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Improvement of current injection uniformity within multi quantum wells in blue-violet laser diode

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ABSTRACT

Nanostructure semiconductor materials based on group-III nitride are very applicable in our nowadays technology and industry [1–4]. Direct wide band gap group III-Nitrides, including GaN, AlGaN and InGaN, can partly cover most parts of the solar spectrum from ultraviolet to infrared spectra due to their ability to vary their band gap. Furthermore, these materials have other good properties such as high mobility, high saturation velocities, high absorption and radiation coefficients [5,6] which make them promising in modern electronic and optoelectronic applications such as blue semiconductor laser, light emitting diodes, photodetectors and photovoltaic devices [7,8]. Multi quantum well lasers for each application special wavelength and power is proposed and used in various devices [8]. Therefore, careful design of waveguide and electrical current flow is necessary for each application [8]. In this paper we try to optimize special class of semiconductor laser based on InGaN multi quantum wells (MQWs) which their most application is in data storage in DVD-HD. To increase data storage capacity in DVD-HDs laser should be optimized for higher output power to increase the data transfer speed, higher thermal stability up to 350 K or even more [9]. Stable lateral has been mode to minimize beam fluctuation and control divergence angel and reduction of noise as result of laser operation at high power condition. To approach these MQWs LD characteristics, novel planar blue-violet laser diodes have been fabricated successfully [9]. In this paper we report a new architecture to optimize the MQWs LD characteristics in [9]. The organization of this paper is the following. In the first section we try to calibrate our MQWs LD material parameters to validate our simulation results. In Section 2, we define our MQWs LD geometrical properties and selected material parameters. In next section, we compare our simulated results of our new MQWs LD with the reference LD to conclude better laser performance through our proposed structure.

1. Introduction

Semiconductor laser are very applicable in our nowadays technology and industry. For each application special wavelength and power is needed. Therefore, careful design of waveguide and electrical current flow is necessary for each application. In this paper, we try to optimize special class of semiconductor laser based on InGaN MQWs which their most application is in data storage in DVD-HD. To increase data storage capacity in DVD-HDs laser should be optimized for higher output power to increase the data transfer speed, higher thermal stability up to 350 K or even more, stable lateral mode to minimize beam fluctuation and control divergence angel and reduction of noise as result of laser operation at high power condition. To approach these LD characteristics, novel planar blue-violet laser diodes have been fabricated successfully [1]. In this paper, we report a new architecture to optimize the LD characteristics in [1]. The organization of this paper is the following. In the first section we try to calibrate our LD material parameters to validate our simulation results. In Section 2, we define our LD geometrical properties and selected material parameters. In next section, we compare our simulated results of our new LD with the reference LD to conclude better laser performance through our proposed structure.

2. Material parameter calibration

Using 3D self-consistent device simulator [2], we simulate the performance of LD [1] and try to assess a new design or optimal characteristics. The main source of our simulation uncertainty is the inclusion of correct material parameter. Published values

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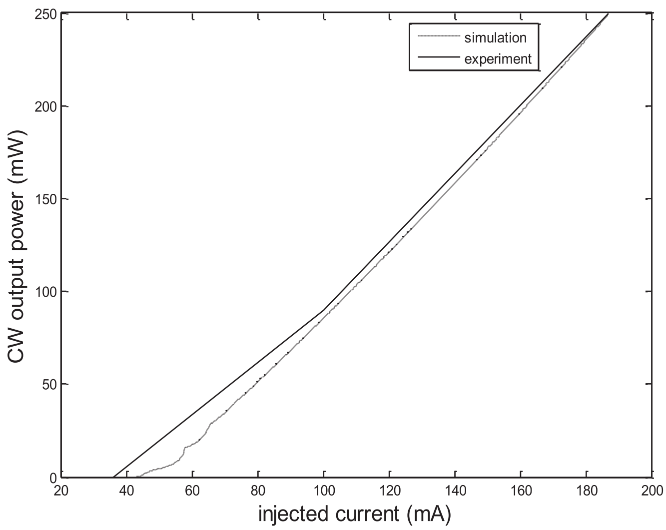

Fig. 1. Comparison between experimental [1] and simulated CW output in terms of injected current.

sometimes spread over a wide range and it is difficult to choose the most accurate ones. Some parameters are very difficult to measure them experimentally like internal optical loss which is mainly controlled by multiple photon scattering within different layer and carrier lifetime within QWs. We used from the most recent literature published values for group-III nitride components. For photon energy near band gap, refractive index is strongly depended on the photon energy. For this purpose we use refractive index according to Adachi model [10]. For thermal conductivity and carrier mobility we use from values which Piprek employed in his simulation for a ridge waveguide structure [9,10]. We estimate the carrier lifetime which strongly affects the threshold condition and internal loss which controls the slope efficiency by fitting the experimental and simulation curves. We obtain 1000 (1/cm) for total background loss and 1 ns for carrier lifetime within QWs. Fig. 1 compares our simulation output power versus injected current and experimental curves. Good agreement between simulation and experiment indicates our careful parameter selection.

3. Geometrical structure

Foremost, we increase the doping level in p-layers. This leads to higher threshold current and decreases the slope efficiency. But devices with highly doped layers are more reliable for operating at high injection condition. Table 1 shows the doping density of each layer and the majority carrier mobility. In the rest of this paper we call this structure as structure 1. This structure has been illustrated in Fig. 2a. Fig. 2 shows two other structures. In Fig. 2b we used another AlN current blocker layer for more confinement of electron current within waveguide. In Fig. 2c we used two 20 nm thick layer of TiO_2 for current blocker layer. We select TiO_2 as an index-match layer with laser cladding layer. Refractive index of TiO_2 is growth depended and *t* can be controlled to be similar to refractive index of $Al_{0.08}Ga_{0.92}N$ cladding layer. Under this condition this layer does not disturb optical mode intensity as it travels in lateral direction. In structure (2.b), we employed two different windows one just for current confinement and the other for optical mode confinement. In referenced device, reduction of inner stripe width leads to better current confinement but leads to instability of lateral mode simultaneously. But in our proposed structure with different electrical and optical aperture, one can reduce the electrical aperture while optical aperture remains unchanged.

Table 1
Carrier mobility and doping concentration of LD.

Parameter	N_{dop} (m^{-3})	μ (cm^2/Vs)
p-$Al_{0.12}Ga_{0.82}$N/GaN (superlattice)	310^{25}	0.5
p-$Al_{0.12}Ga_{0.82}$N/GaN (regrown layer)	310^{25}	0.5
p-GaN (waveguide)	310^{25}	15
$In_{0.02}Ga_{0.98}$N (barrier)	–	850
$In_{0.15}Ga_{0.85}$N (QW)	–	300
$In_{0.02}Ga_{0.98}$N (barrier)	–	850
$In_{0.15}Ga_{0.85}$N (QW)	–	300
$In_{0.02}Ga_{0.98}$N (barrier)	–	850
n-GaN (waveguide)	710^{24}	410
n-$Al_{0.12}Ga_{0.82}$N/GaN (superlattice)	310^{24}	10
$In_{0.1}Ga_{0.9}$N (compliance layer)	310^{24}	390
n-GaN (substrate)	310^{24}	410

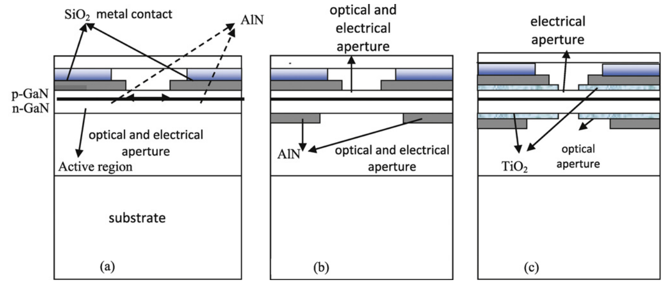

Fig. 2. Geometrical properties of our proposed waveguides, (a) structure 1, (b) structure 2, (c) structure 3.

4. Self-heating stability

In buried heterostructure, self-heating effect is very important, due to the more concentration of carrier in a small region and increase in the Fermi levels. Our simulator considers different source of self-heating, such as joule heat, recombination heat, Thomson heat, optics heat and Peltier heat [11].

Fig. 3 compares the different source of self-heating at laser axis in vertical direction in structure one, two and three with two QWs. As this figure shows, joule heat is very small in three structures and the highest component of heat generation source is the recombination heat within the QW planes. Structure three has the highest generated heat versus structure one and two. Self-heating leads to power roll-over and reduces power at higher injection. Fig. 4 compares output power versus injected current with considering

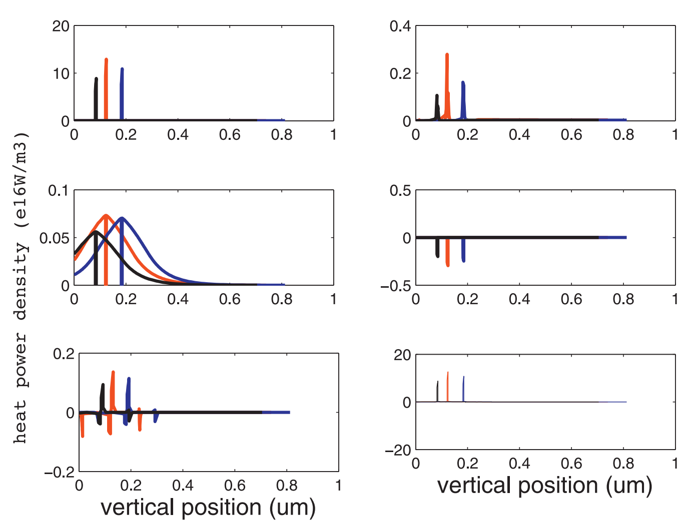

Fig. 3. Geometrical properties of our proposed waveguides, (a) structure 1, (b) structure 2, (c) structure 3.