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Small aperture confined vertical cavity surface emitting laser effects on output performance

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The effect of the various oxide aperture sizes on output performance of GaAs MQWs VCSEL is numerically investigated using ISETCAD simulation program. The influence of the aperture diameter on the output power, threshold current, slope and differential quantum efficiency is observed. In the study, we found that by increasing the aperture diameter, the maximum output power, slope efficiency, and differential quantum efficiency was increased due to more lasing modes being confined inside the active region which lead to increase the number in radiative recombinations inside the active medium.

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Keywords: GaAs, VCSEL, Oxide aperture

1. Introduction

Vertical-cavity surface-emitting lasers (VCSELs) are widely used in low-cost short-haul optical communication systems due to their particular properties. They have good optical beam quality suited for high-speed modulation, cost-effective mass production, and good performance including low threshold current, and high power efficiency. A further advantage is that they have the possibility to be integrated into 2-D arrays. The performance of VCSELs has improved significantly through the use of oxide or air apertures [1, 2], which provide transverse confinement for the injected carriers as well as for the optical field.

In the present paper, the authors aim to present the characteristic features of oxide confined 850nm VCSELs with various oxide aperture sizes. For this, VCSEL devices with various corresponding oxide aperture sizes are simulated by using ISETCAD simulation program. The peak output power and the threshold current for each of these devices are determined. In the study, the device performance in respect of the dependence of their efficiencies (such as differential quantum efficiency and slope output efficiency) and spectral characteristics on the size of the oxide aperture[3-11].

2. VCSEL design in numerical simulation

The ISETCAD program of laser simulation solved the Poisson equation, photon rate equation, the Schrödinger equation, the current continuity equation and the carrier drift diffusion model which included Fermi statistics and incomplete ionization in this simulation.

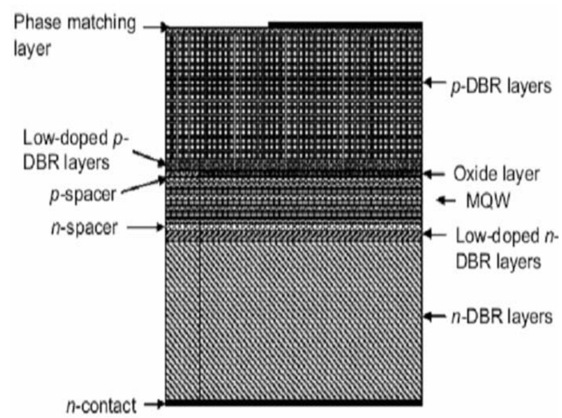

Fig. 1. Structure of the oxide confined VCSEL.

Fig. 1 shows the transverse cross-sectional view of the half portion of the VCSEL structure. The descriptions of all the layers are indicated in this figure. In our design, we constructed the device with n^+- GaAs substrate followed by n^+-DBR. In order to get a good performance of the device, $Al_{0.20}Ga_{0.80}As$ (having high refractive index ~ 3.492) and $Al_{0.90}Ga_{0.10}As$ (having low refractive index ~ 3.062) are used for p^- and n^+- type DBRs respectively. The lower section of the device contains thirty-six pairs of n-DBRs while the upper section of p-DBRs contains twenty pairs with λ/4 thicknesses. An oxide layer is introduced in the structure in a way that it is sandwiched between the p-type spacer layer and the p-DBR layer. This is in order to obtain a better current and index confinement. It is clear from the figure that the oxide layer is deposited in such a way that the central portion of the VCSEL device is left transparent so that the light can be confined in the central region only, both n and p-types DBRs are doped at $1\times10^{+20}$ cm^{-3} doping concentration. The active medium consists of GaAs well with thickness of 6 nm and $Al_{0.20}Ga_{0.80}As$ barrier with thickness of 12 nm. The multiple quantum well (MQW) was sandwiched by two spacers of $Al_{0.30}Ga_{0.70}As$.

3. Simulation results and discussion

To study the effect of aperture diameter on the design, the aperture diameter was increased by step of 1 µm as shown in Fig. 2. We observed an increase in maximum output power with increasing aperture size up to 37.85 mW for aperture diameter 8 µm. this is attributed to the fact that, in large oxide apertures, more lasing modes are being confined inside the active region which lead to increase in the number of radiative recombinations inside the active medium.

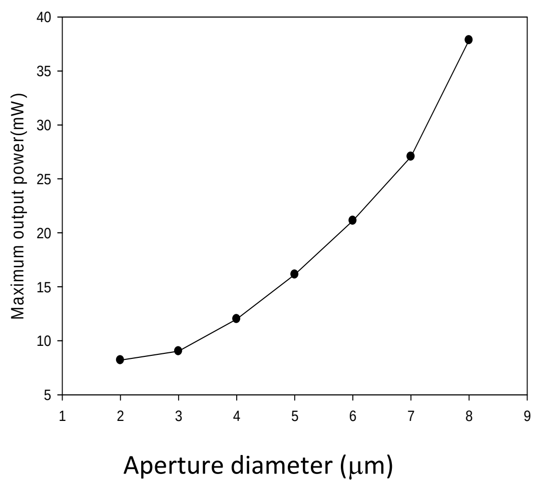

Fig. 2. Variation of maximum output power with aperture diameter.

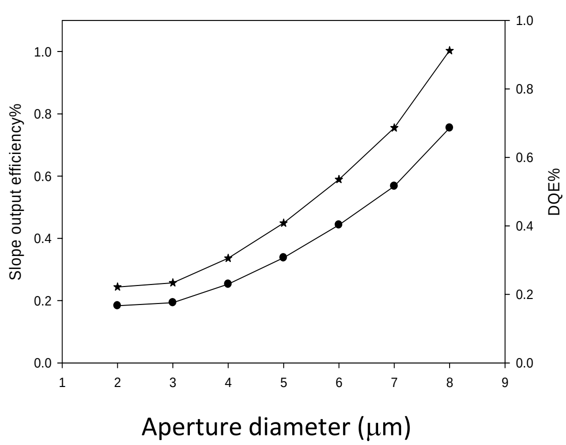

Fig. 3. Variation of slope output and differential quantum efficiency with aperture diameter for the simulated VCSELs.

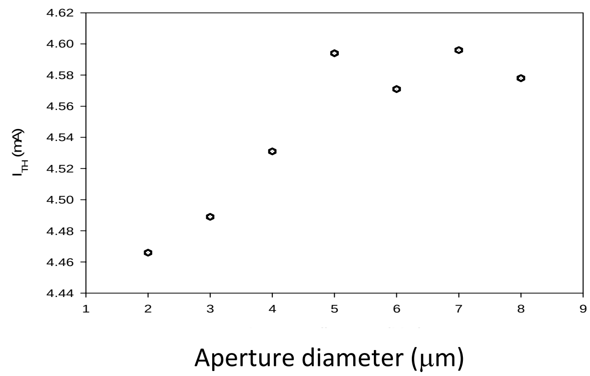

Fig. 4. Variation of threshold current with aperture diameter for the simulated VCSELs.

The differential quantum efficiency (DQE) indicates the efficiency of a VCSEL in converting the injected electron–hole pairs into photons emitted from the device. Fig. 3 illustrates the variation of the slope output efficiency and differential quantum efficiency with the oxide aperture diameter ranging 2 to 8 µm. We observe that the VCSELs with smaller oxide aperture diameter show decreased slope output efficiency and differential quantum efficiency, which is due to the increased scattering loss resulting from the small oxide apertures. Fig. 4shows the increase in the threshold current with increase in the oxide aperture diameter. Since the laser threshold gain essentially depends on threshold current density, as opposed to total threshold current, higher injection current is required for VCSELs with larger aperture sizes to achieve lasing operation.

4. Conclusions

A numerical study has been preformed for the oxide-confined vertical cavity surface emitting lasers (VCSEL) operating at 850 nm region of the electromagnetic spectrum. Relevant VCSEL design with numerous oxide aperture sizes has been designed and characterized by using laser technology-integrated program ISETCAD simulation. In this paper, the effect of oxide aperture size is studied by changing the size of aperture from 1 to 8 µm. The investigations of electrical as well as optical characteristics of the designed VCSEL have been performed, which include the overall device performance as a function of oxide aperture size. It is observed that the increase in the aperture radius of the VCSEL cause increase in both the threshold current to up 4.578 mA andoutput power up to 37.85 mW. Furthermore, the slope output efficiency of up to 1.003% corresponding to differential quantum efficiency up to 68.65% was obtained.

Acknowledgements

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