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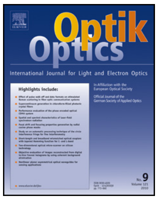

Dependence of output emission wavelength and LD performance on barriers material and thickness

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ABSTRACT

The output emission wavelength of MQW LDs depends on several structural and operating parameters such as the number of QWs, QW and barrier thickness, and material compositions which constitute the active region, operating current, and others. However, output emission wavelength mostly depends on the active region parameters like the thickness and In composition in wells and barriers. In this paper, effect of barriers material and thickness on the performance characteristics of deep violet InGaN DQW LDs were numerically studied. The simulation results demonstrate that output emission wavelength of a particular InGaN LD at different In compositions in the QWs (0.08 to 0.10) and barriers (0.0 (GaN), 0.01, and 0.02) is limited between 388 nm and 398 nm when the In mole fraction of the barriers is 0.0 (GaN). Likewise, output emission wavelength is limited between 391.7 nm and 421.0 nm, and 394.2 nm and 428.2 nm when the In mole fraction of the barriers is 0.01 ($In_{0.01}Ga_{0.99}N$) and 0.02 ($In_{0.02}Ga_{0.98}N$), respectively. Furthermore, the results indicated that by increasing barrier thickness, slope efficiency, output power, and DQE decrease, while threshold current increases. Increasing barrier thickness increased strain and piezoelectric fields in wells, thus resulted in an increasing electric field in the active region which helped increase nonradiative recombination and decrease radiative recombination in wells. The results also showed that optical characteristics decline with decreasing barrier thickness less than the critical thickness. Induced quantum-confined Stark effect (QCSE) in this situation resulting from the piezoelectric effect causes threshold current to increase, and output power, slope efficiency, and DQE to decrease.

1. Introduction

III–V nitride semiconductor materials are attracting much attention in optical and electrical application for research filed and commercial purpose [1–5]. Especially, the InGaN/GaN MQWs are widely used as the active layer in violet, blue, green LED and LD applications. The output emission wavelength of MQW LDs depends on several structural and operating parameters such as the number of QWs, QW and barrier thickness, material compositions which constitute the active region, cavity length, operating temperature, operating current, and others. However, output emission wavelength mostly depends on the active region parameters. Output emission wavelength of InGaN DQW LDs depends mainly on the thickness of InGaN QWs and In composition in wells and barriers [6]. Although laser action takes place in the wells, the barrier layer is used to prevent coupling between adjacent wells. Therefore, barrier thickness and composition are among the important structural parameters that affect optical and electrical properties of InGaN MQW devices [7,8]. Experimental results show that increasing barrier thickness causes an increase in threshold current and a decrease in output power. This result can be attributed to reduced radiative recombination and enhanced nonradiative recombination in the active region with a thicker barrier [9,10]. The effects of barrier thickness on performance characteristics of InGaN MQW devices, such LEDs and LDs, have been experimentally and theoretically studied by several groups of researchers for different wavelengths [9,10]. But in the best of authors knowledge, the barrier effects on the performance characteristics of deep violet InGaN DQW LDs has not studied comprehensively.

In this paper, performance characteristics of InGaN DQW LDs have been numerically investigated to obtain a desired output emission wavelength in the deep violet region of the electromagnetic spectrum. In addition, the effects of barrier thickness on performance characteristics of deep violet $In_{0.082}Ga_{0.918}N$/GaN

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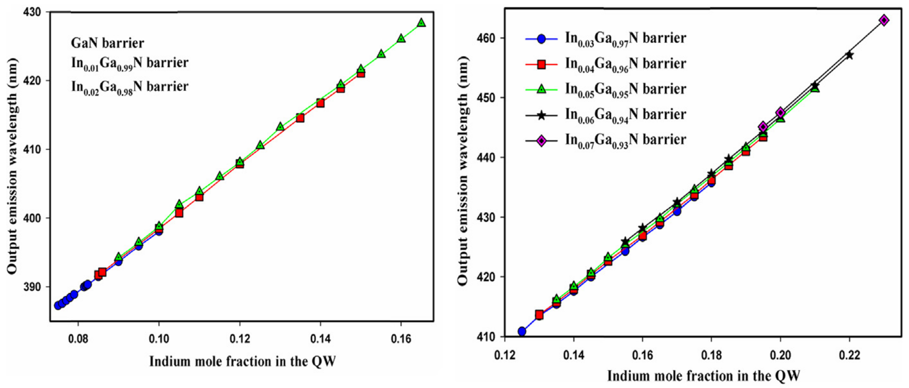

(a) (b)

Fig. 1. Output emission wavelength of InGaN DQW LDs at different In compositions in QWs and barriers. Thickness of QWs and barriers fixed at 2.5 and 10 nm, respectively.

DQW LDs, such as output power, slope efficiency, DQE, and threshold current, have been carried out.

2. Laser structure and simulation parameters

The laser structure used in the simulation is the same as that used in previous study [11] except that in this section, $In_xGa_{1-x}N/In_yGa_{1-y}N$ material composition is used in the DQW active region. The based simulated structure is the same as laser structures fabricated by Nakamura which is used by the most of researchers in their works [12]. All parameters used in the simulation are also based on the new InN band-gap energy of 0.8 eV. The thickness of wells and barriers are considered fixed at 2.5 nm and 10 nm, respectively. Thus, the main variation in this part is found in In composition of wells and barriers. The $In_{0.082}Ga_{0.918}N$/GaN DQW active region of the LD has two 2.5 nm $In_{0.082}Ga_{0.918}N$ QWs and three 8 nm to 12 nm GaN barriers.

Several equations such as the Poisson equation, the Schrodinger equation, the photon rate equation, the current continuity equations, and the scalar wave equation were solved in the laser simulation process using a two dimensional ISE TCAD simulator. The simulator also includes the carrier drift-diffusion model which involves Fermi statistics and incomplete ionization.

3. Simulation results and discussion

Fig. 1(a) and (b) shows the output emission wavelength of InGaN DQW LD at different In compositions in QWs and barriers when the thickness of the QWs and barriers are considered fixed at 2.5 nm and 10 nm. In mole fractions of $In_yGa_{1-y}N$ barriers are 0.0 (GaN), 0.01, and 0.02 in Fig. 1(a), and 0.03 to 0.07 in Fig. 1(b). As shown in these figures, peak emission wavelength (PEW) of $In_xGa_{1-x}N/In_yGa_{1-y}N$ DQW LD is from 387.21 nm to 463.54 nm when In composition is changed from 0.075 to 0.23 in the wells and from 0.0 (GaN) to 0.07 in the barriers. Because the thickness of the QWs and barriers are considered fixed at 2.5 nm and 10 nm, respectively, PEW of InGaN DQW LD depends mainly on the In mole fraction in the wells and barriers.

Fig. 2 shows a magnified part of Fig. 1(a) which demonstrates output emission wavelength of a particular InGaN DQW LD at different In compositions in the QWs (0.08 to 0.10) and barriers (0.0 (GaN), 0.01, and 0.02). As shown in this figure, PEW of this InGaN DQW LD is limited between 388 nm and 398 nm when the In mole fraction of the barriers is 0.0 (GaN). Likewise, PEW is limited between 391.7 nm and 421.0 nm, and 394.2 nm and 428.2 nm when the In mole fraction of the barriers is 0.01 ($In_{0.01}Ga_{0.99}N$) and 0.02 ($In_{0.02}Ga_{0.98}N$), respectively. This finding shows that the lowest PEW increases by increasing In mole fraction of the barriers. This situation can be attributed to that, when In mole fraction of the barriers is increased, the In mole fraction of the wells have to increase as well to satisfy band offset between wells and barriers. Comparison of the results of this study with other published outcomes shows that PEW and related In compositions in wells and barriers are extremely dependent on the structure and parameters of the LD, such as thickness of wells and barriers, number of wells, thickness and composition of n- and p-type layers, cavity length, and others [13].

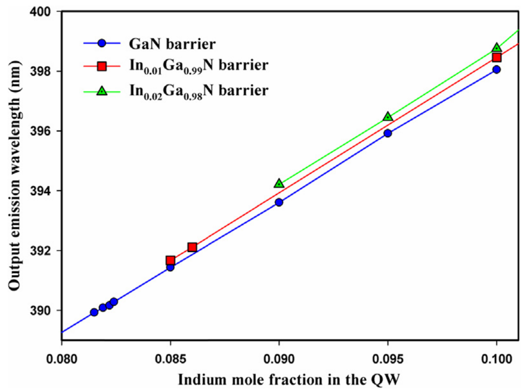

Fig. 2. Output emission wavelength of InGaN DQW LD for different In compositions in the QWs (0.08 to 0.10) and barriers (0.0 (GaN), 0.01 and 0.02).

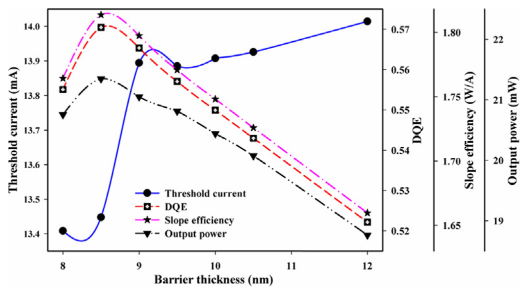

Fig. 3. Threshold current, slope efficiency, output power, and DQE of deep violet $In_{0.082}Ga_{0.918}N$/GaN DQW LDs as a function of the barrier thickness (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

In fact, barrier composition determines potential height in the basic Schrödinger equation. Based on the above results, and because the desired PEW in this study is around 390 nm, GaN barriers have been selected to satisfy band offset with $In_{0.082}Ga_{0.918}N$ wells.

Fig. 3 shows threshold current, slope efficiency, output power, and DQE of deep violet $In_{0.082}Ga_{0.918}N$/GaN DQW LDs as functions