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Marked efficiency enhancement of 222 nm AlGaN-based deep-UV LEDs for disinfection of SARS-2 (Covid-19)

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Abstract- **The AlGaN-based deep ultraviolet light-emitting diodes (DUV LEDs) for the disinfection of SARS-2 (Covid-19) are proposed in this study. The optoelectronic characteristics of DUV LEDs are numerically analyzed. The results show that the internal quantum efficiency (IQE) and radiative recombination rate are excellently improved in the proposed LED. This significant enhancement is due to the optimal recombination of electron-hole pairs in the active region. This is attributed to the increase of potential barrier height for electron, which suppress the electron leakage effectively. Moreover, due to the decrease of lattice mismatch between the last quantum barrier (LQB) and EBL ease the holes transportation to the active region. Therefore, based on these results, we highly believe that this study provides a novel approach for highly efficient DUV LEDs (222 nm) for the disinfection of severe SARS-2 (Covid-19) infection.**

Index Terms – SARS-2, 222 nm LED, Disinfection.

I. INTRODUCTION

III-Nitride-based DUV LEDs have potential due to their unique valuable features such as eco-friendly, cost-effectiveness, compact size, highly efficient, long life cycle, thermal and mechanical stability [1-3]. Due to these outstanding features, DUV LEDs use for many practical applications such as food sterilization, water/air purification, different medical equipment disinfection, medical usage, and even many researchers recently reported DUV for the disinfection SARs-CoV-2 (Covid-19) viruses [4, 5]. Due to these all remarkable features, III-Nitrides-based materials, alloys, and their devices e.g. LEDs and LASER, have been keenly followed and well-studied in the last two decades [6, 7]. In spite of this intensive research, the III-Nitride-based UV LEDs, especially DUV LEDs optoelectronic performance, are not comparable to their counterpart GaN-based visible LEDs [6]. The poor performance of UV LEDs due to many factors includes; in which the overflow of electrons, another critical issue, which is associated with the blockage of holes. This occur due to the two reasons, first is the lower thermal velocity of holes due to its higher effective mass as compared to the electron. Second the Mg-dopant activation energy rise with the increase of Al content, hence, the poor p-doping occur, especially in the Al-rich layers, leading to the lower concentration of holes. This creates the uneven distribution of carriers in the active region, which degrades the performance of UV LEDs, impressively. The induced electric polarization field are also hindering the holes transportation to the active region UV LEDs, which arises from the lattice mismatches between epi-layers [6]. In spite of many efforts, the carrier leakage is still a headache for the researcher and the main barrier in the development of efficient UV LEDs, especially DUV LEDs.

Inspired by the valuable features, of AlGaN-based DUV (222 nm) recently many researcher reported for the disinfection of SARS-2 (COVID-19) [1, 8]. Interestingly, the optoelectronic performance of this specific LED (222 nm) is not satisfactory. Therefore, in this article, we proposed a novel structure for the efficient DUV LED (222 nm). Based on our simulations results, the optoelectronic performance of DUV LED (proposed LED) improved effectively.

II. DEVICE STRUCTURE AND PARAMETERS

The AlGaN-based DUV LED represented by (LED A) is used as a reference LED in this study, which numerically simulated using the SiLENSe 5.14 [9]. The reference LED (LED A) comprises of a 3 μm wide electron injector n-$Al_{0.85}Ga_{0.15}N$ layer with doping concentration (1 x 10^{18} cm^{-3}) , the active region consists five pairs of undoped quantum well (QWs) and barrier ($Al_{0.83}Ga_{0.17}N$/ $Al_{0.92}Ga_{0.08}N$), followed by a 10 nm thick $Al_{0.96}Ga_{0.4}N$ EBL layer with doping concentration (1 x 10^{20} cm^{-3}). Two p-type layers i.e., $Al_{0.8}Ga_{0.2}N$ and GaN each having thickness of 50 nm and doping concentration (1 x 10^{20} cm^{-3}). The proposed LED represented by the (LED B) is identical to LED A except that the conventional EBL sandwich with AlN layer.

III. RESULTS AND DISCUSSION

Fig. 1 (a) illustrates the IQE profile for both LEDs. The peak IQE of LED A and LED B is ~36% and ~56%, respectively. The IQE of LED B is increased by 49% as compared to LED A. Interestingly, the efficiency droop is severely decreased in LED B as compared to LED. Fig. 1

(b) shows the radiative recombination rate at 70 A/cm^2. The electron-hole pairs radiative recombination for LED B is impressively increased almost by 90% when compared with LED A. It is because of the optimal recombination of electron-hole in the active region of LED. The enhancement in IQE and radiative recombination are very clear. So, it is evidence that the optical performance of LED B (proposed structure) is improved because of the sandwiching of EBL with AlN layer.

Figure 1(c) presents the spontaneous emission spectra as a function of wavelength at 70 A/cm^2. Both LEDs exhibit the optimal peak wavelength ~222 nm, which is in the range of DUV spectrum. It also indicates that the AlN layer has no effect on the peak emission wavelength. It is worth noting that the minute blue shift in LED NIII (0.057 nm) is due to the lowering of quantum confinement stark effect (QCSE) due to lower electrostatic field at the interface of LQB and EBL [8]. The emission spectra of LED B impressively enhanced as compared to LED A. This enhancement is attributed to the higher recoupling of electron-hole pairs in the active region of LED B.

Figure 1(d) presents the I-V characterization of both LEDs. The forward voltage of LED B slightly increased as compared to LED A. It is assigned to the hindering of the carriers effectively due to the increase of effective potential barrier height as compared to LED A.

IV. CONCLUSION

We have proposed the AlGaN-based DUV (222 nm) and investigated the effect of EBL sandwich with AlN on its optoelectronics behavior numerically. The results show that our proposed structure improved the recombination of electron-hole pairs in the MQWs, because of reduced polarization which attributed to lattice matching. This not only ameliorated the IQE but also severely reduced the efficiency droop as compared to LED A. So, we highly believe that this approach provides a guideline to the researchers for achieving high IQE as well as near-droop-free efficiency DUV LEDs for the disinfection of severe SARS-2 (Covid-19).

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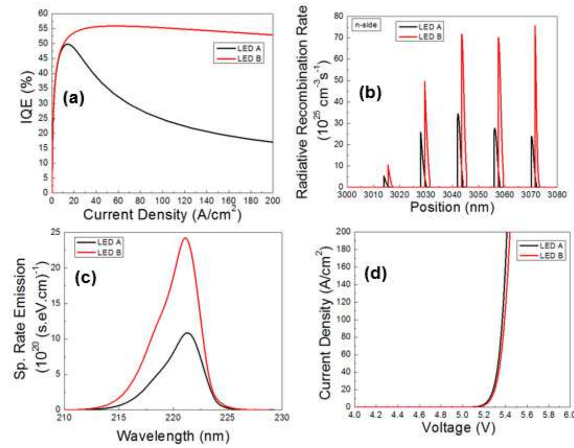

Fig.1 (a) IQE, (b) radiative recombination rate, (c) emission spectra, (d) IV characteristics of both LEDs

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