Calculation and Simulation of Passive Q-Switching Diode Laser Parameters

M. M. KARKHANEHCHI, F. PARANDIN
Dept. of Electronic,
Faculty of Engineering,
Razi University
Behshti boulevard, Taghbostan, Kermanshah
IRAN

Abstract:- In this paper, the parameters of the passive Q-switched semiconductor laser were calculated. First of all, the mathematical model of such a laser was obtained and then these equations were solved analytically. The equations were included three nonlinear equations, which describe the changes of carriers and photons. In solving these equations, two cases were considered. First, when the laser is generating the optical pulses, and the laser characteristics, including pulse width and the generated photons were obtained. Secondly, when the laser was not generated any optical pulses. Using these two cases, one can obtain the repetition rate of the optical pulses, threshold current density and carrier density in threshold point. Finally, the effect of the normalization current values and the other laser parameters were investigated in output laser characteristics.

Key-Words: laser diode, Q-Switching, two section laser, nonlinear effect.

1 Introduction

Passive Q-Switching diode lasers have two sections: one section, which is longer and forward biased, is called optical gain, and other section, which is smaller and reverse biased, is called saturable absorber and generate optical pulses . In fact, saturable absorber part, absorb the generated photons in gain section until saturate and then no longer photons absorbed, then the optical pulses are generated at this time. With photons emission, carriers decrease in gain region and gain value is decreased. At the same time, carriers in absorber section are bleach until decrease to saturated values. But, because of decreasing losses are much higher than decreasing gain, the gain value is larger than the losses and optical pulses are generated. Until gain value is lower than loss value and optical pulses are cut off[1].

Fig. 1 is shown the schematic of a passive Q-Switching two section semiconductor laser.

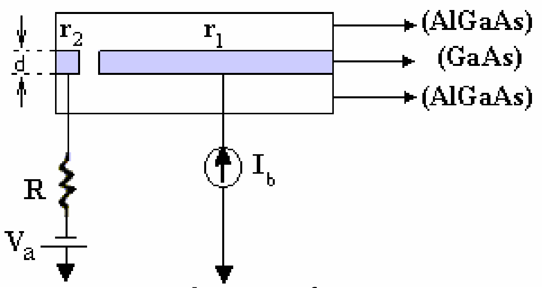

Fig.1: Schematic of a passive Q-Switching two section laser

Where r_1 and r_2 is gain and saturable absorber length, respectivily

2 Mathematical Model and Solution of Equations

The equations, which can be written for gain and absorber section, are [2]:

$$\frac{dn_1}{dt} = \frac{J}{ed} - \frac{n_1}{\tau_1} - v_g g S \qquad (1)$$

$$\frac{dn_2}{dt} = -\frac{n_2}{\tau_2} + v_g \alpha S \qquad (2)$$

The values of g and α may be written as (the effect of nonlinear gain is not considered):

$$g = a_1(n_1 - N_{g_1}) \quad (3)$$

$$\alpha = a_2(N_{g2} - n_2) \quad (4)$$

Also, the rate change of photons may be written as (spontaneous emission is not considered):

$$\frac{dS}{dt} = [\Gamma v_g f_1 g - \Gamma v_g f_2 \alpha - \frac{1}{\tau_{ph}}]S \quad (5)$$

To solve these equations analytically, the following assumptions are considered [3].

1. When optical pulses are generated, the rate changes of the carrier density in saturable absorber, from the beginning of pulses, are very fast.
2. From the beginning of optical pulses generation, the rate change of photons in gain section are very high.
3. The pulsewidth is lower than repetition rate.

Now, to solve these equations, two cases are considered. One case is when the laser is emitting optical pulses, and with considering assumption 1 to 3, the pulsewidth and amplitude of optical pulses can be obtained. The other case is when the laser is not emitting optical pulses, and in this case, the repetition rate of optical pulses can be obtained.

The pulsewidth can be written as [4]:

$$\tau = \frac{2\tau_{ph}}{1+\tau_{ph}v_g\Gamma f_2 a_2 N_{g_2}}\left(A\frac{\Gamma\tau_2 v_g f_2 a_2^2 N_{g_2}}{(a_1 - \frac{a_1^2}{\Gamma\tau_2 v_g f_2 a_2^2 N_{g_2}})} - 1\right) \quad (6)$$

The pulse amplitude can be obtained as:

$$p = \frac{1}{\tau}(E_1 - \frac{S_0}{v_g \Gamma f_2 a_2 N_{g_2}}) \quad (7)$$

where $S_0 = \frac{1}{v_g a_2 \tau_2}$ and $E_1 = \frac{1}{v_g a_1}$.

For calculating threshold current, the laser in threshold lasing is considered. In this case $\frac{dn_1}{dt} = \frac{dn_2}{dt} = 0$, $S = 0$, because pulse is not yet generated. Also, the rate of photons density is zero[5].

Then, from equation (1) the threshold current density is calculated as:

$$J_{th} = \frac{ed}{\tau_1} n_{th} \quad (8)$$

In which n_{th} is calculated from equations (3) and (5), then [4]:

$$n_{th} = N_{g1} + \frac{r_2 a_2}{r_1 a_1} N_{g1} + \frac{1}{v_g \Gamma f_1 a_1 \tau_{ph}} \quad (9)$$

After solving this integral, the repetition rate in term of normalization current is obtained as [4].

$$f = \frac{1}{T} = \left(\tau_1 \ln\left(1 + \frac{\frac{\Delta n}{n_{th}}}{\frac{J}{J_{th}} - 1}\right) \right)^{-1} \quad (10)$$

In which Δn is decrement of the carrier density after lasing.

3 Simulation Results

The parameters, which are used in computer calculations for passive Q-Switching two section laser diode, are in table (1). The repetition rate in terms of normalization current $(\frac{J}{J_{th}})$ is shown in Fig. 2. It shows that the repetition rate of output optical pulses for passive Q-Switching semiconductor laser increases with increasing input current [4].

Table1:Laser diode parameters used in computation

Parameter	symbol	value	unit
Active layer thickness	d	0.2	μm
Laser cavity length	L	300	μm
Internal losses	α_i	20	cm^{-1}
Gain section fraction	f_1	0.9	-
Absorber section fraction	f_2	0.1	-
Confinement factor	Γ	0.3	-
Group velocity of light	v_g	7.5×10^7	m/s
Carrier lifetime in gain	τ_1	1×10^{-9}	s
Carrier lifetime in absorber	τ_2	2×10^{-11}	s
Carrier density for transparency in gain section	N_{g_1}	1.4×10^{18}	cm^{-3}
Carrier density for transparency in absorber section	N_{g_2}	1.4×10^{18}	cm^{-3}
Differential gain parameter	a_1	2×10^{-16}	cm^2
Differential absorption parameter	a_2	6×10^{-16}	cm^2

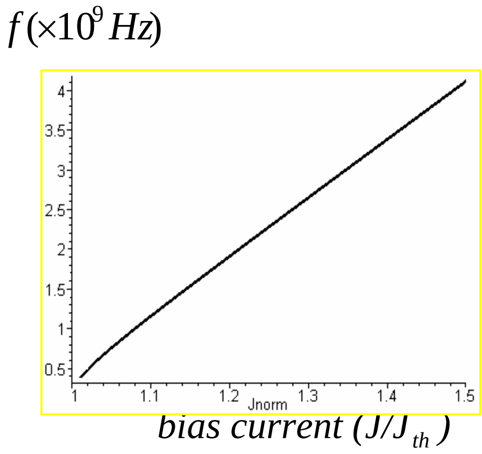

Fig. 2: The repetition rate of optical pulses in terms of normalization current

The characterization of the output laser light is changed when changing the gain and absorber length. These changes are shown in fig. 3 [4]. From this figure, it is obvious that the repetition rate, pulsewidth and threshold current are decreased when the gain length is increased and also output power increases. Therefore, to generate short optical pulses, the gain length must be larger than the absorber length. Normally, the gain length is chosen 90% till 95% of the total cavity length.

4 Conclusion

In this paper, the passive Q-switched laser diode is analyzed and simulated. First, the equations for this kind of laser is solved analytically and then the characteristics of output optical pulses which contain pulsewidth, repetition rate, threshold current and the generated photons are obtained. Then, the changes of the optical pulse characteristics are obtained in terms of the physical parameters such as gain length and input current.

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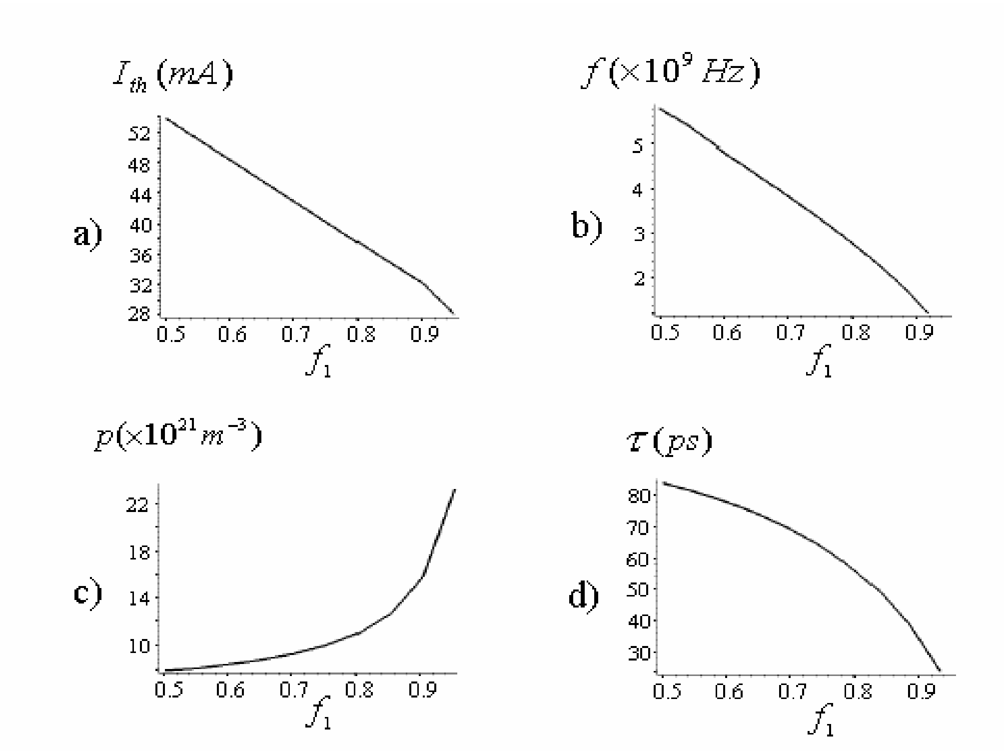

Fig. 3. The characteristics of output laser light in terms of the gain length

a) threshold current b) repetition rate

c) the rate of generated photons d) pulsewidth