Recombination dynamics in GaN and InGaN/GaN multiple quantum wells on air-bridged lateral epitaxial grown GaN layers

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Abstract

Currently, the growth technique of GaN-based semiconductors has been developed rapidly for the fabrication of light emitting devices and robust electron devices. Actually, an epitaxial lateral overgrowth (ELO) method and a pendeo-epitaxy method have been carried out with the aim of achieving good crystallinity of GaN or InGaN with low dislocation density (*DD*). More recently, Kidoguchi et al. [1] accomplished a new crystal growth technique which is called air-bridged lateral epitaxial growth (ABLEG). As for the correlation between threading dislocation and recombination pathway, Sugahara et al. [2] showed by the comparison between transmission electron microscopy and cathodoluminescence mapping that dislocations act as nonradiative recombination centers (NRC). On the other hand, Mukai et al [3] reported that the efficiency of blue LED, whose defect density is lowered by the ELO technique, is almost the same as that of conventional LEDs grown directly on sapphire. And it was reported that the lifetime of photoluminescence (PL) depended hardly on *DD* in ELO-GaN by selective-photo-excitation using a metal-masking technique [4], and by site-selective time-resolved PL (TRPL) spectroscopy with spatial resolution less than a few microns [5]. Furthermore, Nakamura et al. reported that the difference in the emission efficiency between LEDs grown on sapphire and ELO-GaN substrates becomes smaller with increasing indium (In) mole fraction in InGaN [6]. Therefore, it is of great significance to assess the detailed recombination dynamics in InGaN active layers with different In mole fractions and different *DD*s. In this paper, we report optical properties of GaN-based layers grown by the ABLEG technique using TRPL spectroscopy with spatial resolution of a few microns.

Figure 1 shows the TRPL measurement system in conjunction with UV-optical microscope. The excitation source is the second harmonic generated beam of $Al_2O_3$:Ti laser, whose pulse width and repetition rate are 1.5 ps and 80 MHz, respectively. The excitation wavelength is selected as 353nm for GaN layers and 370nm for InGaN/GaN 3QWs, respectively. The beam is focused down to the size with diameter of a few microns using air-gapped objective lens. Fluorescent image can be observed by an optical microscope in conjunction with a CCD camera, and also be detected through UV-optical fiber in order to measure the TRPL using a streak camera. The structure of sample grown by the ABLEG-technique [1] is schematically depicted in Figure 2. Figure 3 shows the temporal behaviors of PL from ABLEG-GaN monitored at A free exciton ($E_{XA}$) at room temperature (RT). It was found that PL lifetime ($\tau_{PL}$) measured at a wing region ($DD=10^6$ cm$^{-2}$) is 130 ps which is larger than the value

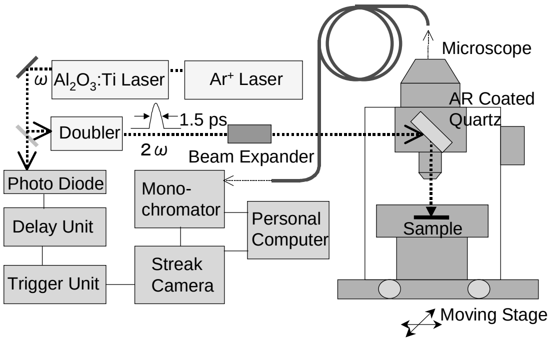


Figure 1 TRPL measurement system in conjunction with UV-optical microscope

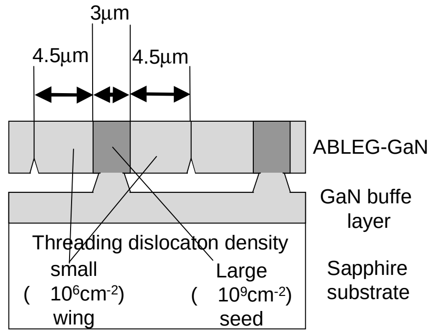


Figure 2 Schematic of sample structures grown by ABLEG technique

monitored at a seed region (90 ps) whose *DD* is three orders of magnitude larger than that in the wing region, indicating the higher density of NRC in the seed region. Figure 4 shows RT PL decay spectra of InGaN/GaN 3QWs grown on ABLEG-GaN. $\tau_{PL}$ values measured at a wing region and at a seed region were 1.74 ns and 1.60 ns, respectively. The tendency that the larger *DD* makes $\tau_{PL}$ shorter is similar to the result for ABLEG-GaN. Therefore, threading dislocation affects emission efficiency in InGaN as well as in ABLEG-GaN. However, comparing the ratio of the difference between $\tau_{PL}$ at the wing and seed regions, the values of InGaN 3QWs and ABLEG-GaN are 8 % and 40 %, respectively. Hence, threading dislocation is not major NRC at room temperature in InGaN. These phenomena can be understood in terms of the model of localization of carriers where the potential fluctuation in GaN is so small that carriers can diffuse easily, so that the carriers are captured at NRC and recombine nonradiatively. On the other hand, in InGaN active layers the potential fluctuation is too large for carriers to diffuse over the potential barriers, therefore it is difficult for carriers to be captured at NRC caused by threading dislocations. The origin of localization in InGaN layers is thought to be the fluctuation of well width and/or In mole fluctuation. It was found that the effect of potential fluctuation on the recombination pathway found in the ELO-grown samples can also be applied to the layers grown by the ABLEG technique.

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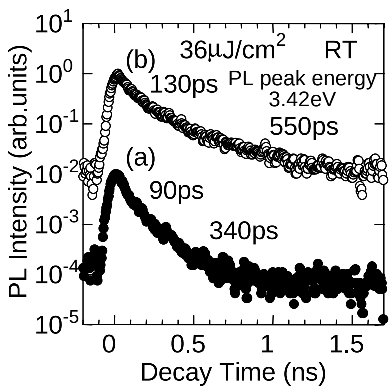


Figure 3 PL decay spectra of ABLEG-GaN at (a) seed region and (b) wing region

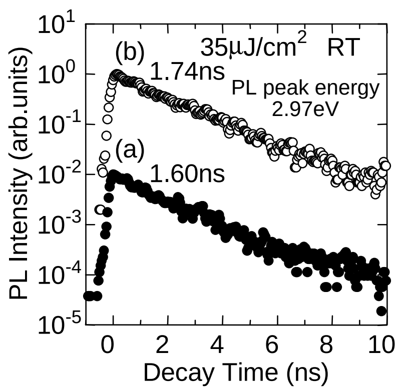


Figure 4 PL decay spectra of InGaN/GaN 3QWs grown on ABLEG-GaN at (a) seed region and (b) wing region