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Enhanced emission from near ultraviolet LED with highly-reflective p-(Al)GaN layer

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Photonic crystal patterns were fabricated on p-(Al)GaN layer of near ultraviolet LED to realize a highly reflective p-(Al)GaN layer. A significant photoluminescence enhancement of 27.4% and an electroluminescence enhancement of 194.7% were achieved.

InGaN MQW-based LEDs are capable of emitting in a broad spectral range from near ultraviolet (NUV) to near infrared (NIR) and a high external quantum efficiency (EQE) above 80% can be achieved on blue LEDs [1]. Meanwhile, InGaN MQW-based NUV-LED with a flip-chip design also shows a great potential in many applications [2]. The efficiency of NUV-LED is limited by the low hole concentration of its p-(Al)GaN layer which leads to an increased contact resistance and then a reduced wall-plug efficiency.

In this work, photonics crystal (PhC) patterns were fabricated into the top p-(Al)GaN layer of NUV-LED sample by using electron-beam lithography and dry etching processes. With designed structure dimension, the PhC layer satisfy the Bragg conditions and therefore function as a Bragg mirror/reflector at the emission wavelength of around 390nm. A 150nm thick aluminum reflective layer was also deposited on the top of the PhC layer to further enhance the reflection. Fig.1a shows a schematic structure of the NUV-LED with PhC patterned p-(Al)GaN layer. Here the PhC structure has a design of: 375nm pitch, 290nm air-hole diameter and 40nm etch depth, which have been confirmed by the observation from scanning electron microscope image (shown in Fig.1b) and atomic force microscope measurement (Fig.1c). Photoluminescence (PL) measurement was carried out on both plain NUV-LED (with Al reflective layer) and PhC patterned NUV-LED (with Al reflective layer), and the results are shown in Fig.2a. An emission enhancement of 27.4% was observed on the PhC-LED which can be attributed to the increased reflection introduced by the PhC layer. Meanwhile, electroluminescence (EL) measurement was also conducted on the two samples and the results were demonstrated in Fig.2b. It is shown that the PhC patterned NUV-LED has an emission enhancement of 194.7% compared with the plain NUV-LED under the same current injection condition. Such significant emission enhancement suggests an increased hole conductivity through the p-(Al)GaN layer apart from the enhanced reflectance.

In summary, we studied using surface PhC pattern as a Bragg reflector layer on NUV-LED. The results confirm this approach as an effective way to enhance the emission efficiency of flip-chip NUV-LED.

[1] Y. Narukawa, et al. J. Phys. D: Appl. Phys., vol.43, pp. 354002 (2010).

[2] S. Kamiyama, et al. Journal of Semiconductors, vol. 32, pp. 013004 (2011).

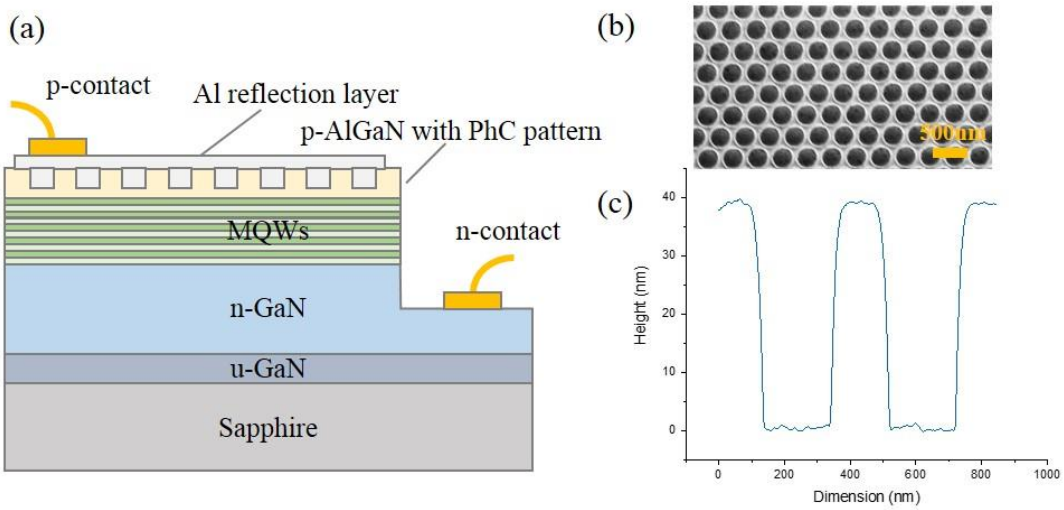

Fig.1 (a) Schematic illustration of NUV-LED with PhC patterned p-(Al)GaN layer; (b) Top-view scanning electron microscopy image of fabricated PhC pattern; (c) Structure profile of features on the PhC pattern measured by atomic force microscope.

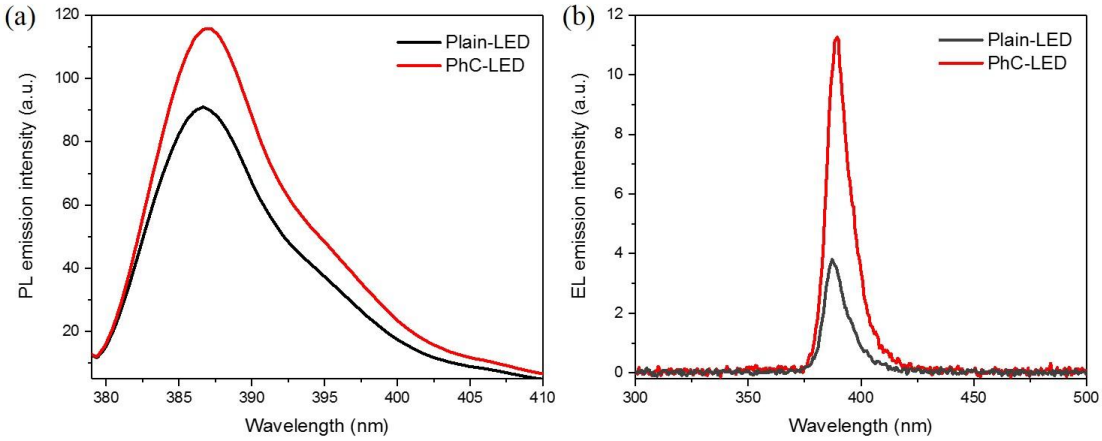

Fig.2 (a) Photoluminescence spectra; and (b) electroluminescence spectra of plain NUV-LED and PhC patterned NUV-LED, respectively.