Exploring Highly Transparent p-AlGaN Layer for 304nm-Band UVB LED via Engineering of nanoPSS and Photonic Crystal

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High power AlGaN-based ultraviolet-B (UVB) light-emitting diodes (LEDs) at 290-310 nm emission light sources are strongly demanded for both medical and agricultural applications, including vitamin D_3 production in the human body, immunotherapy, and enriching phytochemicals in the plants. AlN template-based n-AlGaN buffer layer (BL) and n-AlGaN electron source layer (ESL) require a low dislocation density (TDDs) and cracks free surface underneath the multiple quantum wells (MQWs) for the fabrication of UVB LEDs. Recently, we investigated the influence of Al-graded p-type multi-quantum-barrier electron-blocking-layer (Al-grad p-MQB EBL) and Al-graded p-AlGaN hole source layer (HSL) on the generation and injection of 3D holes in the active region. Using the new UVB LED design, a significant improvement in the experimental external-quantum-efficiency (EQE) and light output power of about 8.2% and 36 mW is noticed [1]. This is accomplished by the transparent nature of Al-graded Mg-doped p-AlGaN HSL for 3D holes generation and p-MQB EBL structure for holes transport toward multi-quantum-wells via intra-band tunnelling. Based on both the numerical and experimental studies, the influence of sub-nanometre scale Ni film deposited underneath the 200 nm-thick Al-film p-electrode on the optical reflectance in UVB LED is investigated. A remarkable improvement in the efficiency (EQE) of up to 9.6% and light output power of 40 mW, even in the absence of standard package, flip-chip, photonic crystal (PhC)/nanoPSS, and resin-like lenses, is achieved on bare-wafer under continuous-wave operation at room temperature [1]. However, we can further enhance the light extraction efficiency (LEE) by exploiting a special design of PhC and nanoPSS [2] simultaneously in 304nm-Band UVB LED.

In this work, FDTD simulation model for nanoPSS in the C-Sapphire as well as Reflecting PhC in the p-AlGaN Contact layer of pure AlGaN based UVB LED was investigated, as shown in Fig. 1(A)-(B). For Reflecting-PhC simulation Plane wave expansion method (PWE) was used, where Phonic Band Structure of Hole (p-AlGaN full of Air), at λ: 304 nm was introduced, shown in Fig. 1(A)-(B). The Bragg`s condition is shown in the inset of Fig. 1(B), where m: order, neff: effective refractive index, λ: wavelength, and a: pitch. To determine the dimension of "d (= Rx2)" and "a" by the substitution some parameters for Bragg condition as shown in the inset of Fig. 1(A)-(B), can be realised using the value of R/a:0.33 up to 0.4 in PhC. The pitch (a), diameter (d) and height (h) were optimized for 304nm emission wavelength. For nanoPSS (hole-shaped), the order m = 10 with d = 596 nm, a = 746 nm, R/a =0.40, and height = 500 nm was found to be suitable. For PhC (hole-shaped), the order m = 3-4 with R/a =0.20-0.40, and height = 150 nm was precious. Consequently, the LEE was enhanced approximately to 140 % by using m: 3 and 4, respectively, in 304nm-Band pure AlGaN UVB LED, as shown in Fig. 1(B).

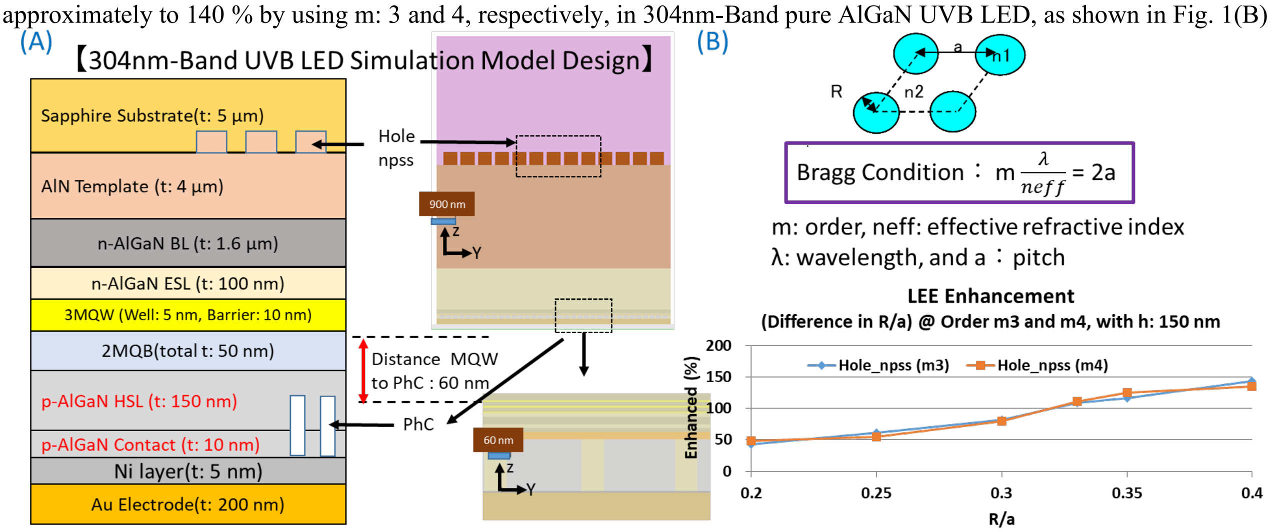

Fig. 1(A) Highly Reflecting Phonic Crystal Periodic Structure (PhC) was introduced in the p-AlGaN Contact layer as well as in nanPSS of 304nm-Band UVB LED, and (B) LEE vs R/a (the Bragg`s condition is shown in the inset).

References

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