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Optical-field profiles in $In_xGa_{1-x}N$-MQW laser structures

Juan A. Martín[a], F. García[b], B.J. García[c], M. Sánchez[d,*]

[a] *Facultad de Informática, Universidad de Ciego de Ávila, Cuba*
[b] *Facultad de Ingeniería, Universidad de Ciego de Ávila, Cuba*
[c] *Dpto. Física Aplicada, Facultad de Ciencias, Universidad Autónoma de Madrid, Espagne*
[d] *Facultad de Física, Universidad de La Habana, San Lázaro y L, Vedado, 10400, La Habana, Cuba*

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Abstract

In this paper, we calculated the optical fields for $In_xGa_{1-x}N$-multiquantum well (MQW) laser structures. Two different optical cavities are compared, the conventional step separate confinement heterostructure (Step) and a graded-index (GRIN) structure with a parabolic variation of the Al content in the $Al_xGa_{1-x}N$ guide layers. A comparison is made regarding the confinement factor, near- and far-field patterns. An anomalous behavior for the confinement factor is observed in the structure, and it can be eliminated by choosing an appropriated combination of the layer's thicknesses forming the waveguide. For $Al_xGa_{1-x}N$, an improved expression for the refractive index is presented, which shows better agreement with experimental data than previously reported expressions.

Keywords: Diode lasers; Optical waveguides; InGaN

1. Introduction

III-nitride semiconductors are of current interest because they have practical application in optoelectronics devices. In spite of the achievement obtained in GaN-based laser diodes, the structures are far from being optimized and furthermore, some physical aspects related to these materials have not yet been well understood. In nitride lasers there are some problems regarding

* Corresponding author.
E-mail address: maruchy@fisica.uh.cu (M. Sánchez).

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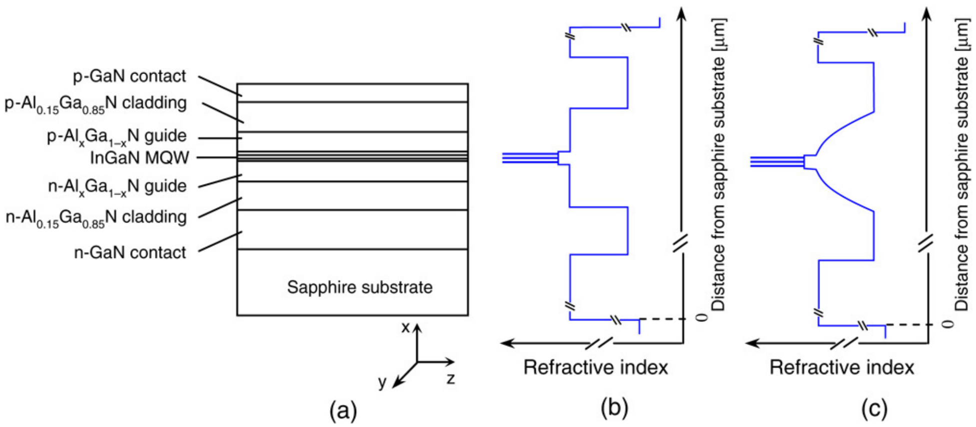

Fig. 1. Schematic of laser structure (a). Refractive index in the layers for a Step structure (b) and GRIN structure (c).

control and stabilization of transverse modes perpendicular to the junction plane. Although theoretical studies on the optimal number of quantum wells needed in nitride lasers to ensure the lowest threshold current have been reported [1,2], relatively little has been reported on optimizing the layer design in order to improve the optical properties of these LDs. Thus it is very important to study the effect of different structure designs. In this paper, we calculated the optical fields for MQW $In_xGa_{1-x}N$ laser for two different optical cavities, the Step and the GRIN structure. The interest in this comparison originated from the success that the GRIN structure has had in arsenide-based lasers. The results presented here provide a guide to layer design of GaN-based laser diodes.

2. Laser diode structure and parameters used in simulation

In this simulation a typical InGaN-MQW separate confinement heterostructure including a sapphire substrate is assumed. Two optical cavities are analyzed; the conventional Step heterostructure and a GRIN, with a parabolic variation of the Al content in the 0.1 µm-thick $Al_xGa_{1-x}N$ guide layers ($0 \le x \le 0.15$). The active regions consist of a 3 nm-thick $In_{0.15}Ga_{0.85}N$ well sandwiched between two 6 nm-thick $In_{0.05}Ga_{0.95}N$ barriers. A schematic of the laser structure is shown in Fig. 1.

3. Calculation results and discussion

The confined modes are calculated by solving the wave equation in the dielectric waveguide [3]:

$$\psi'' + (k_0^2 n^2(x) - \beta_m^2)\psi = 0 \tag{1}$$

where ψ is the component in the y-direction of the electric $\vec{E}$ or magnetic field $\vec{H}$, k_0 is the vacuum wavevector magnitude, $n(x)$ is the refractive index and $\beta_m = k_0 N_m$ is the propagation constant along the z-axis and N_m is the effective refractive index of the mode m.

The solution of Eq. (1) is the same for all the layers in both structures when analyzed, except for the $Al_xGa_{1-x}N$ guide layers surrounding the active layer, the procedure followed is explained elsewhere [4]. With the effective refractive index of the fundamental mode N_0 obtained, the near