Design and simulation of a high power single mode 1550 nm InGaAsP VCSELs

Rahim Faez¹, Azam Marjani², and Saeid Marjani³(a)

¹ Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran
² Department of Chemistry, Arak Branch, Islamic Azad University, Arak-Iran
³ Department of Electrical Engineering, Arak Branch, Islamic Azad University, Arak-Iran

a) saeidmarjani@yahoo.com

Abstract: In the present work, a new structure of vertical cavity surface emitting laser (VCSEL) is designed and simulated. In this structure, InGaAsP is used as the active region which is sandwiched between GaAs/AlGaAs distributed bragg mirror at the top of structure and GaAs/AlAs distributed bragg mirror at the bottom. In this work, the hole etching depth was continued down to the top of lower spacer layer while in the previous work the hole etching depth was only down to top of the upper spacer. In this way, the threshold current decrement of 76.52% and increment the power by 28% from 5 mW to 6.4 mW at bias current of 9 mA was achieved. In this paper, device characteristics such as light power versus electrical current and voltage versus current are simulated and compared with the previous work.

Keywords: design, high power, InGaAsP, VCSEL

Classification: Optoelectronics, Lasers and quantum electronics, Ultrafast optics, Silicon photonics, Planar lightwave circuits

References


DOI: 10.1587/elex.8.1096
Received May 21, 2011
Accepted June 07, 2011
Published July 10, 2011


1 Introduction

In recent decade, the characteristics of vertical cavity surface emitting laser have improved extremely [1]. The single mode performance, high output power and stability in vertical cavity surface emitting laser are very important characteristics for application in optical communication [2, 3]. Efficiency and high speed at low power in VCSEL with wavelength of 850-980 nm are a suitable light source for vast application in short-haul such as Gigabit Ethernet. Longer wavelength at 1300-1500 nm permit higher bit rates over longer distances such as optical communication networks [4].

Used VCSELs at wavelength of 1500 nm are fabricated with different technologies [5, 6, 7, 8, 9, 10, 11, 12]. VCSEL devices developed using the wafer fusion method have achieved continuous wave at wavelength of 1500 nm at power, threshold voltage and current about 0.65 mW, 2.5 V and 1 mA respectively [13].

Fundamental changes in improvement of VCSEL cause increasing power and speed and decreasing dependence on temperature [14]. Present work has improved the structure of a VCSEL which was fabricated [15]. Previous work shows power and threshold current about 5 mW and 2.3 mA respectively [16]. After discussing in Section 2 the basis for modeling VCSEL, we present in Section 3 a new structure of VCSEL. In Section 4 results are presented. Final conclusions are presented in Section 5.

2 Theory

In modeling VCSEL, we must consider electrical and optical interaction during VCSEL performance. Thus base of simulation is to solve Poisson and continuity equations for electrons and holes [17]. Poisson equation is defined by:

$$\nabla \cdot (\varepsilon \nabla \psi) = \rho$$  \hspace{1cm} (1)

where $\psi$ is electrostatic potential, $\rho$ is local charge density and $\varepsilon$ is local permittivity. The continuity equations of electron and hole are given by [18]:

$$\frac{\partial n}{\partial t} = G_n - R_n + \frac{1}{q} \nabla \cdot \vec{J}_n$$  \hspace{1cm} (2)

$$\frac{\partial p}{\partial t} = G_p - R_p + \frac{1}{q} \nabla \cdot \vec{J}_p$$  \hspace{1cm} (3)

where $n$ and $p$ are the electron and hole concentration, $\vec{J}_n$ and $\vec{J}_p$ are the electron and hole current densities, $G_n$ and $G_p$ are the generation rates for electrons and holes, $R_n$ and $R_p$ are the recombination rates and $q$ is the magnitude of electron charge.

The fundamental semiconductor equations (1)-(3) are solved self-consistently together with Helmholtz and the photon rate equations. The applied technique for solution of Helmholtz equation is based on improved effective index model [19] which shows accuracy for great portion of preliminary problems. This model is very good adapted to simulation of VCSEL structures and it is often called effective frequency method [20]. Two-dimensional
Helmholtz equation is solved to determine the transverse optical field profile and it is given by [17]:

$$\nabla^2 E(r, z, \varphi) + \frac{\omega_0}{c^2} \varepsilon(r, z, \varphi, \omega) E(r, z, \varphi) = 0$$

(4)

where $\omega$ is the frequency, $\varepsilon(r, z, \varphi, \omega)$ is the complex dielectric permittivity, $E(r, z, \varphi)$ is the optical electric field and $c$ is the speed of light in vacuum.

The light power equation relates electrical and optical models. The photon rate equation is given by [17]:

$$\frac{dS_m}{dt} = \left( \frac{c}{N_{eff}} G_m - \frac{1}{\tau_{phm}} \right) S_m + R_{spm}$$

(5)

where $S_m$ is the photon number, $G_m$ is the modal gain, $R_{spm}$ is the modal spontaneous emission rate, $L$ represents the losses in the laser, $N_{eff}$ is the group effective refractive index, $\tau_{phm}$ is the modal photon lifetime and $c$ is the speed of light in vacuum.

Eq. (1)-(5) provide an approach that can account for the mutual dependence of electrical and optical.

3 VCSEL structure

Fig. 1 shows schematic 1550 nm air-post VCSEL, which is used for simulation. Device parameters are modeled based on empirical data of fabricated devices [15] as shown in Fig. 1; where the VCSEL circular diameter is 12 $\mu$m, diameter of air-post is 4 $\mu$m. In this structure, the substrate is made of GaAs. The active region consists of six quantum wells where the well is 5.5 nm In$_{0.76}$Ga$_{0.24}$As$_{0.82}$P$_{0.18}$ and the barrier is 8 nm In$_{0.48}$Ga$_{0.52}$As$_{0.82}$P$_{0.18}$. In both sides of this active region, there is InP and on top of it GaAs. The top mirror is 30 layers of GaAs/Al$_{0.33}$Ga$_{0.67}$As with reflection factor of layers 3.38 and 3.05 respectively and the bottom mirror has 28 layers of GaAs/AlAs with

![Fig. 1. schematic structure of the VCSEL device.](image)
reflection factor of layers 3.38 and 2.89 respectively. Part of the top mirror was etched in [16] but in this proposed structured (Fig. 1) the etched region continues to top of bottom InP spacer, which is shown by the circle.

4 Results

In the present work, device characteristics such as light power versus electrical current and voltage versus current are investigated and compared with

![Graph showing light power versus current comparison](image1)

**Fig. 2.** The proposed structure effect on L-I characteristic.

![Graph showing voltage versus current comparison](image2)

**Fig. 3.** The proposed structure effect on V-I characteristic.
the previous results [16]. Results are for room temperature. Fig. 2 shows power versus current curve which compares present work with the previous work [16]. As can be seen from Fig. 2, proposed structure increased slope of power versus current curve. Because lower optical loss introduced by the proposed structure. In this way, the threshold current decrement of 76.52% from 2.3 mA to 0.6 mA and increment the power by 28% from 5 mW to 6.4 mW at bias current of 9 mA was achieved.

Fig. 3 shows voltage versus current curve while the structure is changed. At high voltages, the series resistance has increased about 10% from 228 Ω to 252 Ω that is calculated by the slope of I-V curve. This increment should be mainly due to blocking of current flow by hole etching depth in the upper spacer layer and active region.

5 Conclusion

In this work, a new VCSEL structure for application at wavelength of 1550 nm is introduced. In summary, proposed structure decreases the threshold current about 76.52% from 2.3 mA to 0.6 mA and increases the power 28% from 5 mW to 6.4 mW at bias current of 9 mA in comparison with previous results.