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Design and Modeling of a Semiconductor Laser by Employing Silicon Carbide Polymers (6H-SiC, 3C-SiC and 4H-SiC)

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We present an edge emitting laser structure employing silicon carbide polymers only. In this structure, 3C-SiC well embedded in 6H-SiC barriers are used as the active region, which is sandwiched between the 6H-SiC mirror at the top and bottom of structure. The basic design goal is to use only silicon carbide polymers and decrease the threshold current and stable optical wavelength of the lasers with silicon carbide polymers. This paper provides key results of the device characteristics, including the light power *versus* electrical current and the optical wavelength *versus* current.

Key Words: Modeling, Silicon carbide polymers, Semiconductor laser.

INTRODUCTION

During the past decades, silicon carbide (SiC) has been use as a promising semiconductor material for high frequency, high temperature and high power optoelectronic devices[1]. Properties such as the large breakdown electric field strength, large saturated electron drift velocity, small dielectric constant, reasonably high electron mobility and high thermal conductivity make SiC an attractive candidate for fabricating power devices with reduced power losses and die size[2].

Silicon carbide has many stable poly type, including cubic zinc-blende, hexagonal and rhombohedral poly type. In the cubic zinc-blende structure, it is labeled as 3C-SiC or β-SiC, Si and C occupy ordered sites in a diamond framework. In hexagonal poly type *n*H-SiC and rhombohedral polytype *n* R-SiC, generally referred as αη-SiC. NSi-C bilayers consisting of C and Si layers stack in the primitive unit cell. Fig. 1 shows the lattice structures of the 3C-SiC and 6H-SiC phases, which are most important in this paper[3].

Diode laser emitting at 1.23 μm is used for pumping of light in optical fibers and local area networks. Fundamental changes in improvement of edge emitting laser cause increasing power and speed and decreasing threshold current[4].

Present work has improved the structure of an edge emitting laser which 3C-SiC well embedded in 6H-SiC barriers are used as the active region. After discussing the basis for modeling laser, we present a new structure of edge emitting laser and results are presented.

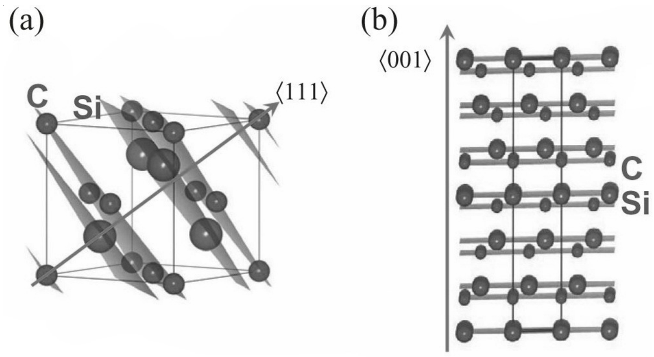

Fig. 1. (a) Unit cell of cubic 3C-SiC; (b) Four unit cells of hexagonal 6H-SiC

THEORY AND MODEL

In modeling edge emitting laser, we must consider electrical and optical interaction during laser performance. Thus base of simulation is to solve Poisson and continuity equations for electrons and holes[5]. Poisson's equation is defined by:

$$\nabla.(\varepsilon\nabla\psi)=\rho \qquad (1)$$

where, ψ is electrostatic potential, ρ is local charge density and ε is local permittivity. The continuity equations of electron and hole are given by previous report[5]:

$$\frac{dn}{dt}=G_n-R_n+\frac{1}{q}\nabla.j_n \qquad (2)$$

$$\frac{dp}{dt} = G_p - R_p + \frac{1}{q}\nabla.j_p \qquad (3)$$

where, n and p are the electron and hole concentration, J_n and J_p are the electron and hole current densities, G_n and G_p are the generation rates for electrons and holes, R_n and R_p are the recombination rates and q is the magnitude of electron charge.

The fundamental semiconductor equations (1)-(3) are solved self-consistently together with Helmholtz and the photon rate equations. The applied technique for solution of Helmholtz equation is based on improved effective index model[6], which shows accuracy for great portion of preliminary problems. This model is good adapted to simulation of laser structures and it is often called effective frequency method[7].

Two-dimensional Helmholtz equation is solved to determine the transverse optical field profile and it is given by previous work[5]:

$$\nabla^2 E(r,z,\varphi) + \frac{\omega_0}{c^2}\varepsilon(r,z,\varphi,\omega)E(r,z,\varphi) = 0 \qquad (4)$$

where ω is the frequency, ε(r, z, φ, ω) is the complex dielectric permittivity, E(r, z, φ) is the optical electric field and c is the speed of light in vacuum. The light power equation relates electrical and optical models. The photon rate equation is given by[5]:

$$\frac{dS_m}{dt} = \left(\frac{c}{N_{eff}}G_m - \frac{1}{\tau_{ph_m}} - \frac{cL}{N_{eff}}\right)S_m + R_{sp_m} \qquad (5)$$

where, S_m is the photon number, G_m is the modal gain, R_{sp_m} is the modal spontaneous emission rate, L represents the losses in the laser, N_{eff} is the group effective refractive index, τ_{ph_m} is the modal photon lifetime and c is the speed of light in vacuum.

Eqn. (1)-(5) provide an approach that can account for the mutual dependence of electrical and optical. Fig. 2 shows the schematic design of 1.23 μm laser device. In this structure, the active region consists of two 1600-nm thick 6H-SiC barrier and 150-nm thick 3C-SiC quantum well (QW). The active region is limited with 6H-SiC layers with different thick. Substrate material is 5500-nm thick 4H-SiC.

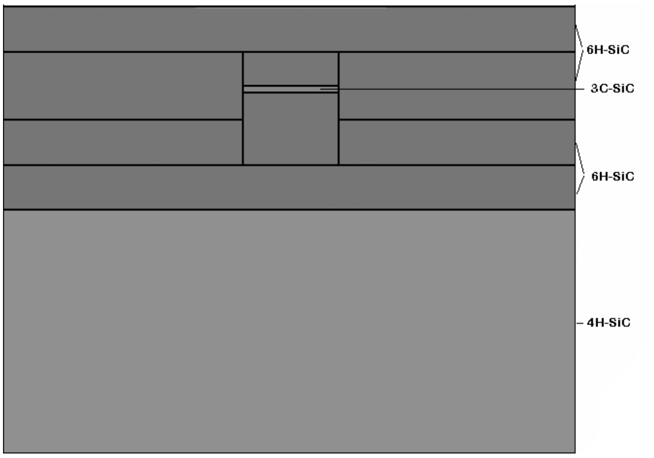

Fig. 2. Schematic structure of the laser device

RESULTS AND DISCUSSION

In this paper, we have used the 6H-SiC/3C-SiC edge emitting laser and have evaluated the effect of these materials on the device characteristics such as voltage- current (V-I), light-current (L-I). Results are for room temperature.

Fig. 3 shows the light-current (L-I) curve at 20 ºC, when the bias current increases from 0 to 0.35 mA. It can be found that the increase of bias current from 0 to 0.35 mA, leads to the higher power. The 6 um device shown in Fig. 3 is capable of more than 1 mW output power where the threshold current is about 2.853 μA. However, by increasing the bias current, the maximum output power reaches saturation because maximum output power is limited by heating. Recent device modeling shows that spatial hole burning and leakage over the carrier confinement barriers are limiting the output power as the device heats up. As the temperature rises due to resistive heating, leakage over the 6H-SiC barriers starts to dominate over other recombination mechanisms.

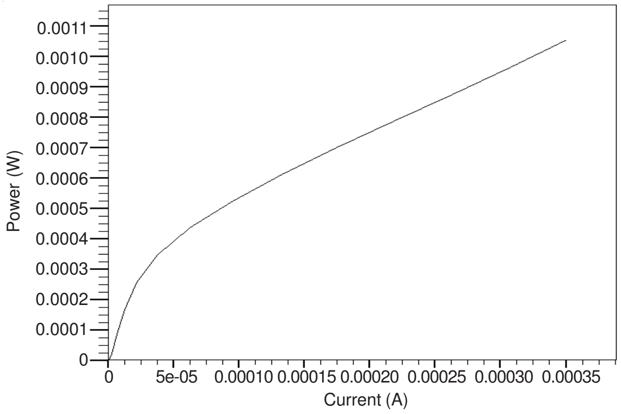

Fig. 3. Light-current (L-I) curve

Fig. 4 shows the optical wavelength for different quantities of current. As shown, the increment in the quantity of current does not affect the optical wavelength curves. The figure clearly shows that the optical wavelength is very stable different quantities of current because for minimum beam divergence, we would like the laser to be operating in its fundamental mode.

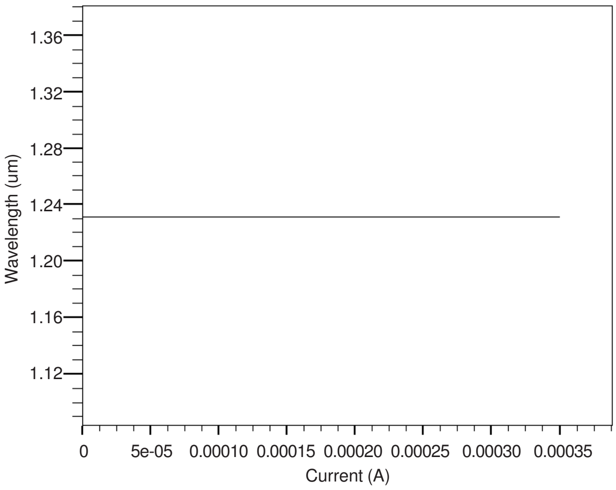

Fig. 4. Optical wavelength for different quantity of the bios current

Conclusion

In this paper, we have developed an edge emitting laser structure operating in the 1230 nm wavelength regime. The basic design goal was to use silicon carbide polymers and decrease the threshold current and stable optical wavelength of the lasers with silicon carbide polymers. Present device is capable of more than 1 mW output power where the threshold current is about 2.853 µA.

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