Enhanced optoelectronic properties of UV-C light-emitting diode

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***Abstract*— We numerically analyzed proposed structure named as LED S2 in comparison to reference structure LED S1. In LED S2 we introduced undoped AlGaN and p-AlGaN layers between the electron blocking layer (EBL) and the p-GaN (hole injecting layer). The simulation finding shows proposed structure (LED S2) provide a better strategy for lowering electron overflow and improving hole strength. This enhancement in the properties is the result of maximum recombination of carriers (electron/hole) in the active region. Furthermore, the mismatch between the epi-layers on the p-side reduces, allowing holes to easily move towards the active region.**

Keywords— IQE, Electric field, Un-doped AlGaN.

I. INTRODUCTION

DUV LEDs based on III-Nitride materials have a lot of potential because of their special characteristics, such as low power consumption, small size and low weight while maintaining high efficiency and mechanical and thermal stability [1-3]. Due to their unique properties, UV LEDs can be used in practical applications, including food sterilisation, water and air purification, disinfection of various medical equipment [4, 5]. Various factors influence the UV LEDs performance which includes the overflow of electrons from the active region and also the holes blockage. These results occur due to the following two causes. Firstly, the hole thermal velocity is lower than that of electron thermal velocity because their effective mass is high. Secondly, the activation energy of Mg-doped layers increases with increase in the Al concentration, which results in poor injection of holes. Furthermore, an unequal concentration of carriers in the active region occurs which significantly lower the UV LEDs performance. Another critical issue which hinders the hole transportation toward the active region is the polarization field which is due to lattice mismatches that occur between epi-layers [6]. Besides, reducing carrier leakage remains a challenging task for researchers and it is the primary barrier that decreases the efficiency UV LEDs. To overcome the above-mentioned problems, we present a highly efficient UV LED structure (LED S2). According to our findings, the performance of the LED S2 is significantly improved.

II. DEVICE STRUCTURE AND PERAMETERS

The reference structure marked as LED S1 consists of a 300 nm electron injecting n-$Al_{0.55}Ga_{0.45}N$ layer with a doping concentration of (5 x 10^{18} cm^{-3}). The active region comprises of five pairs of quantum wells/barriers ($Al_{0.45}Ga_{0.55}N$/ $Al_{0.55}Ga_{0.45}N$), followed by a 15 nm thick $Al_{0.65}Ga_{0.35}N$ EBL layer (Mg-doping 5 x 10^{19} cm^{-3}). Lastly, we used hole injecting layer, i.e., GaN having 100 nm thickness (Mg-doping 1 x 10^{20} cm^{-3}). Furthermore, LED S2 (proposed LED) is similar to LED S1 except the two AlGaN undoped and doped layers sandwiched between EBL and p-GaN. SiLENSe^{TM} 6.13 is used to simulate this structure numerically.

III. RESULTS AND DISCUSSION

The comparison of IQE for both LEDs is illustrated in Fig. 1. The LED S1 has a peak IQE of ~32%, whereas LED S2 has a peak IQE of ~44%. Interestingly, along with peak IQE, the efficiency droop of LED S2 is also improved as compared to LED S1 as shown in Fig. 1.

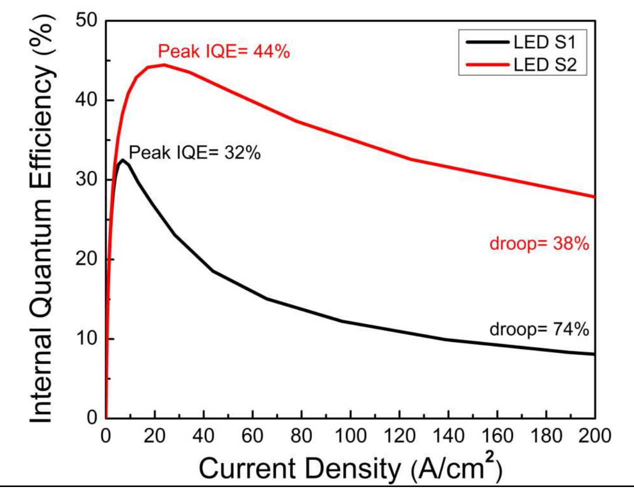

Fig.1 Comparison between IQE of LED S1 and LED S2.

Fig. 2 shows the emission intensity for both LEDs. Both LEDs have a peak wavelength of 275 nm which is in the UV spectrum range. In addition, the intensity of LED S2 is improved impressively when compared to reference LED S1. This improvement occurs due to the maximum recombination of carriers (electron/hole) in the multi quantum wells.

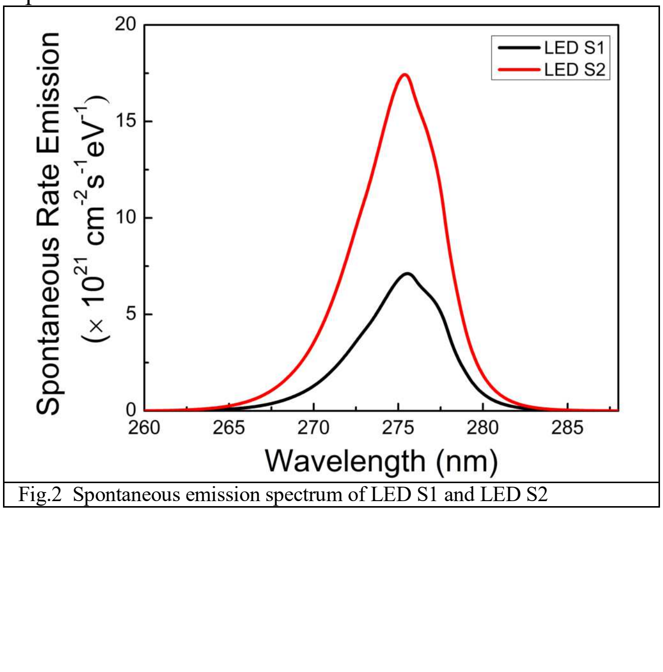

Fig.2 Spontaneous emission spectrum of LED S1 and LED S2

In Fig. 3, the average electric field between EBL and p-GaN for LED S1 and LED S2 are -1.01 V/cm and -0.54 V/cm respectively. From Fig. 3, the electric field in the selected region for LED S2 is weaker than that of LED S1. In addition, the lower negative electric field between EBL/p-GaN of LED S2 results in low charge density. As a result, high recombination of carriers occurs and the performance of LED S2 increases.

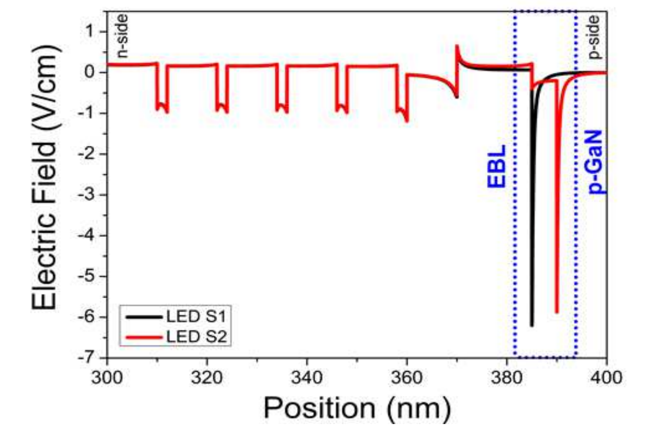

Fig.3 Comparison of Electric field of two LEDs.

Fig. 4 presents the radiative recombination rate for the given two devices at 90 A/cm^2. The radiative recombination rate for LED S2 is increased by ~70% in contrast to LED S1 which is due to overlapping of electrons and holes in the active area. The above discussion shows that, sandwiching two AlGaN layers in between EBL and p-GaN improves the optical performance of LED S2.

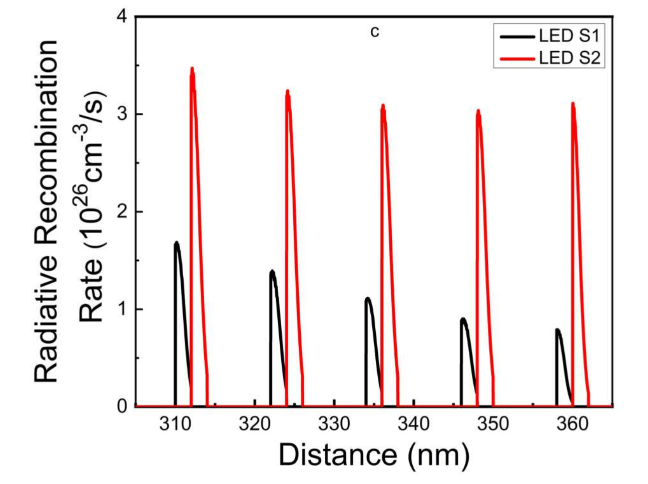

Fig.4 Radiative recombination rate of LED S1 and LED S2

IV. CONCLUSION

We numerically proposed and investigated the influence of undoped AlGaN and p-AlGaN layers on the performance of DUV LEDs. The simulation results shows that the optoelectronic properties of LED S2 are improved due to a reduction in polarization which decreases the lattice matching. Therefore, we think that LED S2 may help the researchers in order to achieve efficient DUV LEDs.

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