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339 nm Deep-UV Emission from $Al_{0.13}Ga_{0.87}N/Al_{0.10}Ga_{0.90}N$ Double Heterostructure Light-Emitting Diode on Sapphire Substrate

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We report 339 nm deep-ultraviolet (UV) emission, which we believe the shortest wavelength from light-emitting diodes (LEDs) on sapphire at room-temperature (RT).

The $Al_xGa_{1-x}N$ compounds have the potential for use in laser diodes (LD) and LEDs covering nearly the entire deep-UV region of the spectrum (200~365 nm). Applications of deep-UV emitters include high-density optical storage systems and high-efficiency lighting. Despite a considerable amount of research directed towards InGaN-based violet LEDs,[1,2] very little research has been conducted on AlGaN-based UV LEDs.[3-5] For the AlGaN double heterostructure (DH) LEDs, the linewidth of emission peak in excess of 40 nm suggests a band-to-impurity transition.[3] Recently, RT operations of multi-quantum well (MQW) LEDs with emission peak wavelengths 346 and 353 nm have been reported.[6,7] Although the introduction of MQW structures is promising, the large strain due to the difference in the Al molar fraction between the well and barrier layers causes a significant piezoelectric field, resulting in the longer emission wavelength and poorer emission efficiency. Thus, it is difficult to shorten the emission wavelength simply by narrowing the well thickness or by increasing the Al molar fraction in the barrier layers.[7] In this paper we report on the fabrication and the characterization of AlGaN DH LEDs consisting of a relatively high Al content active layer grown on sapphire in order for the deep-UV LEDs to suppress the piezoelectric field[7].

We fabricated the LEDs on (0001) sapphire substrate because a crack-free thick GaN layer can be grown on sapphire substrate under the active layer, resulting in the quality of the AlGaN active layer on sapphire substrate being better than that on SiC substrate. We propose a LED structure in which the $Al_{0.10}Ga_{0.90}N$ active layer is sandwiched by undoped $Al_{0.13}Ga_{0.87}N$ barrier layers (BLDH) to suppress carrier recombination involving Mg acceptors,[3] as shown in Fig. 1. The LED structures were grown in a horizontal quartz tube reactor by low-pressure metalorganic vapor phase epitaxy (MOVPE).[8] The RT electroluminescence (EL) spectrum from the BLDH-LED is shown in Fig. 2. An EL emission at 339 nm, which is attributed to the active layer, as inferred from the PL spectrum of the LED structure, is the shortest wavelength for LEDs on sapphire at RT, to our knowledge. For a DH-LED structure without undoped barrier layers, we observed only an EL emission at 371 nm. Therefore, the undoped barrier layers play important roles in obtaining the band-to-band emission of the active layer. The RT EL spectra from the BLDH-LED for several different forward injection current levels are shown in Fig. 3. The intensities of the EL peaks at 339, 363, and 369 nm increase with the injection current with almost the same intensity ratios. The EL peaks do not show any significant broadening or spectral shifts throughout the current range. The EL peaks at 363 and 369 nm are assumed to be attributed to the emission from the n-GaN layer and the recombination involving Mg acceptors still remained in the BLDH-LED, respectively. The dependence of the integrated EL intensity on forward injection current for the 339 nm peak is shown in Fig. 4. The EL intensity increases with the injection current with a power (m) of 1.7 in the injection current range lower than 20 mA, while exhibiting a linear dependence (m=1) in the injection current range higher than 20 mA, as reported for conventional LEDs.[9] These results indicate that the recombination process is changed from recombination currents (m=2), in which the currents are predominantly nonradiative, to diffusion current (m=1), in which the radiative recombination resulting from band-to-band transition is dominant.[10] A full-width at half maximum linewidth of 5.6 nm (60 meV) obtained for the 339 nm peak in the BLDH-LED is significantly narrower than that previously reported for

DH LEDs[3] and as narrow as that of 5.8 nm (57 meV) for MQW LEDs.[6] The narrow linewidth of the BLDH-LED suggests that the emission is attributable to the band-to-band transition.

In summary, we have successfully observed 339 nm deep-UV emission for $Al_{0.13}Ga_{0.87}N$ / $Al_{0.10}Ga_{0.90}N$ DH LEDs with undoped barrier layers on sapphire, which we believe to be the shortest wavelength yet reported. We proposed the introduction of the undoped barrier layer to realize deep-UV emission by suppressing the recombination involving Mg acceptors. The 5.6 nm emission linewidth as narrow as that reported for MQW LEDs suggests band-to-band transition. These results, while providing an initial baseline, offer strong support for the viability of AlGaN UV LEDs.

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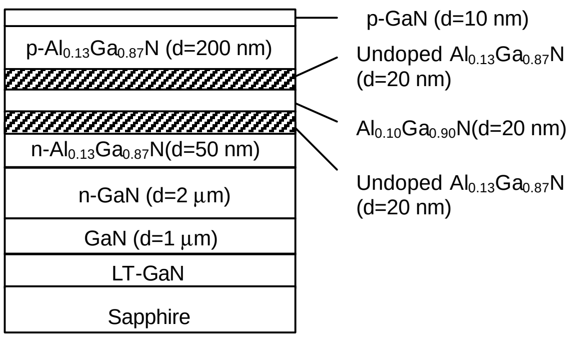

Fig. 1. Schematic of $Al_{0.13}Ga_{0.87}N$ / $Al_{0.10}Ga_{0.90}N$ DH LED structure with undoped barrier layers (BLDH-LED).

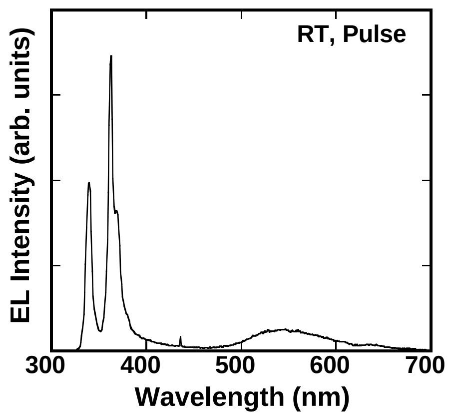

Fig. 2. RT electroluminescence spectrum of BLDH-LED. Emission peaks are at 339, 363 and 369 nm. Injection current is 20 mA.

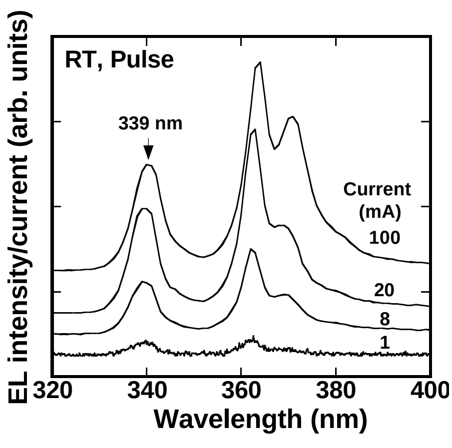

Fig. 3. RT electroluminescence spectra of BLDH-LED under various levels of forward current iniection.

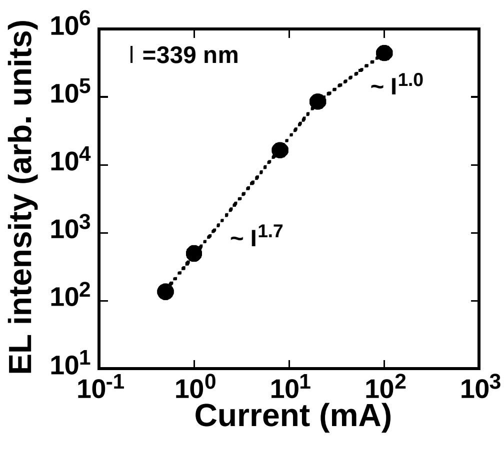

Fig. 4. Dependence of integrated EL intensity on forward injection current for 339 nm peak of BLDH-LED.

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