Analysis of Electrode Structure and Process for High-Power AlGaN-based Deep-Ultraviolet Light-Emitting Diodes

°Guo-Dong Hao[1], Manabu Taniguchi[1], Naoki Tamari[1,2], °Shin-ichiro Inoue[1,3]
(1.NICT, 2.Tokuyama Corp., 3.JST-PREST)
E-mail: gd.hao@nict.go.jp, s_inoue@nict.go.jp

AlGaN-based deep-ultraviolet light-emitting diodes (DUV-LEDs) are undergoing a rapid evolution in recent years. Several groups reported the external quantum efficiency (EQE) in the 270-280 nm spectral range has exceed 10%.[1, 2] We recently demonstrated a record output power exceed 90 mW with an emission of 265 nm.[3] These are the highest EQE and output power reported to date for DUV-LEDs emission shorter than 280 nm. However, these values are still much lower than that achieved in the visible spectral range, and further improvement is required. Here, we report on a dramatically enhancement in wall-plug efficiency (WPE) with an improvement in the output power and a reduction of the operating voltage by using a well-designed *p*-electrode and an optimal annealing temperature in LED fabrication process.

The DUV-LEDs emitting at 265 nm were grown on a (0001) sapphire substrate by MOCVD. The LED structures were composed of AlN buffer layers, a Si-doped *n*-$Al_{0.75}Ga_{0.25}N$ cladding layer, three multiple quantum well active layers, a Mg-doped *p*-AlN electron blocking layer, a *p*- $Al_{0.75}Ga_{0.25}N$ cladding layer and a *p*-GaN layer for ohmic contact formation. The Ti/Al/Au and Ni/Au are used as *n*- and *p*- electrodes to form ohmic contact.

Figure 1 shows the *I-V* characteristics of three DUV-LEDs with the annealing temperatures of 800 ℃, 900 ℃, and 1000 ℃, respectively, for *n*-$Al_{0.75}Ga_{0.25}N$ ohmic contact formation. It shows that both of the turn-on and operating voltages are lowest when the annealing temperature is 900 ℃. This is because a lower annealing temperature of 800 ℃ can cause an increasing contact resistance dropped across *n*-AlGaN/metal contact interface; while a higher annealing temperature of 1000 ℃ could degrade the quality of *p*-GaN resulting in an increased specific contact resistivity in the *p*-GaN to Ni/Au contact and an increased resistivity of *p*-GaN and *p*-$Al_{0.75}Ga_{0.25}N$ layers.

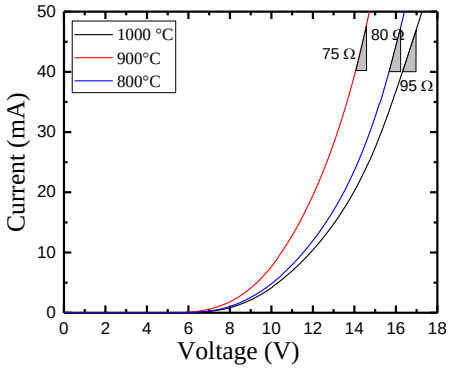

Fig. 1. Current-voltage (*I-V*) characteristics comparison for three samples annealed under different temperature conditions for ohmic contact formation.

We then studied the current crowding problem and designed a uniform-current-spreading *p*-electrode geometry to improve the optical performance of the device. The output power was collected by a Si photodiode from the backside of the device. The comparison of *I-L* and *I-V* characteristics between the LED with the new designed *p*-electrode and the one with a conventional *p*-electrode are given in Fig. 2. The output power was enhanced by a factor of 40%, and the operating voltage was reduced about 18%, corresponding to an enhancement in WPE by a factor of about 68% at an injection current of 280mA.

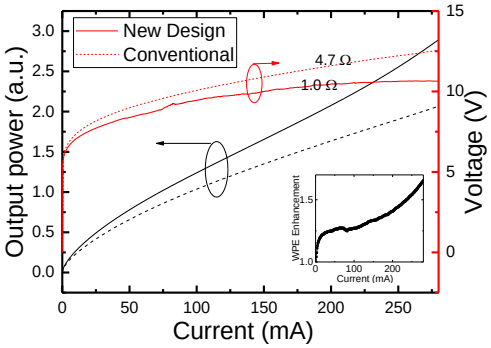

Fig. 2 Comparisons of output power and *I-V* characteristics. Inset is the WPE enhancement with injection current

[1] M. Shatalov et al., Appl. Phys. Express **5**, 082102 (2012).
[2] M. Ippommatsu et al. CLEO-PR, MH1-3 (2013).
[3] S. Inoue et al., Appl. Phys. Lett. **106**, 131104 (2015).

© 2016年 応用物理学会