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آنالیز حرارتی لیزرهای کاواک قائم گسیل سطحی ۹۸۰ نانومتری با قطرهای مختلف دریچه اکسیدی

زهرا دانش کفترودی

گروه علوم مهندسی، دانشکده فنی و مهندسی شرق گیلان، دانشگاه گیلان

چکیده: در این مقاله، آنالیز حرارتی لیزرهای کاواک قائم گسیل سطحی ۹۸۰ نانومتری با قطرهای مختلف دریچه اکسیدی به صورت تئوری با استفاده از شبیه ساز PICS3D که به صورت خودسازگار شبیه سازی سه بعدی سوق حامل، خود گرمایش و موجبری نوری را با یکدیگر ترکیب میکند، صورت گرفته است . پروفایلهای دما و چگالی توان حرارتی با استفاده از مدل تولید و اتلاف گرمایی استوانه ای سه بعدی به دست آمدند. نتایج شبیه سازی نشان می دهد که گرمای ژول منبع اصلی گرما در افزاره است. مقاومت حرارتی مشخصا با کاهش سایز دریچه افزایش می یابد.

کلید واژه- آنالیز حرارتی، بیشینه دمای ناحیه فعال، دریچه اکسیدی، لیزرهای کاواک قائم گسیل سطحی.

Thermal analysis of 980 nm vertical cavity surface emitting lasers with different oxide aperture diameters

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Abstract- In this paper, the thermal analysis of 980 nm vertical cavity surface emitting lasers with different oxide aperture diameters is theoretically performed by using simulation software PICS3D which self-consistently combines three-dimensional simulation of carrier transport, self-heating and optical wave-guiding. Temperature profiles and heat power density were obtained by using a three-dimensional cylindrical heat generation and dissipation model. Simulation results show that Joule heating is the main heat source in the device. The thermal resistance increases significantly with a decrease in oxide aperture size.

Keywords: Thermal analysis, Maximum active region temperature, Oxide aperture, Vertical cavity surface emitting lasers.

1 Introduction

The perpetually increasing demand of our modern society for ever faster access to ever larger amounts of information requires a corresponding permanent increase of the computational power of data center and high-performance computer (HPC) for rapid and efficient data processing and routing. The success of the optical technologies in the HPC applications originates from the decisive advantage of vertical cavity surface emitting lasers (VCSELs)
as a high quality laser light source for short-reach optical interconnects with a large number of channels[1]. In the recent years, we have seen impressive progress in the field of high-speed VCSELs emitting around 980 nm. This wavelength has large advantages in the optical interconnects, especially in HPC applications.

In order to reach very efficient VCSELs, we need to confine both current and optical field in lateral dimension in a way to have maximum interaction with the active region. One important technique that is widely used in VCSEL is oxide aperture. In oxide confined VCSELs, an Al-containing layer such as AlGaAs is placed in the structure during the growth of Bragg mirrors and active layer. Wet oxidation of this layer at elevated temperature forms a mechanically stable phase of Al_2O_3 which has a low refractive index.

Thermal design is very important for VCSELs. Compared with edge-emitting lasers, VCSELs usually have much smaller active regions and higher threshold current densities, which means that the temperatures of these active regions could be much higher. Low thermal resistance of VCSEL device is one of the most important key factors to improve device management. If VCSEL operating at high temperatures should be realized, thermal phenomena inside of the device becomes one of the crucial laser design aspects. It is of great importance to have a deeper understanding of the thermal processes in VCSELs.

Nanometer scale semiconductor structures are often at the heart of modern optoelectronic devices. Their shrinking size and increasing complexity make computer simulation an important tool for designing better devices that meet ever-rising performance requirements. The current need to apply advanced design software in optoelectronics follows the trend observed in the 1980s with simulation software for silicon devices. Today, software for technology computer-aided design (TCAD) and electronic design automation (EDA) represents a fundamental part of the silicon indus- try. In optoelectronics, advanced commercial de -vice software has emerged, and it is expected to play an increasingly important role in the near future.

In this paper, the effect of oxide aperture size on 980 nm VCSEL thermal characterization was theoretically investigated by using simulation software PICS3D which self-consistently combines 3D simulation of carrier transport, self-heating and optical wave-guiding.

2 Theoretical Model

A three-dimensional laser model, which combines carrier transport, optical gain computation, wave-guiding and heat-flux, is employed in PICS3D (Photonic Integrated Circuit Simulator in 3D) [2]. The electrical behavior of semiconductor device is described with finite-element drift-diffusion model in this package. The finite-element model of carriers includes Fermi statistics and thermionic of hetero-barriers. Gain calculations are based on 8×8 k.p band structure computations for the strained quantum wells.

2.1 Thermal Simulation

Self-heating often affects the performance of optoelectronic devices. Heat is produced within the device when carriers transfer part of their energy to the crystal lattice. Therefore, the net thermal energy is increased which is measured as increased temperature of T_L lattice. Assuming the local thermal equilibrium between the lattice and the carrier, we will have: $T=T_L=T_n= T_p$.

To maintain temperature energy conservation, the heat flux equation should be given by Equation (1):

$$\rho_L C_L \frac{\partial T}{\partial t} = -\nabla . J_{Heat} + H_{heat} \quad (1)$$

Which ρ_I is physical density; C_L is specific heat of crystal lattice and H_{heat} is heat source. The heat source can be separated into contributions from Joule heat, generation / recombination heat, absorption heat and Thomson heat.

3 VCSEL Structure

Figure 1 shows a schematic of the structure for a 980 nm VCSEL. The epitaxial VCSEL structure was grown on GaAs substrate. For this structure the bottom n-type distributed Bragg reflector (DBR) mirror consists of 26 pairs of quarter wavelength GaAs/AlAs layers. The top p- type DBR has 25 pairs of GaAs/$Al_{0.75}Ga_{0.25}As$ layers. The cavity contains two $In_{0.2}Ga_{0.8}As$ quantum wells (QWs) with GaAs barriers. The quantum wells stack is sandwiched between undoped $Al_{0.42}Ga_{0.58}As$ spacer layers, which act as a waveguide. On the *p*- side of the structure, the oxide layer is not intentionally doped.

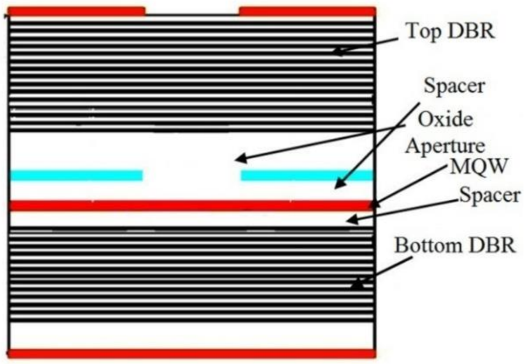

Figure 1: Schematic of a 980 nm VCSEL structure

The VCSEL mode spectrum is shown in Figure 2, which confirms that the proposed structure operates at 980 nm single mode.

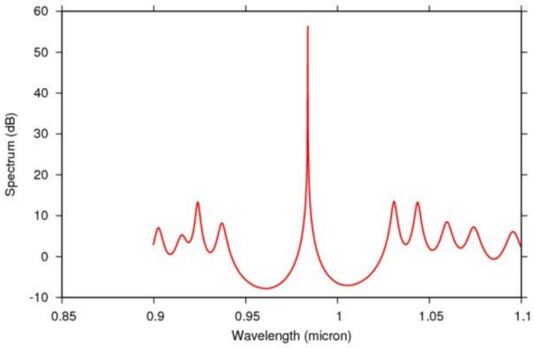

Figure 2: 980 nm VCSEL mode spectrum

3 Simulation Results

Understanding of the thermal behavior of VCSELs is very important because the device performance, i.e., optical output power, threshold current, and modulation speed, was limited by thermal effects. Also, the thermal characteristics of VCSELs are expected to depend on the oxide aperture diameter. Thermal analysis based on the finite element method was conducted to model the heat transport in the VCSEL structure. For devices with different oxide aperture size, the thermal calculation was carried out by the finite element method simulation using a steady-state three-dimensional (3D) cylindrical heat generation that is an dissipation model with physical parameters for the materials.

Figure 3 presents the generated heat power density in device with 5.5 μm oxide aperture diameter.

The electric resistance of interfaces and bulk layers are the main heat sources in VCSELs. Joule heating depends on the local current density. It is essential to know the magnitude of current distribution to correctly understand the internal VCSEL heat power density distribution. Figure 4 shows the radial current density of the mentioned device. As seen in this figure, a high current density exists near the rim of the oxide aperture (current crowding) which causes producing large amount of the joule heating in the device.

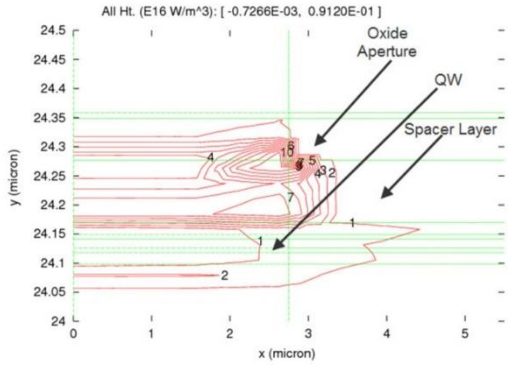

Figure 3: Heat density for 5.5 μm oxide aperture diameter VCSEL

The nonradiative recombination and absorption of spontaneous emission of light are two heat sources in the active region. Large amounts of heat flow radially toward the substrate from heat sources by conduction because the device is in contact with heat sink through bottom DBR and GaAs substrate. Partially, there was the heat extraction to the sides of the mesa through spacer layer and the top surface through top DBR as well as to contact pads in contact with air. Thus the generated heat in the upper part of device is more than the bottom.

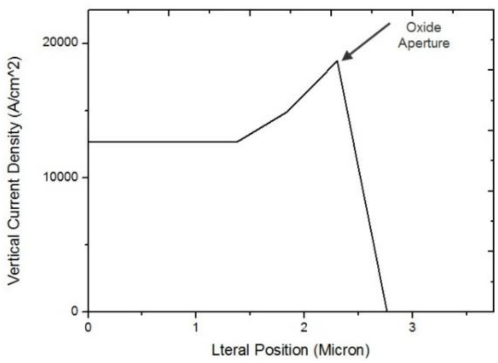

Figure 4: Vertical current density in lateral position for 5.5 μm oxide aperture diameter VCSEL

Figures 5 and 6 show the calculated temperature profile in lateral and vertical directions for devices with different oxide aperture diameters, respectively. The VCSEL mesa is 17 μm. The injected current and ambient temperature are 4 mA and 293K, respectively. From the lateral tempe - rature profiles in Figure 6, it is clear that the heat generated in the active region was filed up within the spacer layer including active region because the oxide aperture layer has a relatively low thermal conductivity. Then, the heat was spread out laterally through the spacer layer. The slightly low temperature distribution at the spacer layer is originated from the enhancement of heat removal through the top DBR.

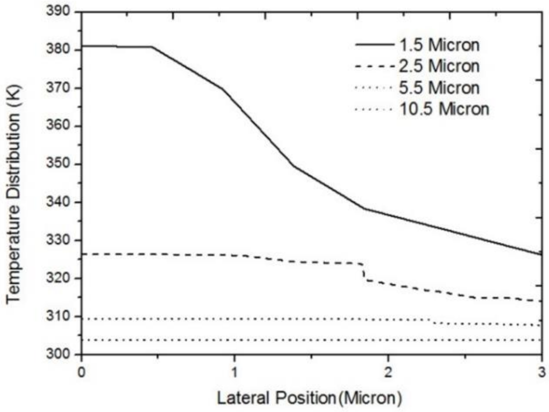

Figure 5: Calculated temperature profile in lateral position for VCSELs with different oxide aperture diameters

The temperature gradient between the active region and substrate is displayed in the vertical direction in Figure 6. It is indicating a dominant heat removal toward the substrate, and decreasing with the smaller aperture size.

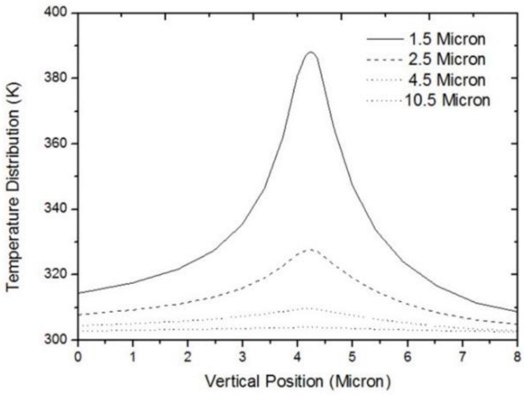

Figure 6: Calculated temperature profile in vertical position for VCSELs with different oxide aperture diameters

The maximum internal temperature, which is caused by the heat generated inside the device, was raised up to 390 K in the active region for VCSEL with 1.5 µm oxide aperture when the heat sink was kept at 293 K. Figure 7 shows the active region temperature rise as a function of oxide aperture diameter. By considering Figure 7, we notice that the heat source density becomes higher with decreasing oxide aperture size. For the narrower oxide aperture, the selectively oxide layer adjacent to the heat generation region extends over the larger area and it prevents the generated heat from spreading out in the lateral direction. Thus, the temperature inside device increased as the oxide aperture diameter decreased. This means that the thermal resistance increased as the oxide aperture diameter decreased.

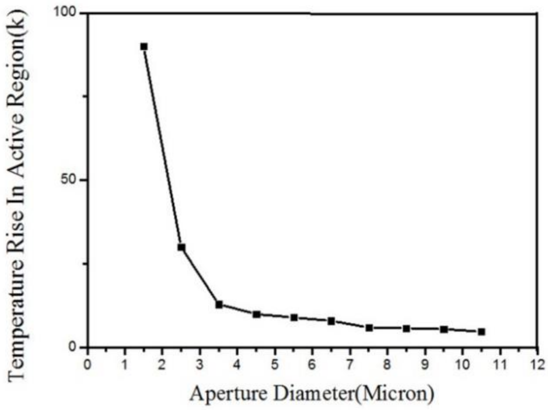

Figure 7: The temperature rise of a active region vs oxide aperture diameter

Simulation results show that by increasing the oxide aperture diameter, the active region temperature is around ambient temperature 293K. These results are in good agreement with other experimental reports [3].

4 Conclusion

The thermal analysis of 980 nm vertical cavity surface emitting lasers with different oxide aperture diameters is theoretically performed.

Simulation results show that Joule heating is the main heat source in device. Downsizing the oxide aperture causes a dramatic increase of the thermal resistance. This is attributed to the reduced initial escape area for the heat generated in the device.

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