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Simulation Analysis of AlGaN/BGaN Based Deep Ultraviolet-A Light Emitting Diodes with Graded Step Electron Barrier Layer

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Abstract

This study designs and analyses step-graded alternating barriers of Aluminum Gallium Nitride/Boron Gallium Nitride (AlGaN/BGaN) in the multiple quantum well (MQW) light-emitting diodes (LEDs). The graded stepwise electron blocking layer (EBL) was introduced in DUV (Deep-ultraviolet)-LED with a luminosity wavelength of 360 nm(EBL). The silicon carbide substrate used in the device is also significant for the device's better optical performance owing to its reduced polarization effect, improved crystal structure, and high thermal conductivity.

Keywords

Boron, GaN, Light-emitting diodes, AlGaN, Multiple quantum well

Introduction

AlGaN-based DEP-LEDs have become popular in recent years due to their protection in the environment, high reliability, quick response, less power consumption, and lightweight portable structure. They are also used extensively in the fields of light curing, sterilization, and disinfection of viruses and germs [1-4]. DUV-LED irradiation has drawn increased attention as a more eco-friendly, secure, and safe disinfection treatment since the COVID-19 epidemic in 2019 [5, 6]. The COVID-19 virus has been shown to be killed by UV-LED irradiation in under one second [7]. DUV-A LEDs have many pros, but there are also a lot of drawbacks when it comes to research and development, including challenges with chip packaging and epitaxial growth, light extraction rates, and both internal and efficiencies below 20% of the conventional LED. For these reasons, it is challenging to widely utilize DUV-LEDs. Aluminum is typically doped with GaN during the epitaxial growth process in order to widen the bandgap and reduce the luminescence wavelength. Although a rise in the aluminum concentration in quantum wells (QWs) increases the dislocation density also has a large polarization impact that lowers the recombination rate of the radiative factor [8].

In contrast, the magnesium acceptor's activation energy is about 500 meV in p-type doped AlGaN based DUV- LEDs, making it harder to activate, directly contributing to a poor hole-injection rate. Additionally, one of the factors contributing to the poor performance of DUV LEDs is a significant electron leakage caused by a mismatch in the carrier injection [9] and by the effects due to polarization [10]. One of the main issues with using DUV LEDs is the efficiency reduction resulting from all these problems. Peak EQE for AlGaN-based DUV LEDs occurs at currents under 20 mA, and as the current increases, the efficiency rapidly declines [11-13].

One typical approach to reducing electron leakage is to add a layer of AlGaN with a larger bandgap between the p-region and the quantum barrier in the last (LQB) to control spill-over issues in the active region. But this approach has several drawbacks. The lower energy band corner of the LQB/EBL interface drops when positive polarization charges are present, which is not advantageous for preventing electron leakage. Since a higher aluminum component causes a stronger charge polarization and a larger energy band drop, increasing the aluminum component of the EBL is not very effective [14].

Additionally, the EBL has an impact on the injection of holes even if it can successfully confine electrons to the active zone. Designing EBL structures may improve hole injection and electron blocking. The EQE is now around 20%, and the efficiency of DUV-LEDs are at lesser levels [15]. Numerous studies have looked at solutions to the issue, suggesting EBL structures through simulations and experimental research, to stabilize the electron and hole concentration.

With the help of simulations, So et al. looked into the issues of a step graded EBL design on a DUV-LED. The results depict that the device significantly outperforms a DUV-LED with a conventional EBL structure in terms of performance [16]. Mondal et al. improved the EBL structure by including a step superlattice structure to enhance the performance of a DUV-LED. Simulation studies showed the new structure's intensity of the quantum efficiency (IQE) improved by 15% and its efficiency droop drop by 15% when compared to the normal EBL structure at a 70 A/cm^2 current density [17].

Wang et al. developed an EBL with W-shape and an M-shaped hole-blocking region in order to enhance the recombination rate of radiative factor and efficiency [18]. Shi et al. created an irregular sawtooth hole barrier layer and EBL to regulate the distribution of carriers, enhance the recombination rate of the radiative factor, and increase the IQE [19]. By reducing electron carrier leakage in the p-side and increasing the holes injection into the recombination area, all of the aforementioned topologies increase the recombination rate and efficiency.

Experimentation

Device structure

Figure 1 depicts a GaN LED representation. Doping of p-type AlGaN barrier is at a range of 5 x 10^{19} cm^{-3} is present at the anode area of the LED, which typically has a GaN cap of about 100 nm thickness. As a result, EBLs are roughly 300 nm thick. As a result, 4 GaN layers with 3 nm thick BGaN well layers are used to create 4 QWs. AlGaN barrier layers that are 7 nm thick are also formed in the structure furthermore to this effect. A 3 x 10^{18} cm^{-3} n-doped GaN layer and an AlGaN layer with a thickness of 100 nm are produced in the cathode region. As a result, the contact terminals of the LEDs are connected to n- and p-doped GaN, respectively. GaN LEDs p-doped and n-doped anodes and cathodes serve as the ohmic contact points. The GaN well is positioned to contain the electrons. The trapping effect must be considered for better optical and electrical parameters of the result [19]. Table 1 presents device parameters with dimensions.

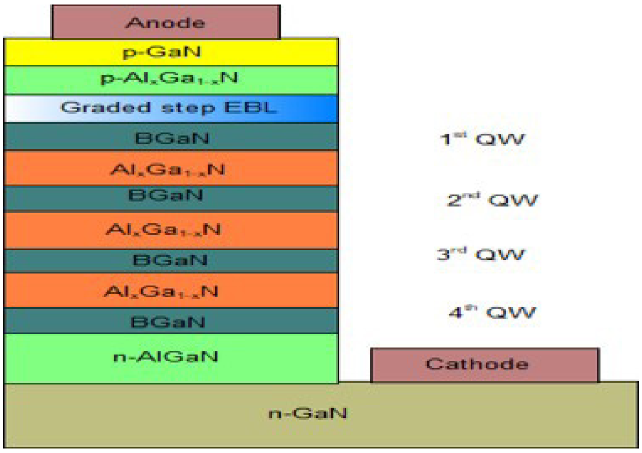

Figure 1: Schematic representation of AlGaN/BGaN MQW LED.

Table 1: Device parameters with dimensions.

Parameter	Dimensions
GaN cap layer	100 nm
p-GaN barrier	300 nm
Graded step EBL	30 nm
GaN well	3 nm
AlGaN barrier	7 nm
n-AlGaN	100 nm
n-doping	3 x 10^{18} cm^{-3}
p-type doping	5 x 10^{19} cm^{-3}

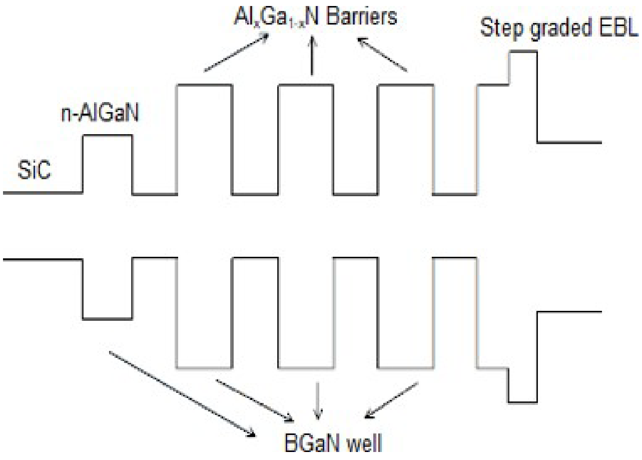

Figure 2: Proposed structure of the MQW-LED structure with step-graded EBL.

Figure 2 presents proposed structure of the MQW-LED structure with step-graded EBL. A 50 nm p-type GaN capping region is placed above the active region with a magnesium concentration of 5 x 10^{19} cm^{-3} and a 30 nm thick p-type Al$_{0.15}$Ga$_{0.85}$N EBL is deposited. Other material characteristics for the study are derived from [20], and the device dimension is proposed in a rectangular shape measuring 1 x 1 mm.

Results and Discussion

Figure 3 depicts the luminance power relative to the anode voltage. The anode voltage causes a rise in the observed luminous power. Figure 4 shows the power spectral density over the emission wavelength. A top point in the power spectra

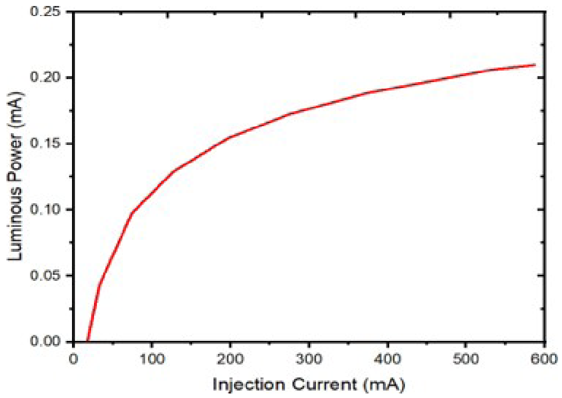

Figure 3: Injection current (mA) vs Luminous power (W).

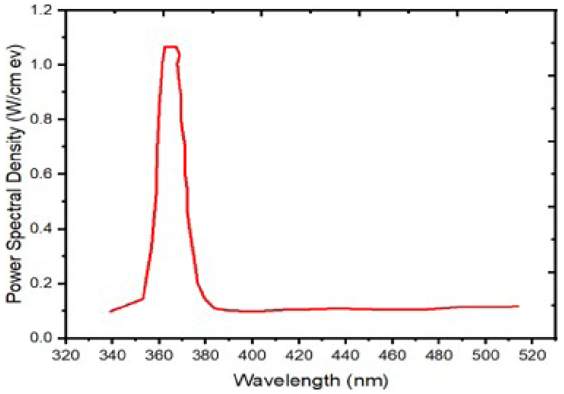

Figure 4: Wavelength (W/cv.ev) vs Power spectral density (W/cm.ev).

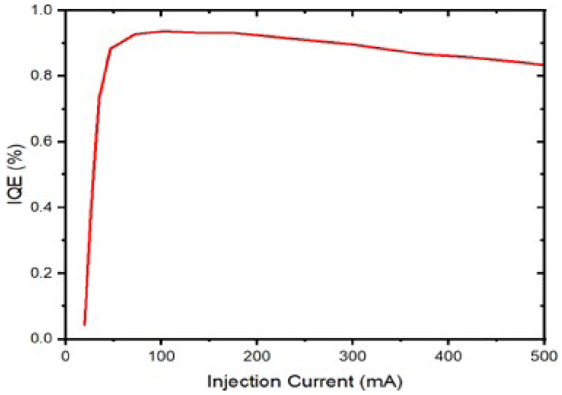

Figure 5: Injection current (mA) vs IQE.

is seen at 360 nm in wavelength. The UV emission of photons from the boron-based GaN well LED device is shown by the spike at 360 nm [21-22]. Figure 5 shows the IQE of a step graded BGaN well LED.IQE increases with injection current when the injection current is low. It then reaches saturation and exhibits efficiency droop.

Conclusion

The LED with boron-doped GaN QW and step-graded EBL was studied in this article. A TCAD simulator is used to investigate the LED, and performance is examined. Simulation results depict the high hole injection due to the p-type GaN barrier near step graded EBL in the device design, which reduces the lattice mismatching between boron based GaN QW and AlGaN step-graded EBL. Therefore, the boron doped GaN LED is an excellent device for lighting applications.

Acknowledgements

None.

Conflict of Interest

None.

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