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Intense Ultraviolet Electroluminescence Properties of the High-Power InGaN-Based LEDs Fabricated on Patterned Sapphire Substrates

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1. Introduction

Recent remarkable progress on GaN-based semiconductors has led to a realization of high-brightness blue and ultraviolet (UV) light-emitting diodes (LEDs) [1]. These achievements enabled us to open a path toward the realization of the *semiconductor lighting*[2,3]. High-quantum efficiency in UV LED is essential for exciting phosphor materials to produce efficient white light source, which can replace the three colors (R. G. B.) fluorescent lamp[3]. Very recently, we have demonstrated a near-UV InGaN-based LED with a 24 % external quantum efficiency at 382 nm at room temperature (RT). This is the highest value reported to date for LEDs in the UV-to-blue portion of the wavelength spectrum[4].

We will report in this conference on the electroluminescence (EL) characterization of the high-efficient InGaN MQW UV LEDs under direct current (DC) and high pulsed current.

2. Results and discussion

2.1 Typical electroluminescence properties

The InGaN MQW UV LEDs used in this study were grown on patterned sapphire substrates using a metalorganic chemical vapor deposition method. The UV LED structure consisted of a GaN buffer layer (27 nm), n-GaN:Si (6 μm), n-AlGaN:Si (50 nm), a 4-period MQW consisting of 3-nm-thick InGaN wells and 10-nm-thick GaN barriers, p-AlGaN:Mg (50 nm), and p-GaN:Mg (100 nm). Figure 1 shows the forward-biased EL spectra obtained at RT under various DC conditions. There appears a single emission band at 3.235 eV (383 nm) with a band width of 94 meV at 1 mA. With increasing forward current, the luminescence intensity increases linearly up to 50 mA, but is not saturated as seen in the inset of Fig. 1.

2.2 Electroluminescence under high pulsed current

We have also investigated the EL spectral properties under forward-biased high pulsed current. The repetition rate and the pulse width were 10 Hz and 100 ns, respectively. In order to prevent the heat generation due to the high pulsed current, we performed the experiments under low-duty cycle. Figure 2 shows the EL spectra at RT under forward-biased pulsed current. The EL peak energies for both the DC and pulse conditions are located at the same energy position. With increasing forward-pulsed current, the luminescence intensity increases linearly up to 1000 mA. This experimental result demonstrates the steady performance of the UV LED under high pulsed current. Figure 3 shows the EL peak energy and luminescence intensity as a function of forward-biased pulsed current. The shift of the EL peak position and the saturation of the luminescence intensity are not observed. This experimental result indicates that the effect of piezoelectric field on the emission properties is negligibly small. It is noted that the broadening of the higher-energy portion of the EL spectrum with current takes place. This spectral broadening might be due to the effect of hot electrons

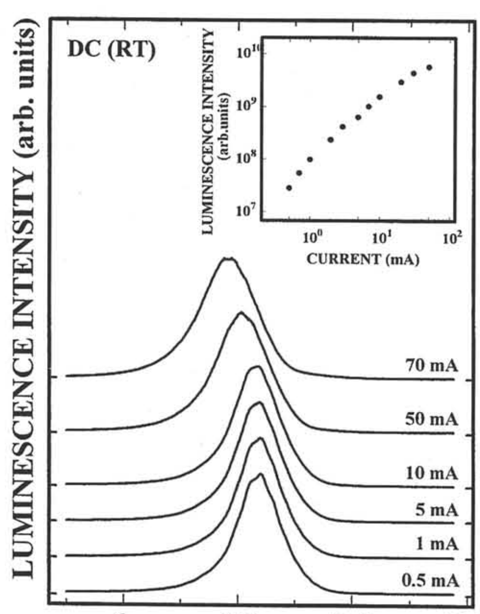

Fig. 1 Forward-biased EL spectra obtained at RT under various DC conditions. The inset shows the luminescence intensity as a function of forward current.

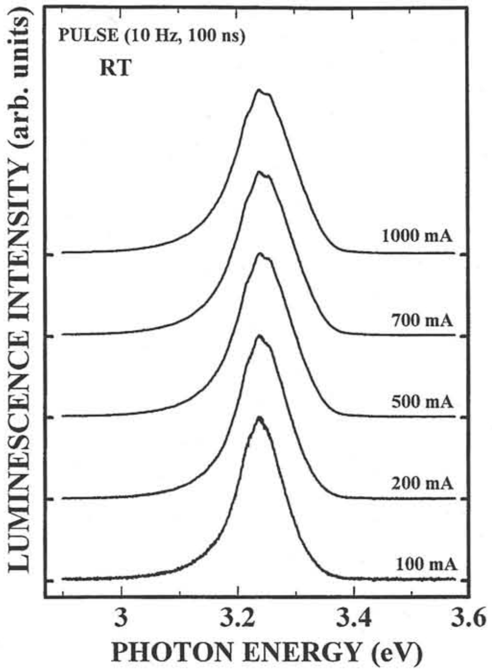

Fig. 2 Forward-biased EL spectra obtained at RT under forward-biased pulsed current.

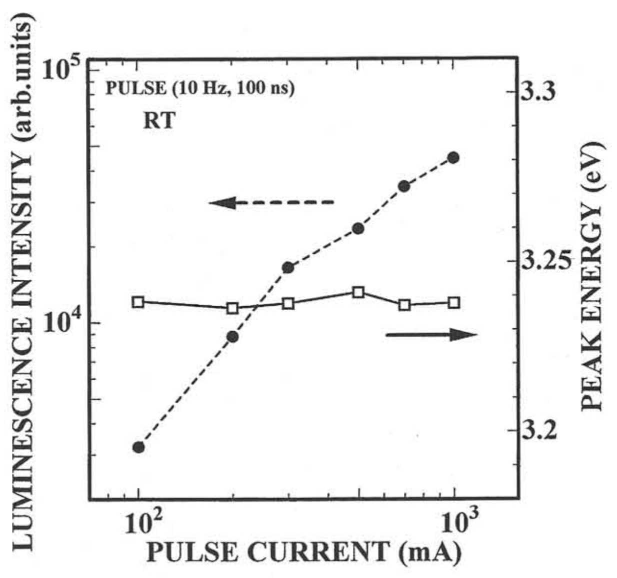

Fig. 3 EL peak energy and luminescence intensity at RT as a function of forward-biased pulsed current.

injected in the InGaN active layer as was reported in Ref 5.

2.3 High-efficient recombination mechanism

One of the origin of the high-efficient recombination is the reduction of dislocation density realized by the lateral epitaxy on the patterned substrates (LEPS)[4]. In order to investigate the effect of the patterned sapphire substrates, we performed the time-resolved photoluminescence (PL) measurements for GaN epitaxial layers grown on the patterned and the standard sapphire substrates. As a result, the GaN on the patterned sapphire substrates had a longer decay-time constant compared to that on the standard sapphire substrates. This experimental result suggests that the transport of carriers to nonradiative recombination centers is suppressed by the LEPS.

Up to now, we have extensively investigated the radiative recombination mechanism of a $In_{0.08}Ga_{0.92}N$ epitaxial layer, and proposed that a polaron related recombination process was dominant[6-8]. In the present UV LEDs, it is expected that the InGaN active layer has almost the same In composition as the $In_{0.08}Ga_{0.92}N$ epitaxial layer, because the PL peak energies for both the UV LEDs and the $In_{0.08}Ga_{0.92}N$ epitaxial layer are located at the same energy position. It is therefore adequate to consider that the polaron interaction plays an important role in the high-efficient luminescence properties of the InGaN MQW UV LEDs.

3. Conclusions

We have performed the EL characterization of the high-efficient InGaN MQW UV LEDs under DC and high pulsed current, and put forward the consideration on the origin of the high-efficient recombination mechanism. There appeared a single emission band at 3.235 eV (383 nm) with a band width of 94 meV at RT under DC. With increasing forward current, the luminescence intensity was not saturated and increased linearly up to 50 mA. Under pulsed current, the luminescence intensity increased linearly up to 1000 mA. This experimental result demonstrated the steady performance of the UV LED under high pulsed current. We propose that the effects of the reduction of dislocation density and the polaron play an important role in the high-efficient EL properties.

Acknowledgements

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