Enhancement in light-extraction efficiency of deep ultraviolet light-emitting diodes by utilizing transverse-magnetic-dominant emission

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AlGaN-based deep ultraviolet (DUV) light-emitting diodes (LEDs) have attracted a great attention for their potential applications such as purification of air and water, sterilization in food processing, UV curing, medical-, and defense-related light sources [1]. However, external quantum efficiency (EQE) of AlGaN-based DUV LEDs is very poor particularly due to low hole concentration and light extraction efficiency (LEE) [2]. Conventional LEE-enhancing techniques used for GaInN-based visible LEDs turned out to be ineffective for DUV LEDs due to difference in intrinsic material property between GaInN and AlGaN (Al>~30%) [3]. Unlike GaInN visible LEDs, DUV light from a high Al-content AlGaN active region is strongly transverse-magnetic (TM) polarized, that is, the electric field vector is parallel to the (0001) c-axis and shows strong sidewall emission through m- or a-plane due to crystal-field split-off hole band being top most valence band [3,4]. Therefore, a new LEE-enhancing approach addressing the unique intrinsic property of AlGaN DUV LEDs is strongly desired.

In this study, we propose a new type of LEE-enhancing method for AlGaN-based DUV LEDs by utilizing its strong side emission, called sidewall-emission-enhanced (SEE) DUV LEDs [5]. The $Al_{0.55}Ga_{0.45}N/Al_{0.4}Ga_{0.6}N$ multiple quantum well LED structure with peak wavelength of ~280nm is grown by MOCVD on a c-plane sapphire substrate. The proposed SEE DUV LEDs include multiple narrow active-region mesa stripes with Al-based reflectors. The geometries of the SEE DUV LED are designed to extract the strong TM-polarized sidewall emission and to reflect UV photons, either up to the free space by Al-on-regrown-GaN reflector (top-emitting SEE DUV LEDs) or down to the free space by MgF_2/Al omnidirectional reflector on inclined surface of trapezoidal active mesa stripes (bottom-emitting SEE DUV LEDs). We experimentally observed that the light output power increases upon increasing the active-region sidewall perimeter, which is elucidated by the strong sidewall emission of the AlGaN active layer with high Al content. In addition, the operating voltage of SEE DUV LEDs is much lower than that of the reference, and decreases with increasing the active-region sidewall perimeter due to a less resistive n-contact on larger contact area. Therefore, the optically and electrically improved AlGaN DUV LEDs are demonstrated by means of a greater LEE and lower operating voltage. The effect of enhanced sidewall emission and the DUV reflection by the Al coated reflectors is analyzed by using finite element method and analytical modeling. Finally, strategies to further enhance the LEE up to the theoretical optimum value and control emission directionality are discussed.

References

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