L_W = 2.8$ nm are smaller than that of the $L_W = 1.4$ nm samples, whose intensity decreases drastically with increase of N composition. The PL intensity of $L_W = 0.85$ nm sample is very high compared to those of 1.4 nm and 2.8 nm samples. Therefore, QW with thinner GaNAs layer and with higher N composition will be candidate for high PL intensity.

Reference