Effect of 4µm-thick Buffer as well as 50% relaxed n-AlGaN Electron Injection Layer on the Performance of 308nm UV-B LED

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Eco-friendly, smart and high-power DUV and UV-B LED light sources on AlN template are strongly demanded for both medical and agricultural applications, including vitamin D3 production in the human body, immunotherapy, and enriching phytochemicals in the plants. AlN template-based n-AlGaN buffer layer (BL) and n-AlGaN electron injection layer (EIL) require a low dislocation densities (TDDs) and cracks free surface underneath the multiple quantum wells (MQWs) for the fabrication of LEDs. The crystal structure of AlN template grown on c-(0001)-sapphire substrates was improved using a well-known technique of "ammonia (NH_3) pulsed-flow multilayer (ML) growth" in Riken, where FWHM values of the XRCs for the (0002) and (10-12) planes approximately 200 and 350 arcsec, respectively (TDDs ~5×10^{8} cm^{-2}) were achieved [1]. But still the growth of $Al_{0.40}Ga_{0.60}N$ BL on AlN template, with x~0.40 Al-content for UV-B emission, can have a lattice mismatch >1.7% and subsequently can generate a huge number of vertically propagating TDDs in the n-AlGaN EIL underneath the MQWs and can deteriorate the internal quantum efficiency (IQE). Hirayama et al. successfully achieved the highest relative IQE of 86% at 280nm, using InAlGaN MQWs [1] and Wang et al. reported about high relative IQE of 85% in AlGaN MQWs at 280nm grown on AlN template having FWHM values of XRC for (002) and (102), namely 331 and 652arcsec [2]. Shatalov et al. also reported about the relative IQE of 60% in AlGaN MQWs at 278nm grown on AlN templates [3]. But when it comes to x=0.38-42 Al-contents for 295-310nm-band UV-B emission then the TDDs are relatively more challenging. Very recently we successfully achieve the relative IQE of 40-50% from the AlGaN UV-B LED using a 1.8µm-thick n-AlGaN BL and 200nm-thick n-AlGaN EIL (TDDs ~$1.4\text{-}1.1\times10^{9}$ cm^{-2}) with FWHM values for (102) plan respectively 590 and 579arcsec[4].

In this work, using the same growth condition as given in Ref [4] for 295nm UV-B emission, except the Si-doping level variation as well as thickness variation of n-AlGaN BL were revisited to investigate the effect of both on emission efficiency from UV-B MQWs. First 1.8µm-thick n-AlGaN BL and then a 200nm-thick n-AlGaN EIL over layer were grown on AlN template using Si flows of 0.1sccm (sample Ref, similar to the growth condition of Ref [4]) and confirm the relative IQE of 50% from AlGaN UV-B MQWs grown on the sample Ref. Next 3.2µm-thick n-AlGaN BL was grown on the AlN template and then subsequently a 200nm-thick n-AlGaN EIL using Si flows of 0.1 sccm (sample I) were grown on the overlayer. In this case a very high PL intensity was observed, but at the same time we encountered with perpendicular cracks to the radial direction on the surface of sample I. When we reduced the Si-doping level flows from 0.1 to 0.02 sccm in the 4µm-thick n-AlGaN BL and keeping the same level of Si flows of 0.1 sccm in the 200nm-thick n-AlGaN EIL (sample II), the cracks on the surface were eliminated and the n-AlGaN EIL layer were drastically relaxed from our previous value of 30% (Ref [4]) to 50% (this work) as shown in reciprocal space mapping (RSM) of Fig. 1(a). Subsequently the AlGaN MQWs (sample III) were grown on the over layer of n-AlGaN EIL (sample II), where the FWHM value of XRC for (102), was reduced to 549 arcsec. Thanks to the 4µm-thick and 50% relaxed n-AlGaN EIL layer, where a record PL emission intensity of 5×10^{7} [a.u] were achieved at low temperature in MQWs and finally the light power of UV-B LED at 308nm emission were improved from 8mW(previous) to 12mW, shown in Figs. 1(b)-(c). Single peak EL spectra under different dc drive were confirmed, shown in the inset of Fig. 1(c).

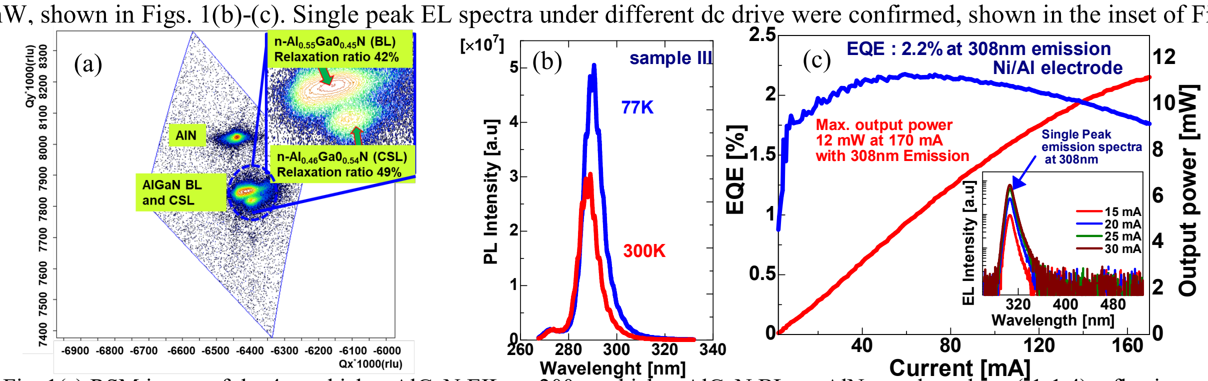

Fig. 1(a) RSM image of the 4µm-thick n-AlGaN EIL on 200nm-thick n-AlGaN BL on AlN template along (-1-1 4) reflection and (b) PL emission spectra of UV-B MQWs (sample III) for both at RT and LT, and (c) UV-B LED performance at 308nm emission.

References

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