Design Analysis of Linear Graded Quantum barriers in Ultavoilet-C Laser Diodes

Shazma Ali
[a]Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi, 23460, Khyber Pakhtunkhwa, Pakistan.
alishazma1998@gmail.com

Muhammad Usman[a]*
Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi, 23460, Khyber Pakhtunkhwa, Pakistan.
m.usman@giki.edu.pk

Sana Saeed
Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi, 23460, Khyber Pakhtunkhwa, Pakistan.
sanasaeed400721@gmail.com

Abstract—**We demonstrated ultraviolet laser diode with improved optical and electrical features. By employing linear graded rising aluminium concentration in phases from first quantum barrier to last quantum barrier, the suggested LD design improves internal quantum efficiency (IQE) and output power while minimizing the lasing threshold. The proposed LD increases optical gain while lowering carrier leakage from the active region. This study demonstrates high-efficiency AlGaN-based ultraviolet laser diodes with high optical gain and output power.**

Keywords— Ultraviolet-C, AlGaN, Laser Diodes

I. INTRODUCTION

III-Nitride laser diodes (LDs) are promising candidates for general lighting, laser projectors, data storage devices [1]. Because of their high mobility, electrons travel quickly towards the active region and may penetrate the p-region, resulting in low internal quantum efficiency (IQE) and decreased device power [2]. The Mg-doping in p-layers that effects the injection of holes in active region is another major issue in DUV laser diodes [3]. Designs such as Superlattice Last Quantum Barrier [4] and sandwiched GaN/AlGaN/GaN lower quantum barrier [5] have been reported to overcome these issues.

In this work, we proposed LD design with linear-graded aluminum content increasing in steps from first barrier to last barrier. This schematic design shows improved efficiency, optical gain and power of the device.

II. DESIGN AND SIMULATION TOOL

The proposed structure is designated as LD G2 and the reference structure is designated as LD G1. LD G1 consists of a 100 nm thick $Al_{0.69}Ga_{0.31}N$ layer, 700 nm thick $Al_{0.68}Ga_{0.32}N$ cladding, and 30 nm $Al_{0.6}Ga_{0.4}N$ waveguide. All n-layers have silicon doping of 1×10^{18} cm^{-3}. The active zone has four 3 nm thick multiple quantum wells (MQWs) ($Al_{0.45}Ga_{0.55}N$) with five 8 nm thick quantum barriers ($Al_{0.55}Ga_{0.45}N$). The p-region contains a 30 nm $Al_{0.6}Ga_{0.4}N$ waveguide, a 10 nm thick $Al_{0.78}Ga_{0.4}N$ electron blocking layer (EBL). Both layers have Mg-doping of 5×10^{19} cm^{-3}. A 200 nm p-$Al_{0.68}Ga_{0.32}N$ cladding (5×10^{20} cm^{-3}) and a 50 nm p-$Al_{0.69}Ga_{0.31}N$ layer (5×10^{20} cm^{-3}). We utilized the linear-graded quantum barriers with increasing Al concentration as shown in Table 1. The cavity length of both LDs is 1500 μm. We used SiLENSe™ 6.4 to examine both structures numerically. Table.1 represents Al concentration in barriers.

Barriers	Linear-graded Al concentration (%)
1	63-67
2	67-71
3	71-75
4	75-79

III. REDULTS AND DISCUSSION

The IQE versus current density plots of LD G1 and LD G2 is depicted in Figure 1. The IQE peak of LD G1 is 44% while that of LD G2 is 49%. The droop in efficiency is reduced from 54% (LD G1) to 12% (LD G2). The linear-graded Al concentration in steps from n to p direction results in high carrier confinement in MQWs. The inset represents the injection efficiency of both LDs. The injection of carriers is high in LD G2 as compared to LD G1. The high injection means that there is less leakage from the active region. The reduced leakage and high injection results in high IQE in LD G2.
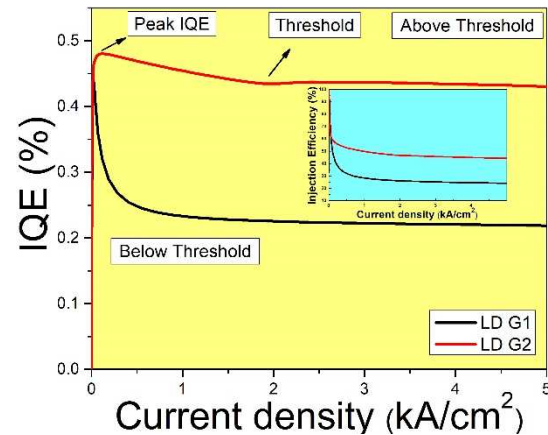

Fig. 1. IQE versus current density profiles

Figure 2 shows the optical gain profiles of LD G1 and LD G2. LD G2 has a higher peak gain than LD G1. The shift in wavelength from 267 to 273 nm is due to variation in the band gap energy of epitaxial layers in the active zone caused by graded Al concentration in steps. Stimulated recombination occurs at the lasing condition (threshold current density), resulting in a positive gain. LD G2 enhances optical confinement, resulting in high optical gain and a low lasing threshold.
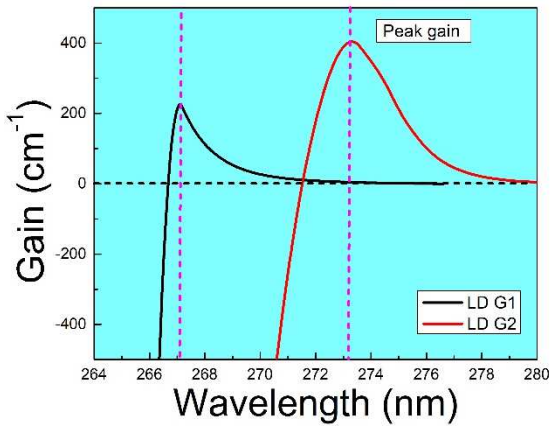
Fig. 2. Gain profiles of LD G1 and LD G2.

Figure 3 shows the carrier current density near the active zone of LD G1 and LD G2. The electrons from the n-region are pumped into the MQW and recombine with holes in quantum wells, resulting in a reduced electron current density in the quantum well profile.
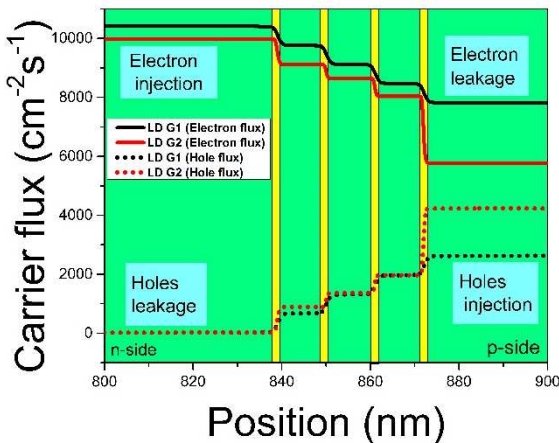

Fig. 3. Carriers flux versus position plots of LD G1 and LD G2.

The reduction in electron current density from the n-region to the p-region is also higher because more carriers contribute to the radiative recombination rate. In LD G1, electron leakage is greater than LD G2. LD G2 also has a high injection of holes than LD G1.

Figure 4 shows the output power versus current charts of LD G1 and LD G2. In MQWs, carrier recombination increases as the current increases. The proposed LD G2 lowers the threshold current to 57 mA. In LD G2, the slope efficiency increases from 0.50 W/A to 1.22 W/A. Due to its high optical

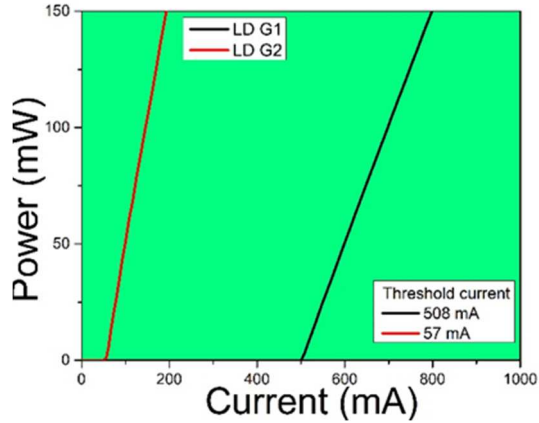gain, the proposed LD G2 has a low lasing threshold, resulting in enhanced slope efficiency.

Fig. 4. Power versus current plots of LD G1 and LD G2.

CONCLUSION

We studied the effect of linear-graded barriers on the performance of ultraviolet laser diodes. In our suggested structure, IQE and gain is enhanced greatly with reduced lasing threshold and enhanced slope efficiency. As a result, linear graded barriers are considered to be essential in the development of DUV III-Nitride Laser diodes.

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