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The effect of doping concentration on VCSEL performance

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The performance of 850 nm GaAs multiple quantum well (MQWs) vertical cavity surface emitting laser (VCSEL) laser structure has been numerically investigated by using laser technology-integrated program ISETCAD simulation. The effect of the doping concentration on the VCSEL output performance has been investigated. The maximum output power and lower threshold current was observed when both distributed Bragg reflector DBR and spacer layers are doped with high level doping concentration. In addition, it was observed that doping can strongly affect the slope efficiency of the VCSEL.

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1. Introduction

The various types of designs of vertical cavity surface emitting laser (VCSEL) and their specific applications have been reported. The VCSEL has been attracting great attention recently due to its general characteristics by single longitudinal mode operation, circular symmetric Gaussian beam profiles, high quality low divergence, low threshold current, wave-scale integration and simple packaging. The VCSEL offers the possibility of large 2-dimentional (2-D) array integration and low manufacturing cost of device. Considering all these features, successful research on 850nm VCSELs could develop a standard technology to commercialize their applications in local area networks [1-5].

The doping concentrations effects on the 850 nm (MQWs) VCSEL are simulated in the ISE TCAD program. The doping plays a critical role in increasing both the output power, radiative recombination and decreasing the threshold current. Therefore doping can strongly affect the efficiency of the VCSEL laser through free carrier absorption loss [6-12].

2. VCSEL design in numerical simulations

The ISE TCAD 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. The band gap energy for AlGaAs at room temperature is calculated using the direct and indirect energy band gap equations [7]:

$$Eg(x)_{dir} = 1.424 + 1.247x \quad \text{eV} \qquad x < 0.45 \text{ (direct energy band gap)}$$

$$Eg(x)_{ind} = 1.900 + 1.250x + 0.143x^2 \text{ eV} \qquad x \geq 0.45 \text{ (indirect energy band gap)}$$

The electrons, light and heavy holes effective masses for AlGaAs active layer are used in our simulation which can calculate by the following equations [8]:

$$\frac{m_e}{m_o} = 0.067 + 0.083x \tag{1}$$

$$\frac{m_{lh}}{m_o} = 0.087 + 0.063x \tag{2}$$

$$\frac{m_{hh}}{m_o} = 0.500 + 0.290x \tag{3}$$

A schematic diagram of 850 nm GaAs/AlGaAs top surface emitting VCSEL laser structure is shown in Fig.1. 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, both p^- and n^+- type DBRs made by $Al_{0.20}Ga_{0.80}As$ (having high refractive index ~ 3.492) and $Al_{0.90}Ga_{0.10}As$ (having low refractive index ~ 3.062) material respectively. The lower section of the device contains thirty-six pairs of n-DBRs with λ/4 thicknesses. (AlAs) aperture with thickness of 236 nm is sandwiched between the n-type spacer layer and the lower n-type DBR. This is in order to obtain a batter current and optical confinement in the active medium. The upper section of p-DBRs contains twenty pairs, Less number of mirrors is taken in the p-type DBR section as compare to the n-type DBR to give finally less reflectivity in the upper section and enable the extract light from the p-type DBR with higher intensity. The active medium consists of GaAs well with thickness of 6nm and $Al_{0.20}Ga_{0.80}As$ barrier with thickness of 12nm. The multiple quantum well (MQW) was sandwiched by two spacers of $Al_{0.30}Ga_{0.70}As$.

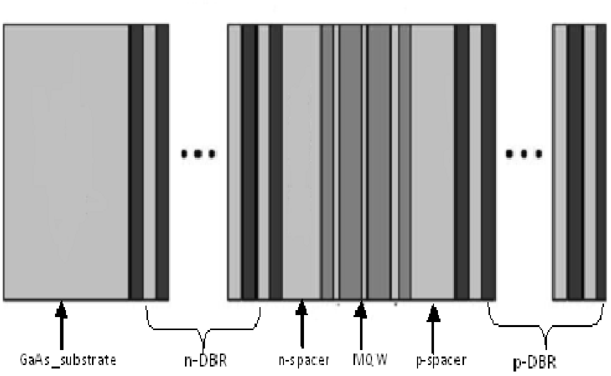

Fig.1. A schematic diagram of 850 nm MQWs GaAs/AlGaAs top surface emitting VCSEL laser structure.

3. Simulation results and discussion

Both n- and p-type DBRs are doped at $1\times10^{17}cm^{-3}$ and $5\times10^{17}cm^{-3}$ respectively [This difference is dependent in the fact that the diffusion constant length of electrons is higher compared with holes which causes the electron leakage out of the active region to be more severe than hole leakage]. The effect of doping concentration of the VCSEL output performance is extremely studied. The doping concentration level of the DBR layers is increased in 5 times step as shown in fig.2. The maximum output power with minimum threshold current was observed up 47.09 mW and 0.94 mA in 1×10^{20} doping concentration. This may be attributed to the reduction of the carrier escaping from active region and low carrier escaping from active medium lead to higher injection of carriers into active region hence generating higher radiative recombination which causes an increase in the internal quantum efficiency.

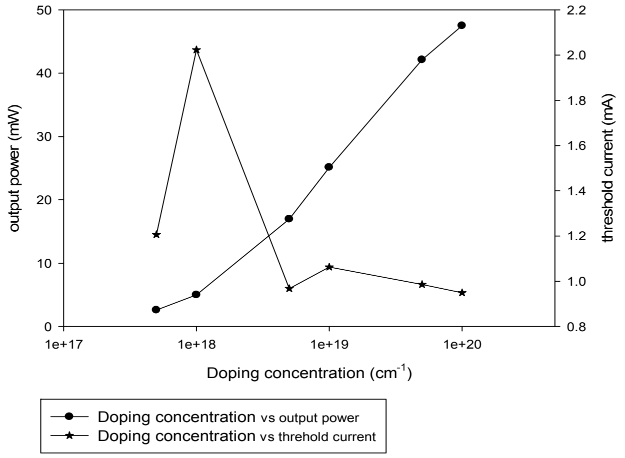

Fig. 2. The output power and threshold current as a function of the DBR doping concentration (without spacer).

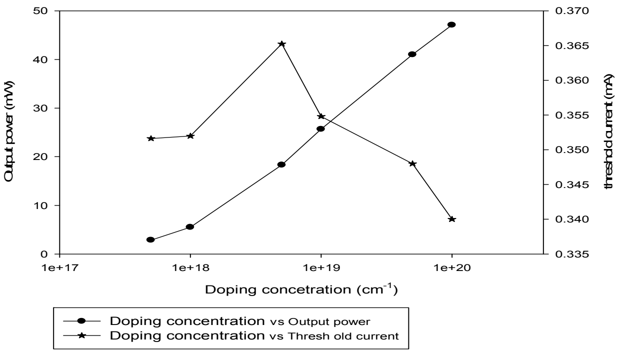

Fig. 3. The output power and threshold current as a function of the DBR with spacer doping concentration.

Fig. 3 shows the effect of spacer doping on the output power and threshold current. We observed an increase in the output power with increasing DBR spacer layers doping concentration up and threshold current reduced to 47.49 mW and 0.34 mA for 1×10^{20} doping concentration. This is attributed to the lowering spacer heights in the active region with increase in doping level. Low spacer heights lead to increase of the number of radiative recombination's inside the active medium.

4. Conclusions

The effect of the doping concentration on output performance of the GaAs MQWs VCSEL laser with ISE TCAD simulation program is numerically investigated. The influence of the DBR- and spacer- layers concentration on the output power, threshold current and slope efficiency is observed. Under study we observed that the problem of carrier escaping from active region can be solved by doping both DBRs and spacers with high concentration level. The high doping concentration facilitates higher injection of carriers into the active region generating higher radiative recombination's which lead to higher output power and higher slope efficiency.

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