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InGaN quantum wells with small potential fluctuation

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1. Introduction

InGaN quantum wells (QWs) have been widely used as the active layers of light emitting diodes and laser diodes that emit light from visible to ultraviolet regions. Nevertheless, the performance of these devices has been limited, in part by the emission efficiency of InGaN QWs. The emission efficiency of InGaN QWs is governed by various factors, such as the quantum confinement Stark effect, potential fluctuation by the phase separation in InGaN QWs, and nonradiative recombination centers (NRCs). The potential fluctuation in InGaN QWs is a crucial issue, especially in the case of high InN composition (i.e. for longer wavelength emission). InGaN QWs grown on InGaN under-lying layers (ULs) exhibit the highest luminescent efficiency at room temperature (RT) ever reported, because InGaN ULs function to reduce the NRCs near InGaN QWs [1]. In this study, we attempted to decrease the potential fluctuation in InGaN QWs using InGaN ULs. Time-resolved photoluminescence (TR-PL) revealed that InGaN ULs effectively reduce the potential fluctuation even for InGaN QWs with comparatively high InN composition.

2. Experimental

A schematic diagram of the sample structure is shown in Fig. 1. Samples were grown on (0001) Si-oriented n-type 4H-SiC substrates by metalorganic vapor phase epitaxy. The sample consisted of a Si-doped 700-nm-thick $Al_{0.1}Ga_{0.9}N$ layer, a Si-doped 50-nm-thick GaN layer, a Si-doped UL, an InGaN MQW consisting of three pairs of Si-doped 5-nm-thick InGaN barriers and undoped 2.5-nm-thick InGaN wells, and a Si-doped 25-nm-thick $Al_{0.2}Ga_{0.8}N$ layer. Four kinds of MQWs, which emitted light ranging from 375 to 480 nm at ~17 K, were prepared by varying the substrate temperatures and the flow rate of trimethylindium. Two kinds of ULs were prepared: a Si-doped 50-nm-thick GaN grown at 1000 ℃, namely high-temperature-grown GaN UL (HT-GaN UL); and a Si-doped 50-nm-thick InGaN grown at 780 ℃ (InGaN UL). Note that the HT-GaN UL provides the conventional sample structure. Integrated photoluminescence (PL) was measured using a continuous wave He-Cd laser (λ=325 nm) at RT. The excitation power density was approximately 5 W/cm^2. TR-PL were measured at low temperatures ~17 K. Pulsed excitation was performed by the frequency-doubled beam of a mode-locked Ti:sapphire laser. A conventional fast-scan streak camera was used for TR-PL measurements. The excitation wavelength was 365~400 nm. The excitation power density was 600 nJ/cm^2, which generated photo-carriers of <10^{17} cm^{-3} in QWs.

3. Results and discussion

Figure 2 shows PL spectra measured at RT using the He-Cd laser for InGaN MQWs emitting blue-purplish lights grown on an InGaN UL and an HT-GaN UL. The integrated intensity for the InGaN UL sample is approximately 50 times stronger than that for the HT-GaN UL sample. This is because the NRCs near the InGaN QWs are effectively eliminated by incorporation of indium atoms into the UL [1].

The photon energy dependence of PL lifetime measured by TR-PL at 17 K is shown in Fig. 3 for the InGaN MQW emitting UV light (375nm). The integrated PL spectra are also shown in the figure. The PL lifetimes increase with decreasing photon energy. This is characteristic of localized systems, wherein the decay of excitons consists of both radiative recombination and the transfer process to tail states. The depth of localization was evaluated by assuming the exponential distribution of the density of tail states and by fitting the photon energy dependence of the PL liftime, τ_{PL}, using the following equation:

$$\tau_{PL}(E) = \frac{\tau_{rad}}{1+\exp\frac{E-E_{me}}{E_0}} \qquad (1)$$

where τ_{rad}, E_{me}, and E_0 are the radiative lifetime, the energy similar to the mobility edge, and the depth of localization (degree of potential fluctuation), respectively. By fitting, τ_{rad}=0.73 ns, E_{me}=3.39 eV, and E_0=23.0 meV were obtained. The same analysis was performed for various InGaN MQWs emitting light ranging from 375 to 480 nm. The results are summarized in Fig. 4, where the degree of potential fluctuation, E_0, is plotted as a function of E_{me} and the values of E_0 from the literature are also plotted. It can be clearly seen in Fig. 4 that the E_0 values for the InGaN UL are smaller than that for the HT-GaN UL and those from the literature in the whole photon energy range. Especially, it is noteworthy that E_0 of 21.6 meV at E_{me} of 2.90 eV (430nm) is much smaller than that of 60.0 meV in Ref. 2. It can be concluded that InGaN ULs effectively reduce the potential fluctuation in InGaN QWs. One possible reason for this improvement is that indium atoms supplied during the growth of ULs might act as surfactants to improve the crystal quality of the MQWs.

4. Conclusions

Various kinds of InGaN MQWs emitting light ranging from 375 to 480 nm were prepared using InGaN ULs. The degree of the potential fluctuation in the MQWs was greatly reduced in the whole wavelength range. This reduction occurs because indium atoms supplied during the growth of ULs seem to act as surfactants to improve the crystal quality of the InGaN MQWs.

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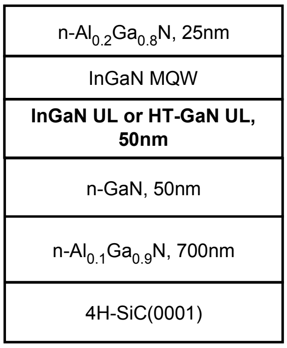

Fig. 1: A schematic diagram of the sample structure.

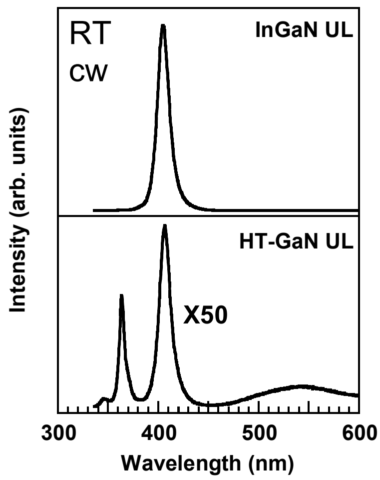

Fig. 2: Integrated PL spectra measured using the He-Cd laser at RT for blue-purplish InGaN MQWs grown on HT-GaN and InGaN ULs.

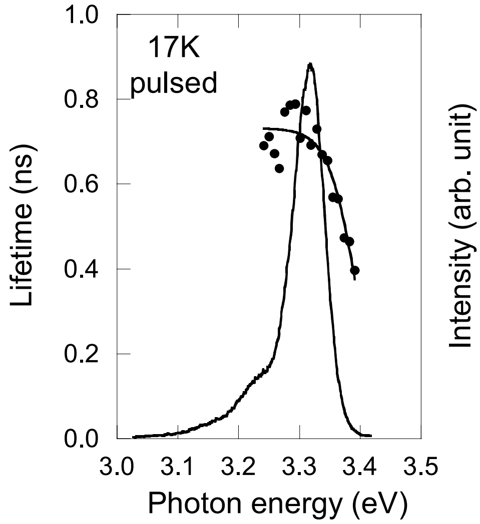

Fig. 3: Photon energy dependence of PL lifetime measured by TR-PL at 17 K for the UV-emitting InGaN MQW grown on an InGaN UL. The integrated PL spectrum is also shown in the figure.

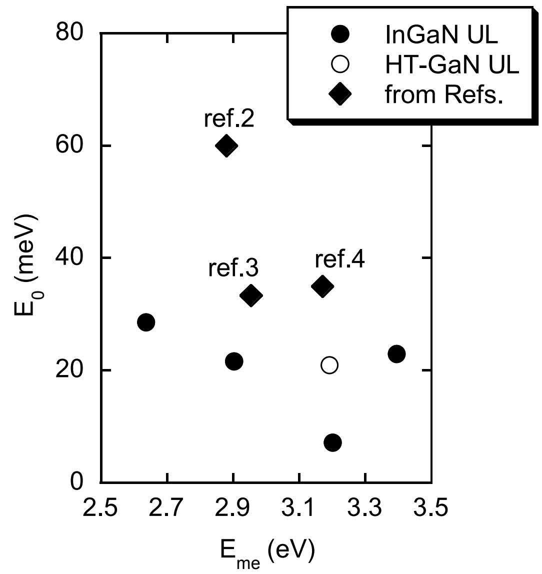

Fig. 4: The degree of potential fluctuation, E_0, plotted as a function of E_{me}. The values of E_0 from the literature (Ref. [2-4]) are also plotted.