Engineering the Active Region to Enhance the IQE by ~8% in AlGaN/GaN based UV-C LED

Jayant Acharya*, Sugandham Venkateshh*, Kankat Ghosh#
Department of Electrical Engineering, IIT Jammu, Jammu, J&K-181221, India
*Equal Contribution, #Corresponding Author: kankat.ghosh@iitjammu.ac.in

***Abstract*- To increase the internal quantum efficiency (IQE) of AlGaN/GaN based multi quantum-well (MQW) UV-C LED, the aluminium composition of barriers and wells in the active region has been engineered. Increase in electron-hole overlap and hence the radiative recombination rate in the final engineered structure has enabled to enhance the IQE by 8%.**

I. Introduction

Over the last decades, significant research attention has been developed in III-nitride UV LEDs as they possess a number of properties that are not accessible in any other semiconductors. III-nitrides have some unique properties which include high dielectric breakdown voltage and wide range of bandgap that spans from the infrared to the deep ultraviolet regions. AlGaN ternary alloy has a direct-bandgap which is tunable between 3.43 eV and 6.11 eV and is suitable for the fabrication of optical devices with a wavelength range between 200 nm and 365 nm [1]. Also, as people have become more concerned about environmental protection, UV-C LEDs gained importance as they replaced traditionally available mercury based UV-lamps and thereby reducing production, use and trade of mercury [2]. UV-C LEDs that emit radiation in the range of 260-280 nm are used for disinfection. In this paper we would like to increase the internal quantum efficiency (IQE) of UV-C LED that emits radiation around 267 nm.

II. Device Structure And Parameters

The design of UV-C LED structure reported by SaifAddin Burhan K et al. [3] has been taken as a reference. In our structure(Fig.1), sapphire has been chosen as substrate upon which, there is a buffer layer of AlN and n-type Si-doped $Al_{0.65}Ga_{0.35}N$ of 550nm thickness with doping concentration $1x10^{18}/cm^3$ followed by a 14nm thick undoped $Al_{0.65}Ga_{0.35}N$ between the n-layer and the active region. The active region consisted of three periods of multiple quantum-well (MQW) structure consisting of 2.8nm thick $Al_{0.55}Ga_{0.45}N$ quantum well and 9nm thick $Al_{0.65}Ga_{0.35}N$ barrier and is followed by a final quantum barrier of 19nm thick undoped $Al_{0.65}Ga_{0.35}N$. The structure contained an electron blocking layer (EBL) of 2.7nm p-type Mg-doped $Al_{0.89}Ga_{0.11}N$ which is followed by a 50nm p-type Mg-doped $Al_{0.65}Ga_{0.35}N$ of doping concentration $1x10^{17}/cm^3$. Finally a p-GaN of 5nm thickness and a doping concentration of $1x10^{18}/cm^3$ is used as the cap layer. The considered values of electron and hole mobilities are 100 $cm^2/V.s$ and 10 $cm^2/V.s$ respectively [4]. Here, the activation

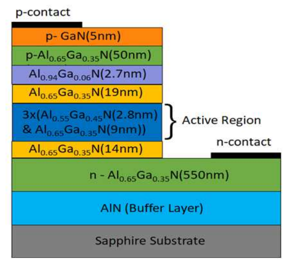

Fig. 1. Device Structure

energy for n-$Al_{0.65}Ga_{0.35}N$ is considered 25 meV and that of p-GaN is 170 meV, p- $Al_{0.65}Ga_{0.35}N$ is 380meV and p-$Al_{0.89}Ga_{0.11}N$ is 470meV as mentioned by hasan et al.[5]. The structure is simulated using One Dimensional Poisson, Drift-Diffusion, and Schrodinger Solver (1D-DDCC) software [6].

III. Results And Discussion

Poor carrier injection and high defect densities cause low performance characteristics of UV-C LEDs compared to visible LEDs. One way to improve efficiency is to increase the radiative recombination rate. For that quantum wells in active region are graded to enhance the performance of UV-LED [7]. In this paper, we would like to grade the barriers along with the

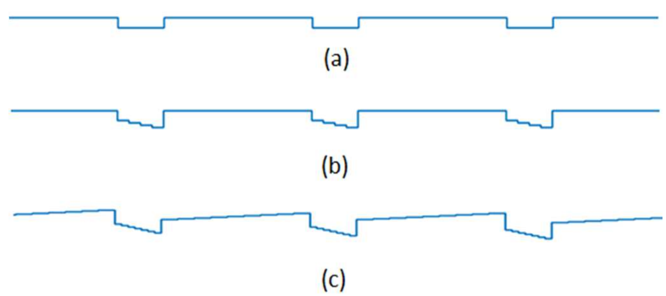

Fig. 2 (i). Reference and engineered conduction band profiles in active region

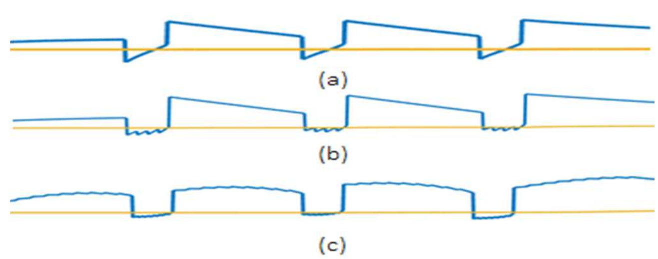

Fig. 2 (ii). Conduction band diagrams of reference and engineered active regions at a current density of 12 A/cm^2

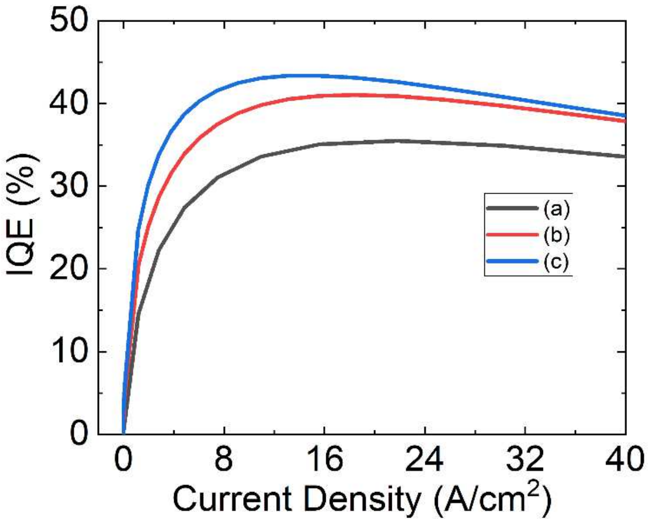

Fig. 3. IQE vs Current Density

wells to improve the internal quantum efficiency by increasing radiative recombination rate of UV-C LED. As shown in shown in fig.2 (i), in the reference structure (a) the Al composition is constant in both the well and barrier, in the structure (b), Al composition is varied in the range of 0.57 to 0.51 in the quantum wells and in the structure (c) Al composition is varied in both well and barrier, from 0.61 to 0.69 in barrier, i.e., 0.65 to 0.69 in first barrier (towards p-layer), 0.63 to 0.67 in second and third barriers and 0.61 to 0.65 in the last barrier(towards n-layer). Al composition is also varied in the range of 0.57 to 0.51 in the quantum wells. The band profiles of all the three structures at 12 A/cm^2 (corresponding to maximum IQE) are shown in the fig.2 (ii). The result shows that in case of structure (a) the quantum wells are not flat which is improved in structure (b) where the decrease of Al composition in quantum wells has resulted in flat well. In structure (c), with the decrease and increase of Al composition in wells and barriers respectively, both wells and barriers got flattened. As the wells and barriers of conduction band get flattened, e-h overlap increases and thereby increasing the electron-hole radiative recombination as evident in figure 4. This helps in increasing the IQE as depicted

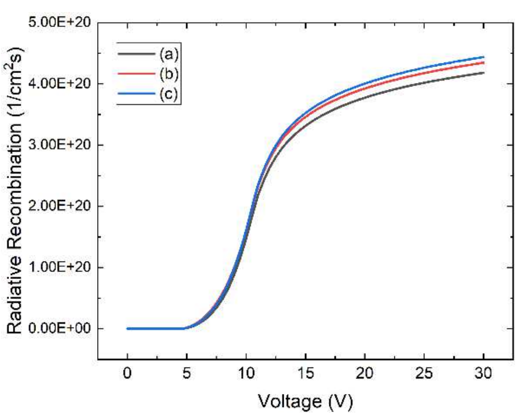

Fig. 4. Radiative Recombination Rate vs Voltage

in figure 3. We observe that Structure (c) has a maximum IQE of 43.37% as compared to that of structures (a) & (b) which have IQE of 35.49% and 41.05% respectively. Thus we achieve an increase of IQE by ~8% from the reference structure (a) to the finally engineered structure (c).

IV. Conclusion

With grading of barriers and wells in the active region, significantly improved IQE is achieved compared to only grading in quantum wells. Thus, structure (c) has improved the optoelectronic performance of AlGaN-based UV LED by improving e-h overlap and hence radiative recombination rate in the active region than the structures (a) & (b). The proposed structure (c) may be used for growth of UV-C LED to realize the improved IQE.

Acknowledgement

The authors would like to acknowledge the group of Dr. Yuh-Renn Wu, National Taiwan University for making the DDCC software available online free of cost. The authors would also like to acknowledge the Department of Electrical Engineering, IIT Jammu for providing the necessary infrastructure to carry out the research work.

References

[1] Michael Kneissl, Jens Rass, III-Nitride Ultra Violet Emitters, Springer International Publishing Switzerland, 2016.

[2] Nagasawa, Y.; Hirano, A. "A Review of AlGaN-Based Deep-Ultraviolet Light-Emitting Diodes on Sapphire," Appl. Sci., Vol. 8, p 1264, 2018.

[3] SaifAddin Burhan K. and Almogbel, Abdullah S. and Zollner, Christian J. and Wu, Feng and Bonef, Bastien and Iza, Michael and Nakamura, Shuji and DenBaars, Steven P. and Speck, James S, "AlGaN Deep-Ultraviolet Light-Emitting Diodes Grown on SiC Substrates," ACS Photonics, Vol.7, pp.554-561, 2020.

[4] Hasan, Md & Mehedi, Ibrahim & Reza, s.M. & Kaysir, Md. Rejvi & Islam, Md., "Analytical investigation of activation energy for Mg-doped p-AlGaN," Optical and Quantum Electronics, Vol. 52, p 348, 2020.

[5] S.Pearton, GaN and ZnO-based Materials and Devices, Springer BerlinHeidelberg, 2012.

[6] http://yrwu-wk.ee.ntu.edu.tw/index.php/ddcc-1d/

[7] Ramit Kumar Mondal, Vijay Chatterjee, Suchandan Pal, "Correlation between performance and compositional grading in quantum well of deep UV-LED," Optik, Vol.210, p 164510(1-8), 2020.