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Temperature effect on VCSEL output performance

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The steady state performance of vertical cavity surface emitting laser (VCSEL) structure under the influence of the temperature are numerically investigated by using laser technology-integrated program ISETCAD simulation. In this study, we observed that the increase in temperature causes the increase in the threshold current, the reduction of output power, shift of the lasing wavelength, and decrease in both of the slope output efficiency and the differential quantum efficiency. Additionally, the operating lifetime of semiconductor lasers usually decreases exponentially with temperature. Therefore it is essential to design lasers with consistently low temperature for better reliability. All material parameters are evaluated based on the recent literature values.

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Keywords: ISETCAD, Temperature effect, VCSEL

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

A schematic diagram of 850 nm GaAs/AlGaAs top surface emitting VCSEL laser structure is shown in Fig. 1. The 850 nm GaAs/AlGaAs top surface emitting VCSEL was constructed with active medium, which consists of GaAs wells with thickness of 6 nm and $Al_{0.20}Ga_{0.80}As$ barriers with thickness of 12 nm. The active medium was sandwiched between two spacers of $Al_{0.30}Ga_{0.70}As$ and two p^- and n^+- type DBRs. Each pair of the p^- and n^+- type DBRs was 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). The lower section of the device contains thirty-six pairs of n-DBRs while the upper section contains twenty pairs 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. In order to investigate the effects of temperature**,** we designed many models with different temperatures ranging from 200 until 400 K.

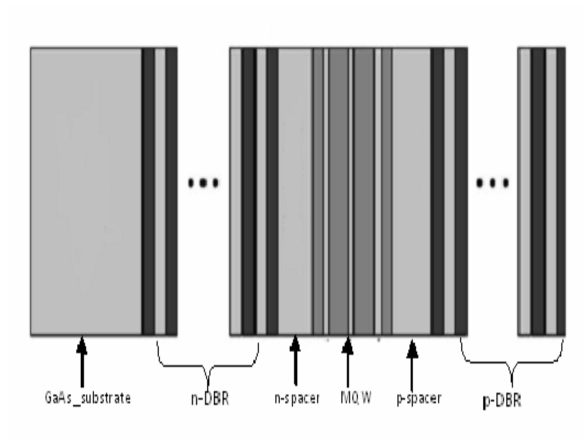

Fig. 1. A MQWs GaAs/AlGaAs top surface emitting VCSEL laser structure.

3. Simulation results and discussion

To study the effect of temperature on the design, the temperature is increased 10 times in each step from 200 K until 400 K as shown in Fig. 2.

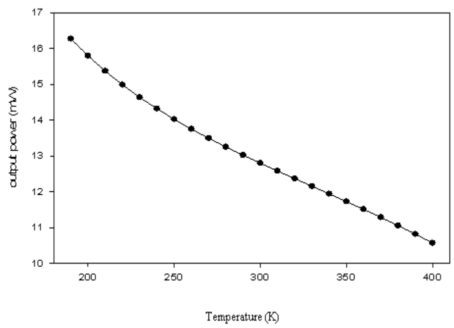

Fig. 2. VCSEL maximum output power as a function of temperature.

It can be observed the output power decreased with increasing temperature of the design to 0.137 W at 400 K.

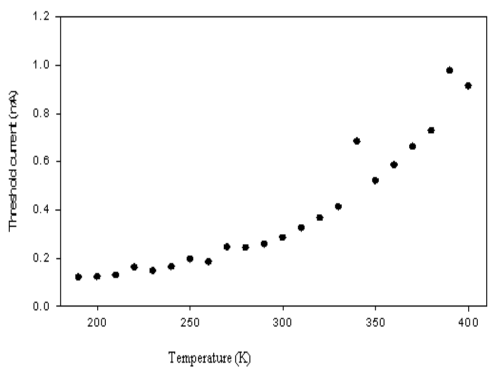

Fig. 3. VCSEL threshold current as a function of temperature.

Fig. 3 shows the threshold current as a function of temperature, a strong increase in threshold current was observed with increasing temperature. This is directly related to the properties of the multiple quantum wells (MQWs), and was discussed in great detail by Piprek based on numerical modeling [2]. It is meant that the main contribution of the increasing in threshold current was found to be Auger recombination and vertical carrier leakage over the barriers.

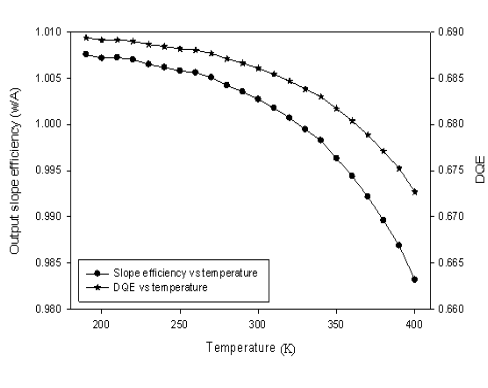

Fig. 4. VCSEL slope output and differential quantum efficiency as a function of temperature.

Fig. 4 shows VCSEL slope output and differential quantum efficiency as a function of temperature. The higher threshold current for our VCSEL indicated that more heat will be generated with time and decrease both the slope and differential quantum efficiency (DQE) as shown in Fig. 4.

Fig. 5 shows the output power-current (P-I) characteristics of 4 μm GaAs based VCSEL, with emission wavelength of 850 nm for various temperatures. The threshold current increases significantly with increasing temperature and output drops approximately linearly.

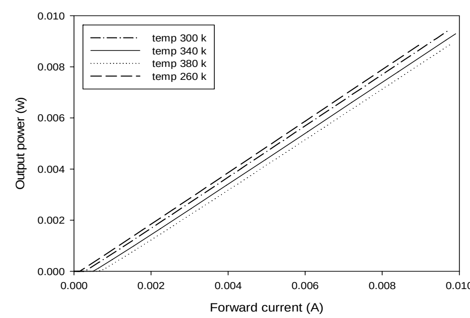

Fig. 5. The output power-current (P-I) characteristics of 4 µm GaAs based VCSEL as a function of temperature.

In the case of 6 nm thick quantum well, the calculated resonant wavelength at 300 K is 851.6 nm, while the material gain peak occurs at 842.5 nm.

Fig. 6 shows the resonant wavelength turns out to be consistently better tuned into the spectral profile of material gain as the active region is heated from 300 to 320 K (842.5 nm at 300 K, 849 nm at 320 K).

After that optimal temperature is reached, the resonant wavelength is gradually detuned from the gain maximum as the temperature in the active region increased further. Increase in thermal broadening make the process of detuning not as intense as the temperature goes up (getting to 857.5 nm at 350 K).

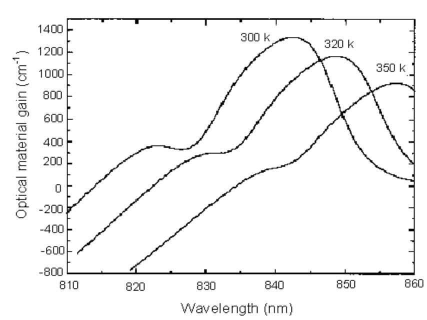

Fig. 6. Optical material gain as a function of wavelength.

It was taken into account that the resonant wavelength shift with temperature is estimated to be about five times smaller than that of the gain peak position.

4. Conclusions

The steady state characteristics of GaAs MQWs VCSEL laser under the influence of temperature are analyzed by using ISETCAD simulation program. The dependence of threshold current, output power and lasing wavelength on the temperature of the laser cavity is investigated. It was observed that the threshold current increases with increase of temperature, while both the slope output efficiency and the differential quantum efficiency decrease with the increase of temperature; the peak output power diminishes with increase in temperature, and a shift in the lasing wavelength with the reduction in the temperature of laser cavity occurs.

Acknowledgements

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