OCSim Modules (Lasers: Carrier Density and Optical Power of Laser Diodes for DC Currents)

MODULE 7: LASERS: CARRIER DENSITY AND OPTICAL POWER OF LASER DIODES FOR DC CURRENTS

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OCSim Advanced Level Software Modules

Softwares for Fiber Optic Communication Systems

Module 7: Lasers: Carrier Density and Optical Power of Laser Diodes for DC Currents

Scientific Manual

Background Theory and Formulation of the Module

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Laser Rate Equations

Background Theory and Formulation of the Module

In semiconductor lasers, the rate of change of carrier density and photon density are given by,

$$\frac{dN_e}{dt} = R_{pump} + R_{stim} + R_{sp} + R_{nr}$$

$$= R_{pump} - GN_{ph} - \frac{N_e}{\tau_e} \quad (1)$$

$$\frac{dN_{ph}}{dt} = R_{stim} + R_{sp} + R_{loss}$$

$$= GN_{ph} + R_{sp} - \frac{N_{ph}}{\tau_{ph}} \quad (2)$$

Here, N_e is carrier density, N_{ph} is photon density, τ_e is the lifetime of carriers associated with spontaneous emission and non-radiative transition, τ_{ph} is the photon lifetime, G is the gain rate given by,

$$G = \Gamma g v \quad (3)$$

where Γ is confinement factor which is the ratio of optical power in the active region to the total optical power carried by the mode, g is the gain coefficient and v is the speed of light in the gain medium. R_{sp} is the spontaneous emission rate. R_{pump} is the electron pumping rate per unit volume given by,

$$R_{pump} = \frac{I}{qdwL} \tag{4}$$

where d, w and L are thickness, width and length of the active layer, respectively, as shown in Fig. 1b. Using Eq. (4) in Eqs. (1) and (2) and after ignoring emission,

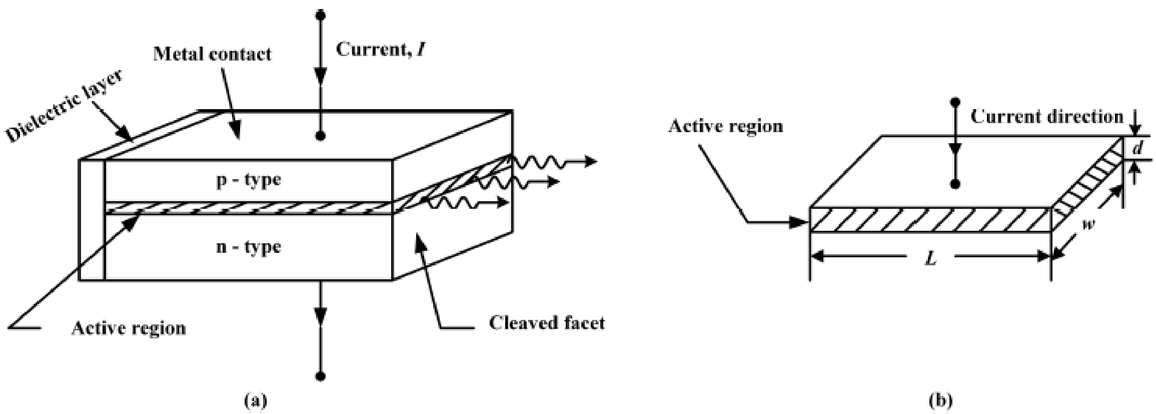


Figure 1. (a) Forward-biased heterojunction laser (b) Active region.

we find,

$$\frac{dN_e}{dt} = \frac{1}{qV} - GN_{ph} - \frac{N_e}{\tau_e} \tag{5}$$

$$\frac{dN_{ph}}{dt} = GN_{ph} - \frac{N_{ph}}{\tau_{ph}} \tag{6}$$

The gain coefficient g may be approximated as,

$$g = \sigma_g(N_e - N_{e0}) \tag{7}$$

where σ_g and N_{e0} are the parameters that depend on the specific design. σ_g is called the gain cross-section and N_{e0} is the value of the carrier density at which the gain coefficient becomes zero. Using Eq. (3), we find,

$$G = \Gamma g v = G_0(N_e - N_{e0}) \tag{8}$$

where

$$G_0 = \Gamma \sigma_g v \tag{9}$$

Under steady state conditions, the time derivatives in Eqs. (5) and (6) can be set to zero,

$$\frac{dN_{ph}}{dt} = \frac{dN_e}{dt} = 0 \tag{10}$$

From Eq. (6), we have,

$$G\tau_{ph} = 1 \tag{11}$$

Using Eq. (8), we obtain,

$$G_0(N_e - N_{e0})\tau_{ph} = 1 \tag{12}$$

$$N_e = N_{e0} + \frac{1}{G_0\tau_{ph}} \tag{13}$$

From Eq. (11), it follows that,

$$\Gamma g = \alpha_{cav} \tag{14}$$

where α_{cav}, is the cavity loss coefficient. This is a restatement of the fact that gain should be equal to loss. If the current I is very small, there will not be enough electrons in the conduction band to achieve population inversion. In this case, the gain coefficient will be much smaller than the loss coefficient and photons will not build up. For a certain current I, the gain coefficient Γg becomes equal to the loss coefficient α_{cav}, and this current is known as threshold current, I_{th}. If $I > I_{th}$, stimulated emission could become the dominant effect and the photon density could be significant. Under steady state conditions, there are two possibilities.

Case (i): $I = I_{th-}$: Stimulated emission is negligible and $N_{ph} \cong 0$,

$$\frac{dN_e}{dt} = -\frac{N_e}{\tau_e} + \frac{1}{qV} = 0 \tag{15}$$

Let $N_e = N_{e,th}$. From Eq. (15), we have,

$$I_{th} = \frac{N_{e,th} qV}{\tau_e} \tag{16}$$

From Eq. (13), we have,

$$N_{e,th} = N_{e0} + \frac{1}{G_0 \tau_{ph}} \tag{17}$$

Case (ii): $I > I_{th}$: When the current exceeds threshold current, one may expect that the electron density N_e to be larger than $N_{e,th}$. However, the electron density will be clamped to $N_{e,th}$ when $I > I_{th}$. This can be explained as follows. The threshold current is the minimum current required to achieve population inversion. When $I > I_{th}$, the excess electrons in the conduction band recombine with holes and therefore, the photon density increases while the electron density would maintain its value at threshold. Using Eqs. (10) and (11) in Eq. (5), we obtain,

$$\frac{N_{ph}}{\tau_{ph}} = \frac{1}{qV} - \frac{N_{e,th}}{\tau_e} \tag{18}$$

Using Eq. (16), Eq. (18) can be written as,

$$N_{ph} = \frac{(I - I_{th})\tau_{ph}}{qV} \tag{19}$$

The mean optical power generated can be written as,

$$P_{gen} = N_{ph}\hbar\omega\upsilon A \tag{20}$$

where A is the effective cross-section of the mode, $\hbar$ is the reduced Planck constant and ω is the angular frequency. Using Eq. (19) in Eq. (20), we finally obtain,

$$P_{gen} = \frac{(I - I_{th})\tau_{ph}\hbar\omega\upsilon A}{q\omega dL} \tag{21}$$

Note that the above equation is valid only when $I > I_{th}$. If $I \leq I_{th}$, $P_{gen=}0$ under our approximations.

Company Researchers & Developers

Integrate the Modules with your in-house and Commercial Software & Hardware Products

(1) Modify the Source Code Modules / Components to the Next Level for Your Research Papers, Research Projects and Theses.

(2) Integrate Different Source Code Modules / Components in the OCSim Package to Realize Your Own Fiber Optic Communication Systems.

(3) Use the Existing Source Code Modules / Components for Your Research Papers, Research Projects and Theses.

(4) Use the Existing Source Code Modules for Laboratory Simulation Experiments and Exercises.

Simulation of Carrier Density and Optical Power of Laser Diodes for DC Currents

Source Code File

Main File : laser diode.m

The laser rate equations in a laser diode are simulated to obtain the photon density and carrier density.

The main file calls the following function:

(1) rate_eqn.m: solves the laser rate equations in a laser diode.

Explore Further this Module:

1. **Choose** a drive current I_0 to be more than the threshold current. **Plot** the carrier density as a function of time. Under stead state conditions (large T), **compare** the carrier density with the threshold carrier density N_{ph}. **Provide explanation**. **Compare** the power generated under steady state conditions with the analytical calculations.

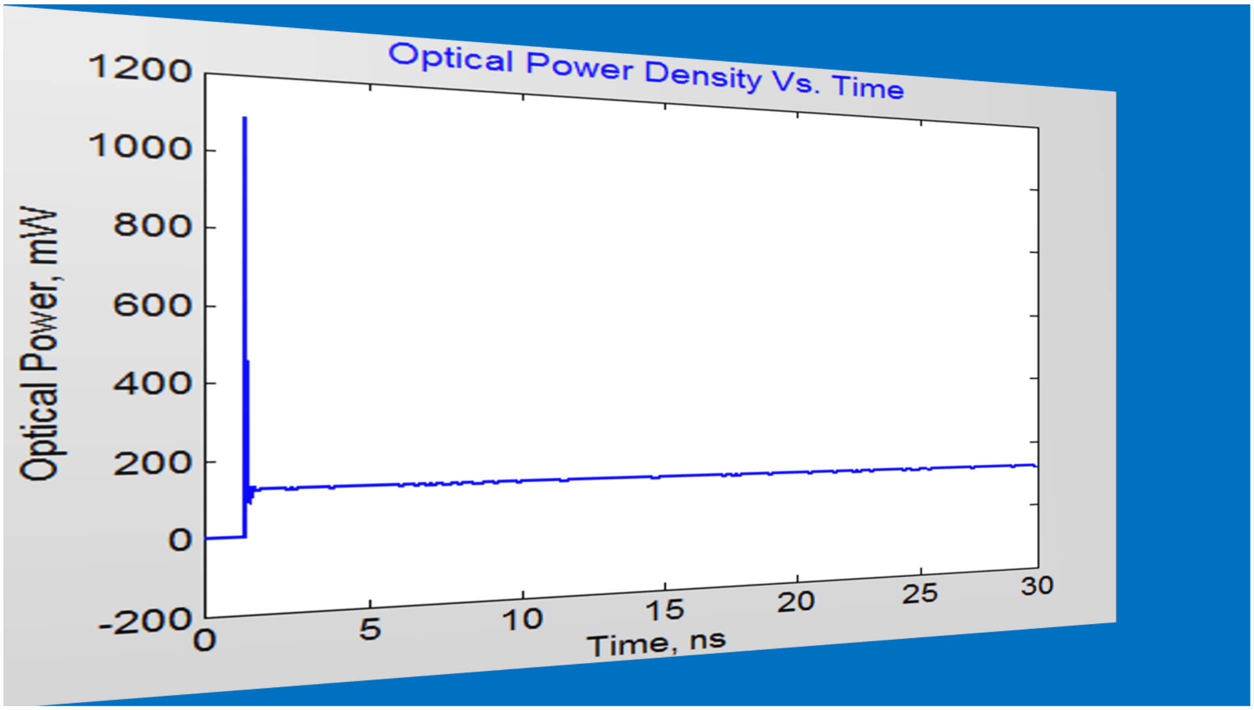
2. **Choose** a drive current that is less than the threshold current. **Plot** the power generated as a function of time. Is the generated power significant? **Explain** your findings.

3. **Change** the value of the drive current, I_0 from I_{th} (threshold current) to 2 I_{th} with a suitable increment and **plot** the steady state power generated (at tfinal) as a function of the drive current. This curve is known as P-I curve.

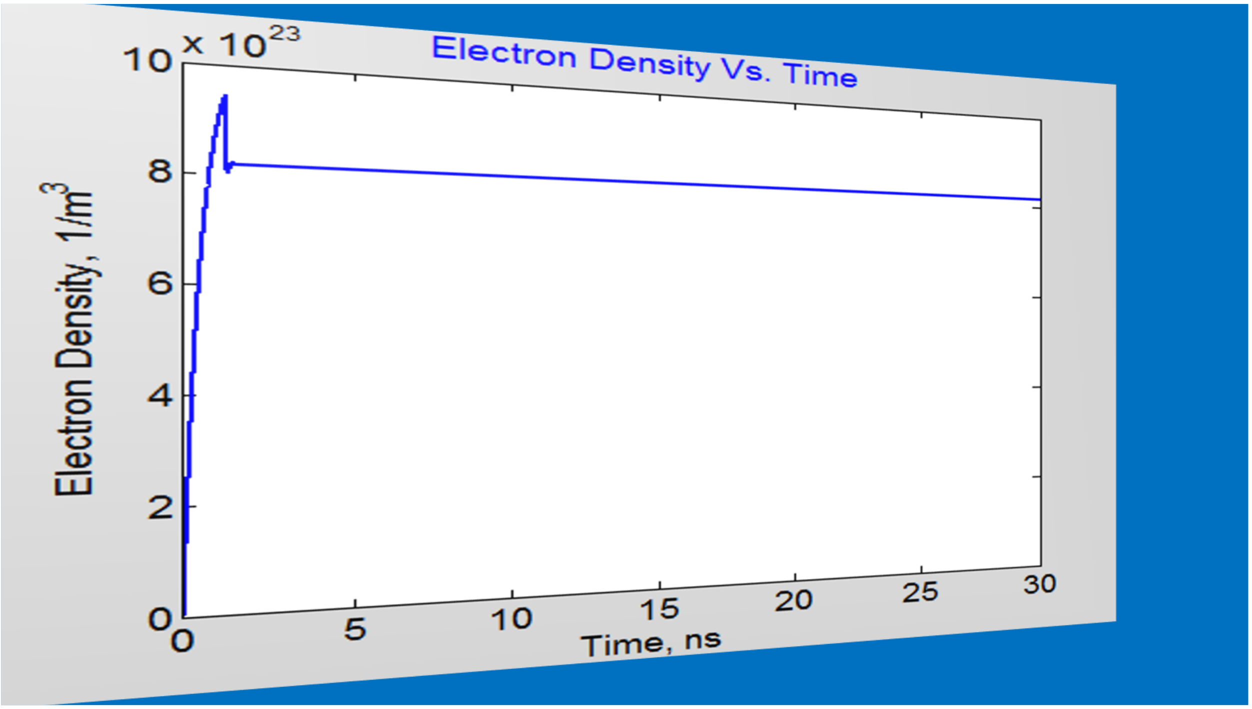
   Note: At larger drive currents, tolerances for ode45 may have to be changed.

Selected Simulated Results Using this Module

Electron Density Vs. Time



Optical Power Density Vs. Time



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