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A thermal analysis of stable-polarization VCSELs

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ABSTRACT

In this paper, the thermal analysis of metal-grating stable-polarization vertical cavity surface emitting laser is theoretically and experimentally performed. The pairs of P-DBRs are reduced to achieve the maximum difference threshold gain of two orthogonal polarizations. As a result, more excellent temperature characteristics have been obtained, to be specific, the temperature of active region with the aperture of 150um is reduced from 357 K of normal device to 343 K at the current of 4 A. The wavelength/current is 0.57 nm/A of grating device which is smaller than that of 0.71 nm/A of normal device. Better near field distribution of grating devices has been displayed owing to the better temperature characteristic.

1. Introduction

Recently, 1064 nm VCSEL which can be used as radiation source of compact type optical phase array radar [1] has gained growing attention. While if one laser is used as the radiation source of compact type optical phase array radar, the laser must have some specific characteristics such as minute extension, low power consumption, long lifetime [2], high stability, high beam quality, and stable working wavelength [3].

Possessing the positive features of the vertical emitting geometry, vertical-cavity surface-emitting lasers (VCSELs) have shown many advantages, for instance, a circular light-output mode, a high power density, a small volume, a long life time, a high packing density for two-dimensional arrays and single longitudinal mode emission due to the inherent short cavity length [4–6]. While as a type a semiconductor laser, VCSEL have some problems like a bad beam quality [7], non-stable polarization [8] and a drift working wavelength [9] which are required to be solved when used in optical phase array.

Before, our group tried to import metal-grating as a polarizer to control the polarization of large aperture 980 nm VCSEL which was shown as Fig. 1. The pairs of P-DBRs of metal-grating device were reduced from 30 pairs to 17 pairs in order to realize the maximum difference threshold gain of two orthogonal polarizations. Therefore, the polarization ratios of 3 at continuous-wave operation at room temperature were demonstrated [10].

The heat sources of VCSEL consist of three parts: joule heats of P-DBR and N-DBR, and the heat of active region [11]. The joule heat of P-DBR takes a large proportion of the gross heat budget due to the structure of VCSEL, thereby, optimizing joule heat of P-DBR is a critical step to gain a good performance of device [12].

According to the structure mentioned previously, the pairs of P-DBR of metal-grating device were reduced from 30 to 17 in order that the series resistance of P-DBR could be reduced largely. Predictably, this device would perform well with

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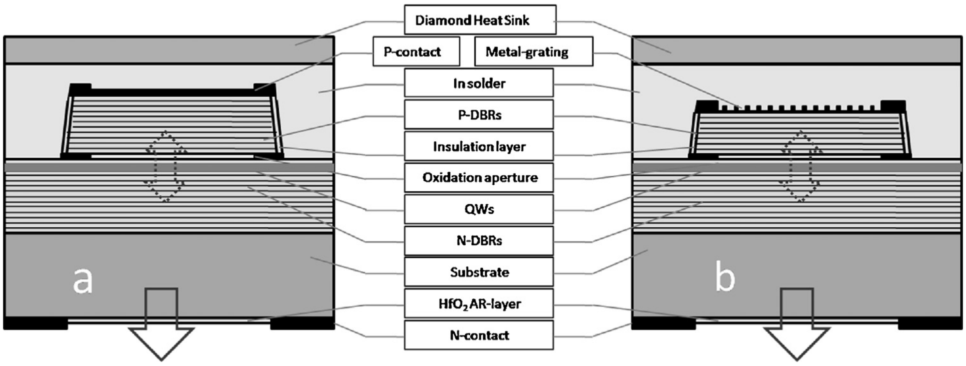

Fig. 1. The structure of normal(a) and metal-grating VCSEL(b).

thermal characteristic and stable working wavelength. This paper would elaborate the thermal characteristic of the device both theoretically and experimentally.

2. Simulation

In order to the get the specific thermal distribution of the device, the thermal distribution of the device will be simulated by finite elements.

The thermal simulation is based on the following steady-state heat-flux equation [13]:

$$C_p \rho \nabla T = \nabla \cdot (\kappa \nabla T) + Q_{tot}$$

where, C_p is the specific heat, ρ is the density of the material, κ is lattice thermal conductivity, Q_{tot} is the heat source.

In this formula

$$\kappa \nabla T = q_0 + h(T_{\text{inf}} - T) + \varepsilon \sigma (T_{amb}^4 - T^4)$$

where, T is the initial temperature (293.15 K), q_0 is inward heat flow, h is coefficient of thermal conductivity, ε is the surface emissivity, σ is he boltzmann constant, T_{inf} is the volume environment temperature, T_{amb} is radiation environment temperature.

Total heat can be described below:

$$Q_{tot} = Q_J + Q_{Aug} + Q_{nrad}$$

Where Q_J is joule heat,mainly form P-DBR N-DBR and substrate;Q_{Aug} and Q_{nrad} are the heat from auger recombination and non-radiative recombination respectively,generated mainly from the active region.

These three parts of heat can be describe as below [14]:

$$Q_J = J_n^2/(q\mu_n n) + J_p^2/(q\mu_p p)$$

Where, J_{n} is electron current density, J_p is hole current density, μ_n is electronic mobility, μ_p is hole mobility, n is electron density, p is hole density.

$$Q_{Aug} = R_{Aug} \cdot (E_{Fn} - E_{Fp})$$

Where R_{Aug} is auger recombination rate:

$$R_{Aug} = C_n \cdot n^2 \cdot p + C_p \cdot n \cdot p^2$$

Where, C_n is auger recombination rate of electron, C_p is auger recombination rate of hole. Suppose $C = C_n = C_p = 3.5 \times 10^{-30}\ \text{cm}^6/\text{s}$.

$$Q_{nrad} = qV_{act}AN$$

where, V_{act} is voltage of active region,A is non-radiative recombination rate.

The parameters used for simulation are shown in Table 1.

The result of the simulation of the grating device thermal distribution with the current of 4A and the aperture of 150 μm is shown in Figs. 2 and 3. It can be seen that heat accumulated around the edge of oxide layer, where carriers gather which would bring lower threshold gain of the active region and a greater likelihood of lasing. Accordingly, there would be a problem that a great deal of heat from auger recombination and non-radiative recombination is generated. The maximum temperature around the edge of oxide region is about 352 K while the temperature heat of the center in the active region tends to flat at about 340 K.