J. Basic. Appl. Sci. Res., 2(4)4079-4084, 2012
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ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

The effective factors on threshold conditions in laser diode Passive Q-Switching

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ABSTRACT

In this paper, semi-conductor passive Q-switching laser is studied and threshold conditions including density of threshold current and concentration of carriers are calculated in laser threshold. To calculate these parameters, at first a mathematical model for laser is presented including three non-linear equations. These equations are solved by considering a series of assumptions as analytical. Then, the influence of different parameters of laser such as carriers life, fraction of gain length and the thickness of active layer on density of threshold current is investigated and presented in the chart.
KEYWORDS: Passive Q-switching; gain; absorber; semiconductor; Photons.

INTRODUCTION

Semiconductor passive Q-switching laser is one of different kinds of two or multi-parts lasers consisting of two main zones of saturable absorber and gain saturated.

These lasers are used to produce narrow-band optical pulse and depending on the type of bias are divided into two groups:

1. Semi-conductor active Q-switching laser
2. Semi-conductor passive Q-switching laser

These lasers are equal from physical structure point but they are different from applying stimulation current and the performance is different.

Figure (1) shows the structure of two types of semi-conductor active Q-switching laser (a) and semi-conductor passive Q-switching laser (b).

In these types of lasers, the gain part is taller is forward biased and by reverse congestion the condition is provided to produce photon. The other part is shorter and it is called saturable absorber and is reversed biased in order that by absorbing photon and instabilities produce optical pulses [1].

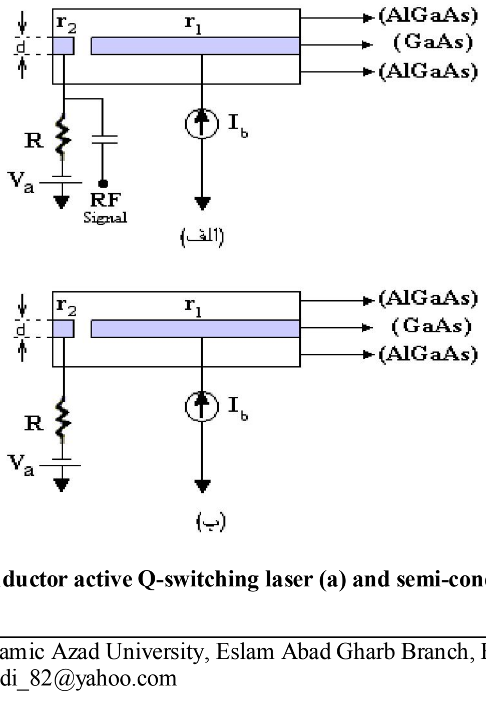

Figure (1): two types of semi-conductor active Q-switching laser (a) and semi-conductor passive Q-switching laser (b)

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In the active type, a modulator electrical signal is app lied to saturable absorber section to act as external cavity absorber and loss modulator. When an electric pulse is applied to this section, peak pulse makes this section in a short moment forward biased and carriers are saturated and then the produced photons in the gain section are not absorbed and optical pulse is.

Figure (2) shows the chart of loss, gain and optical pulse in time in active Q-switching laser [2].

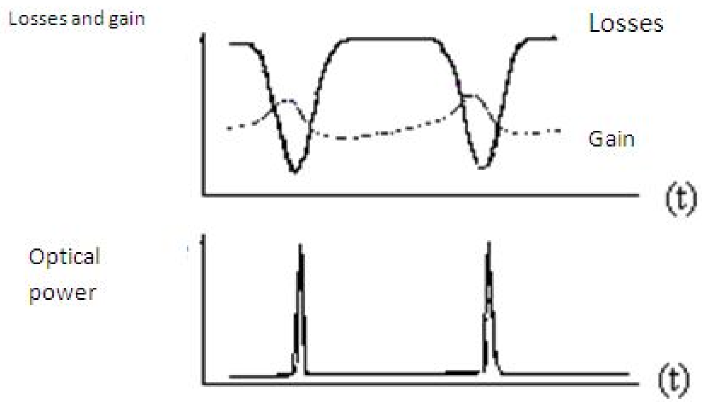

Figure (2): Displaying loss, gain and optical power in active Q-switching laser

The calculation of threshold current

Mathematical model that can be written for semi-conductor Q-switching laser is including 3 non-linear equations describing the rate of carrier's density changes in the gain and absorber and the rate of density changes of photons in gain section.

The equation of changes rate of carriers' density in two sections of laser is written as the followings [2]:

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

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

Also, the equation of photons changes is as the followings [2]:

$$\frac{dS}{dt} = [\Gamma v_g f_1 g - \Gamma v_g f_2 \alpha - \frac{1}{\tau_{ph}}]S \qquad (3)$$

In previous equations, n_1, n_2 are respectively concentration of carriers in gain section and saturable absorber and S is density of the photons produces in gain section. Parameter g is gain coefficient in gain section and α is gain coefficient in saturable absorber and by ignoring non-linear effect of gain are calculated from the following equations:

$$g = a_1(n_1 - N_{g_1}) \text{ و } \alpha = a_2(N_{g2} - n_2) \qquad (4)$$

An equation for photons life is written as the followings [4]:

$$\tau_{ph} = \frac{1}{v_g(\alpha_m + \alpha_i)} \qquad (5)$$

Where α_i is internal loss and α_m mirrors loss and is achieved by the following equation [5]:

$$\alpha_m = \frac{1}{2L}\ln\frac{1}{R_1 R_2} \qquad (6)$$

To solve equations we assume that laser is producing pulse and we consider one pulse of it. If τ is pulse width and p is pulse amplitude, the equation being compatible with the shape of pulse, is a hyperbolic secant equation.

During production of pulse, losses changes (α) is very rapid and this means that the changes of carriers density in saturable absorber section was rapid from the beginning of pulse as during production of pulse we can assume that these changes equal zero and equation $\frac{dn_2}{dt} = 0$ is established.

Now density of carriers is gained in absorber section. Also, at this time, as the number of produced photons is very much in gain section, equation (1) can be simplified and calculate the density of carriers in gain section.
To calculate threshold current, we consider the time laser didn't produce pulse and it is in the threshold of laser starting. At laser starting time, carriers are reversely congested in gain section and are saturated in absorber and other concentration of carriers is fixed in two zones. It means that equation $\frac{dn_1}{dt} = \frac{dn_2}{dt} = 0$ is established and as no pulse is generated yet, S=0 equation is true and the changes of photons density is zero.
Now, the carriers' concentration in gain section is given by equations (2) and (3) and this is the same as threshold concentration density [3]:

$$n_{th} = N_{g1} + \frac{r_2 a_2}{r_1 a_1} N_{g1} + \frac{1}{v_g \Gamma f_1 a_1 \tau_{ph}} \qquad (7)$$

Now by equation (1) we can obtain the density of threshold current.

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

Thus, threshold current is calculated as the followings:

$$I_{th} = eV_1 \left(\frac{n_{th}}{\tau_1}\right) \qquad (9)$$

Where, V_1 is the volume of active section.

Computer calculations and charts

As it is shown in equation (9), threshold current is dependent upon some parameters such as life time of carriers in gain section and the volume of active section and also the length of gain section and density of threshold current and the density of threshold current is dependent upon other parameters of laser.

Here we show dependency of threshold current to some parameters such as fraction of gain length, life time of gain carriers and thickness of active layer in the chart [6].
The parameters being used for computer analysis of laser are shown in table (1) [2].
Figure (3) shows the chart of threshold current in carriers' lifetime in gain section.

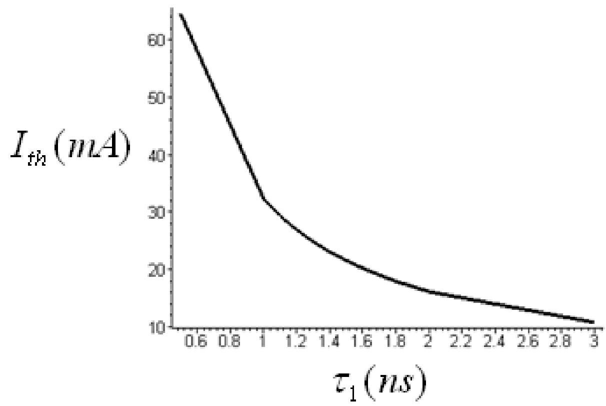

Figure (3): The chart of threshold current in carriers' lifetime in gain section

As it is shown in the chart, to reduce threshold current, carriers lifetime should be very much in gain section. Figure (4) shows threshold current chart in ratio to gain length fraction. Considering the chart we can say that the longer the length of gain section in comparison to the length of absorber section, threshold current is reduced. Practically, the length of gain is selected 90% to 95% of cavity total length.

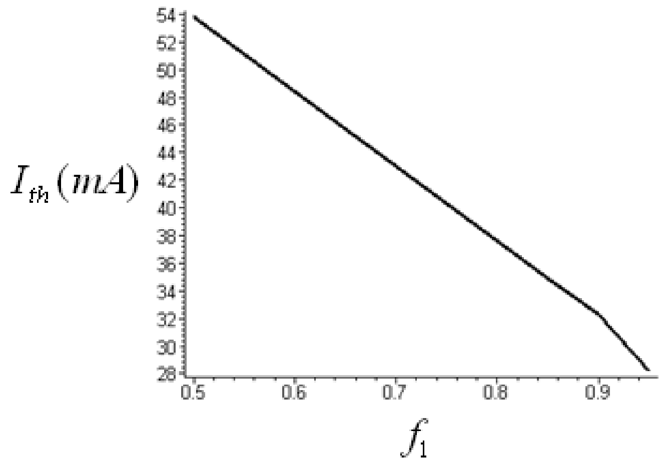

Figure (4): The chart of threshold current in gain length fraction (f_1)

Threshold current changers chart in thickness of active layer is shown in figure (5).

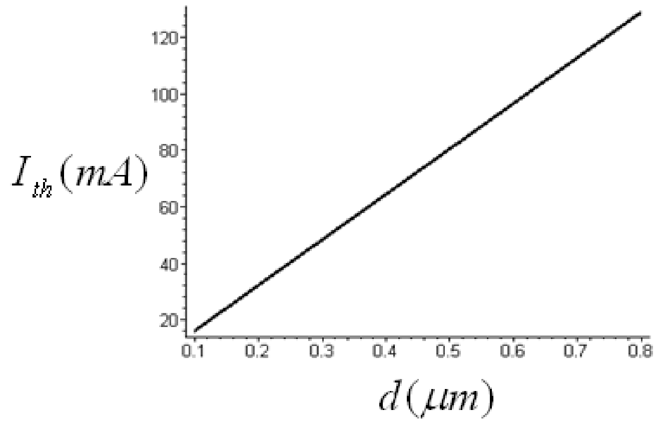

Figure (5): Threshold current chart in thickness of active layer (d)

It is seen that by increasing the thickness of active layer, threshold current is increased. Thus, for building laser, it is attempted to select the thickness of active layer as smaller.

Conclusion

In this paper, semi-conductor passive Q-switching laser is analyzed and threshold condtions is considered for passive laser. At first we obtained density of threshold current for these types of lasers and studied the effective factors on threshold conditions. Then, the changes of threshold current density are shown in the chart according to the related effective factors.

Table (1): The parameters being used in computer calculations

parameter	symbol	Value	
Thickness of active layer	d	0.2 μm	
The length of laser cavity	L	300 μm	
width of active section	y	2 μm	in gain section
Internal losses	α_i	20 cm^{-1}	
Gain length	$f_1 = \frac{r_1}{L}$	0.9	fraction
Absorber length	$f_2 = \frac{r_2}{L}$	0.1	fraction
Optical constraint	Γ	0.3	coefficient
Group speed of photon	V_g	7.5×10^7 m/s	
Carriers' lifetime in gain section	τ_1	1×10^{-9} s	
Carriers' lifetime in absorber section	τ_2	2×10^{-11} s	

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