14 Milliwatt Operation of Highly Transparent AlGaN-Based (254-258 nm)-Band DUV LED

M. Ajmal Khan,[1*] Noritoshi Maeda,[1] and Hideki Hirayama[1]

[1]RIKEN Cluster for Pioneering Research (CPR), 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

*Email: muhammad.khan@riken.jp

AlGaN-based deep-ultraviolet (DUV) light-emitting diodes (LEDs) at 222-255 nm emission are critical to replace low-pressure mercury lamps emitting at 253.7 nm with smart, green solid-state UV germicidal irradiation (UVGI) sources for surface, air, water, and food disinfection [1]. Recently it was also realized that COVID-19 changed the dynamic of the UVC LED technology market [2]. Especially, the market for UV disinfection/purification applications emerged much more rapidly than expected in 2017. UVC LED market is expected to grow from $308M to $2.5B in 2025 [2]. Yet the performance of these AlGaN-based DUV LEDs, emitting in the 250 nm, are largely lagged behind their blue brethren in terms of efficiency and cost [1]. Previously, Adivarahan et al. reported about AlGaN DUV LEDs at 250 and 255 nm, respectively, using p-GaN as a contact layer [3]. Quite low peak powers of 0.16 mW and 0.57 mW, respectively, at 250 nm and 255 nm emission were achieved [3]. Previously Hirayama et al. successfully boost up the efficiency of 250 nm AlGaN LEDs up to 1.5%, by replacing a single barrier electron-blocking-layer (EBL) with p-type multi-quantum-barrier EBL (p-MQB EBL) [1]. Therefore, in this work, we attempted to further improve the external-quantum-efficiency (EQE) of (254-258nm)-band DUV LEDs by improving the design (Fig. 1A) and crystal quality of the multi-quantum-well (MQWs).

Design of highly transparent AlGaN-based DUV LED structures at (254-258nm)-band emissions were grown by metalorganic chemical vapor deposition (MOCVD) at 1160°C under 76 Torr pressure (Fig.1A). Two types of DUV LEDs at 258 nm and 254 nm emission, respectively, were fabricated to investigate the EQE and light power (L) using pure p-AlGaN contact layer (by omitting p-GaN contact layer). The 258nm-band DUV device's structure comprised an AlN template (4 µm) on a C-Sapphire substrate (400 µm), an n-type $Al_{0.74}Ga_{0.26}N$:Si electron source layer (ESL), AlGaN MQWs, an $Al_{0.74}Ga_{0.26}N$ (blocking)/ $Al_{0.55}Ga_{0.45}N$ (Valley):Mg multi-quantum-barrier electron-blocking-layer (p-MQB EBL), and a p-AGaN:Mg hole source layer (HSL) including p-AlGaN:Mg contact layer (Fig. 1A). The Al composition in the quantum-wells (QW) and quantum-well-barrier (QWB) of the MQWs were 60 and 74%, respectively. In second 254nm-band DUV LED device, MQWs parts of the previous design was replaced with Al composition in the wells and barrier layers of the MQWs were 64 and 78%, respectively. Ni/Au and In (dot) electrodes, respectively, were evaporated as a (n) p-contacts on the p-AlGaN:Mg contact and n-AlGaN:Si ESL in both devices (Fig. 1A-D). (254-258nm)-band AlGaN DUV LEDs containing a transparent p-AlGaN layers are reported in this paper.

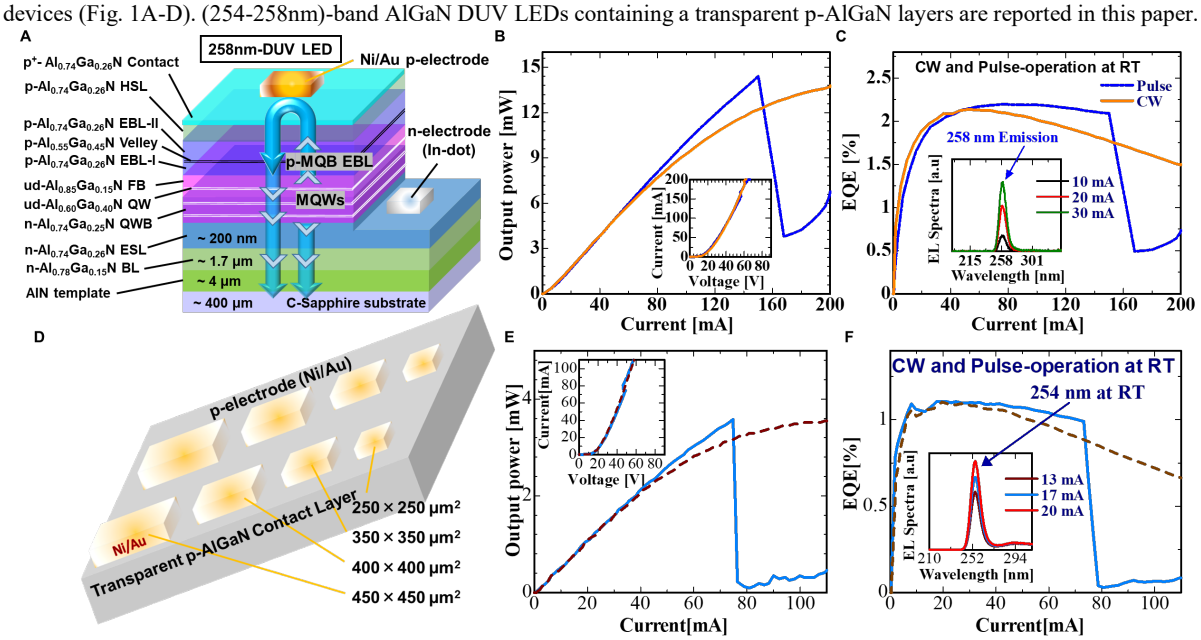

Fig. 1 (A) Schematic view of 258nm-band AlGaN-based DUV LED. Single peak ooperation of 258nm-band DUV LEDs, using highly transparent p-AlGaN contact layer with chip size 250×250 µm², (B). current vs output power (I-L) and I-V characteristic is given in the inset, (C) current vs EQE (I-EQE) characteristics and electroluminescence (EL) spectra at RT is shown in the inset, and (D) illustrated real image of the devices with chip size of 250×250 µm², 350×350 µm² 400×400 µm² and 450×450 µm² on p-AlGaN contact layer. Single peak operation of 254nm-band DUV LEDs, with chip size 250×250 µm², (B). I-L and I-V characteristic is given in the inset, and (C) I-EQE characteristics and EL spectra at RT is shown in the inset.

The DUV LEDs showed relatively improved efficiencies on wafer of 2.2% at 258 nm emission and 1.2% at 254 nm emission both under CW and pulse-operation, respectively (Fig. 1C-F). The light power of 14 mW and 3.8 mW, respectively, at 258 nm and 254 nm emissions, respectively, on wafer under pulse-operation were achieved (Fig. 1B-E). The DUV LED showed a relatively good electrical contact with operating voltage of 22 V at 20 mA (Fig. 1B-E), which is comparable with the p-GaN LED.

References

[1] H. Hirayama, N. Maeda, S. Fujikawa, S. Toyoda, and N. Kamata, Jpn. J. Appl. Phys. **53**, 100209 (2014).
[2] "UV LEDs – Market and Technology Trends" 2020 Report from Yole Développement (www.i-micronews.com).
[3] V. Adivarahan, W. H. Sun, A. Chitnis, M. Shatalov, S. Wu, H. P. Maruska, and M. Asif Khan, Appl. Phys. Lett. 85, 2175 (2004).