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Modeling and Simulation of an All Optical Flip Flop Based on Gain Clamped Semiconductor Optical Amplifier

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***Abstract* — In this article, modeling and simulation of an all optical flip flop based on gain clamped semiconductor optical amplifier according to distributed bragg reflectors by extensive band model of wave diffusion in time domain has been analyzed by finite difference time method through MATLAB. Factors such as material profile in grating waveguide constructions, optical field length changes, carrier density, and extensive band spontaneous noise dispatch has been mentioned in this simulation. Besides, bistability property which is the required element of the flip flop function will be used. The effect of the input optical power parameter and designing active region length change parameter in the function of the segment was analyzed.**

***Keyword* — Gain Clamped Semiconductor Optical Amplifier (GC-SOA), All Optical flip flop (AOff), Distributed bragg reflector (DBR), bistablility property.**

1. INTRODUCTION

In the communication era and ongoing need increase of optical telecommunication networks capacity, make researchers to present some solutions in eliminating current system limitations and consider the optimization of the new optical implements design for the use of all optical systems. Nonlinear optical phenomenon like optical bistability is a factor which works as the base of the function behavior of the semiconductor optical laser construction [4]. Optical amplifier is one of the components of compensating the fibro and other optical implements adjoint losses uses. One of the optical amplifiers which are usually acts as a power amplifier and pre-amplifier in telecommunication links is semiconductor optical amplifiers. This segment in the optical electronic complex imports has been used widely [5]. This bistability property originates from the effect of distribute carriers resonance on the attribute of the threshold bragg reflector (DBR). bistability curve depends on the DBR laser parameters. Optical injection along with the out of the network disconnection band frequency caused carriers' non-uniform distribution, which increases the threshold of the optical amplifiers. This causes the hysteresis effect, which can be used for turning the laser on and off. Semiconductor optical amplifiers are using for constructing flip flops; but because they have low output saturation power and show high number of noise in their operations which this makes limitations in applications with high rates in multiplex division of wavelength systems [2]. Some solutions presented for eliminating these errors which uses for increasing the output saturation power from DBR and DFB gratings with accumulated semiconductor optical amplifiers in a uniform way. These amplifiers are called Gain Clamped Semiconductor Optical Amplifier (GC-SOA). All optical flip flop is one of the main factors because of its short term memory element application [3]. Normally flip flops are designed based on a bistability with the switching ability between two different states through the use of short optical pulses.

2. SEGMENT APPLICATION BASE

The output of this flip flop is occurred based on the optical bistablility in gain clamped semiconductor optical amplifier (GC-SOA) when the input signal power Pin placed on the two bifurcation of the bistablility picture; That is, Pin=PH described in figure 1. The output signal power with Pin changes through higher powers in lower powers from switching threshold on the bifurcation can change between and Optical Set is shown with the increase in optical power with more than upward switching threshold [6]. this is happen because of the increase in optical power in SOA causes increase in pair recombination of electron - hole and this increases the refractive coefficient on its own and because of that signal, it increases the wave number and optical phase and with approaching the bragg resonance with the wave length signal, the inner optical power, non-linear refractive coefficient, and the bragg resonance will be shifted through wavelength signal.

Flip flop will be reset with decrease in input power more than the hysteresis curve downward switching threshold. Decrease in higher power in GC-SOA make the wavelength signal further from the required amount of recombination of electron – hole; as a result decrease in power and resonance return to the primary state will be occurred.

With the decrease in input power and Reset occurrence, when in a resonance passes through wavelength signals, a positive feedback loop (acting against the behavior of switch to high) shifts the resonance bragg toward the shorter wavelength and lower output power from .The construction of all optical flip flop based on gain clamped semiconductor optical amplifier AOFF-GC-SOA is in a way that in this segment leasing swing is happening through optical feedback of the selected wavelength from the bragg distributed grating which is located in both sides of active region. losses of DBR inactive part assumed 500m^{-1}. In active region In$_{1-x}$Ga$_x$As$_y$P$_{1-y}$ with 1.595 wavelength was utilized. The used parameters in this simulation are presented in the Table(1).

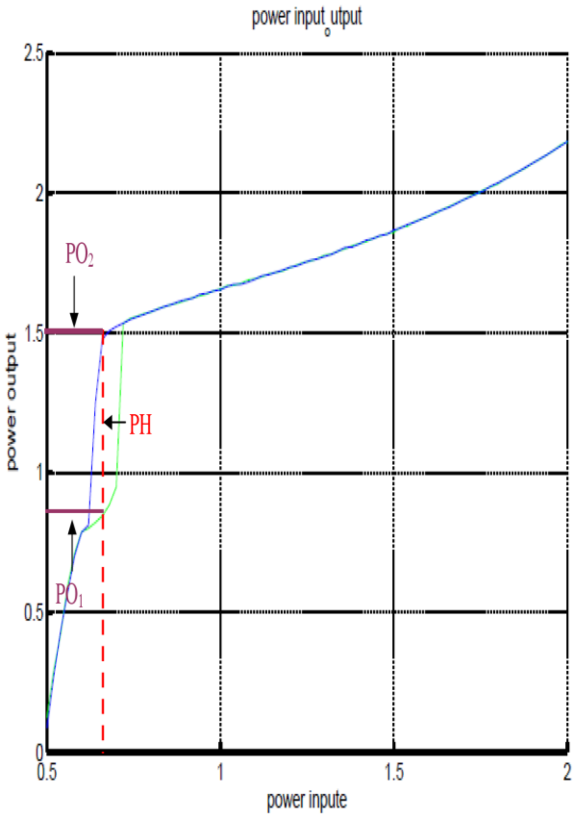

Fig.1. output power according to input power

Table(1) physical parameters used in simulation

Symbol	Description	Value	Unit
L	Active region length	600	µm
W	Active region width	2	µm
d	Active region thickness	0.2	µm
Γ	Optical confinement factor	0.35	-
am	Line width enhancement factor	5	-
No	Carrier density at transparency	$1.5*10^{18}$	m^{-3}
n	Modal refractive index	3.3	-
σ	Mode cross section	10^{-12}	m^2
KL	Coupling coefficient	2	-
R_1=R_2	Facets Reflectivities	0	-
A_{nrad}	Nonradiative recombination constant	$1.7*10^8$	s^{-1}
B_{rad}	Radiative recombination constant	$2.5*10^{-9}$	cm^3/s
C_{Aug}	Auger recombination constant	$9.4*10^{-29}$	cm^3/s
λ_o	Wave length at trans parency	1595	nm
γ	Spantaneous coupling coefficient	$4.8*10^{-5}$	
α	Loss per segment	0.980	
V_g	Group velocity	$8.1*10^{13}$	µm/s

2.1.Progressive wave in time domain and

Progressive wave in time domain which is based on the coupled wave equations is suitable for DBR and DFB lasers simulations because carriers and photons have non-uniform location distribution [1]. With division of segment into M parts; changes in each part are considered, and after solving in each part, the output as a primary condition for another part is considered separately. In this simulation according to the matter that, this is a various combination of progressive and regressive waves optical field, we divide the whole construction into 30parts, 20 parts in DBR section in both sides of the active region and 10 parts of active region. The equations will be as the equation(1) [5].

$$\frac{1}{vg}\frac{\partial E_{(f,r)}(z,t,\lambda_k)}{\partial t}\pm\frac{\partial E_{(f,r)}(z,t,\lambda_k)}{\partial z}= \qquad (1)$$

$$\left\{-J\delta+\frac{1}{2}\left(\Gamma g(z,t,\lambda_k)-\alpha_s\right)\right\}$$

$$E_{(f,r)}(z,t,\lambda)+jkE_{(f,r)}(z,t,\lambda_k)+s_{(f,r)}(z,t,\lambda_k).$$

In this relation E(f,r) is a progressive and regressive waves, K(cm^{-1}) is a grating coupling coefficient, Vg (cm/s) is the group velocity., Γ is the optical confinement factor, α(cm^{-1}) is an account for internal loss which is assumed to be neligible, and g is the material gain according to (cm^{-1}).

The phase mismatch coefficient which is assigned from bragg wavelength is:

$$\delta=\beta(\lambda_s)+\frac{1}{2}\Gamma\alpha_m g(z,t,\lambda_k)-\beta_0. \qquad (2)$$

In this relation B(λs)=2πneff/λs is the signal wave propagation constant and λs(nm) is the signal wavelength, $B_\circ=\frac{\pi}{\Lambda}$ is the propagation constant at the bragg wavelength, Λ(nm) is grathing period, and αm is the Line width enhancement factor. Following border conditions used in both ends of the segment:

$$E_f(0,t,\lambda_k)=\sqrt{R_1}E_r(0,t,\lambda_k)+\sqrt{1-R_1}E_{in}(0,t,\lambda_k). \qquad (3)$$

$$E_r(L,t,\lambda_k)=\sqrt{R_2}E_f(L,t,\lambda_k)+\sqrt{1-R_2}E_{in}(L,t,\lambda_k). \quad (4)$$

The input signal field comes from fiber to the segment is:

$$E_{in}(0,t,\lambda_k)=\sqrt{\frac{\alpha_{in}P_{in}}{h\nu_k wdvg}}. \quad (5)$$

Which α_{in} is the input coupling loss from fiber to waveguide and P_{in} is the input power in x^{th} canal. The output power of the SOA x^{th} canal is:

$$P_{out}=h\nu_k A_{eff} Vg\,\alpha_{out}\left|\sqrt{1-R_2}E_f(L,t,\lambda_k)\right|^2. \quad (6)$$

In this relation α_{in} is the output loss from fiber to waveguide and $\mathrm{Aeff}=\frac{\mathrm{wd}}{\Gamma}$ is an effective active level. For calculating the output power with suitable attention after reaching the stable state, the average amount of that during a suitable time period must be achieved. In this simulation, we assumed the facets reflectivity coefficient $R_1 \simeq R_2 = 0$.

3. CARRIERS RATE EQUATION

Field equations in different wavelength interval in relation1 through sharing carriers which is achieved by the following equation are coupled together [5].

$$\frac{\partial N(z,t)}{\partial t}=\frac{j}{gd}-\left\{A_{nard}+B_{rad}N(z,t)+C_{aug}N^2(z,t)\right\}\times$$
$$N(z,t)-R_{stim}(z,t). \quad (7)$$

In which the parameter (s^{-1}) A_{nard} is the nonradiative recombination constant, (cm^3s^{-1}) B_{rad} is the total radiative recombination rate and two molecules, (cm^6s^{-1}) C_{aug} is the Auger processes , respectivety and finally R_{stim} is the stimulated emission rate which is achieved by the equation (8):

$$R_{stin}(z,t)=\sum_{K=1}^{Nd} Vg\; g(z,t,\lambda_k)\times \quad (8)$$
$$\left|E_f(z,t,\lambda_k)+E_r(z,t,\lambda_k)\right|^2.$$

In $\mathrm{j}=\frac{\mathrm{I}}{\mathrm{WL}}$ relation, j and L are the current density and the length of active region respectively.

And the carriers lifetime is introduced as the following:

$$\tau_c=\left\{A_{nrad}+B_{rad}N(z,t)+C_{aug}N^2(z,t)\right\}^{-1}. \quad (9)$$

3.1. Simulation and results

For solving the previous section coupled equations, in finite difference time method with central and average gray difference method Lax of the equations is written as follows:

$$F_{Z+1}^{T+1}=AF_Z^T+BR_{Z+1}^T+C1s_f+C2s_f. \quad (10)$$
$$R_Z^{T+1}=DF_Z^T+ER_{Z-1}^T+G1s_f+G2s_f.$$

If we describe the determinant in the equation (11) :

$$\Delta=\left(L-\frac{s}{2}(gL-jdL)\right)^2+\left(\frac{kLs}{2}\right)^2. \quad (11)$$

Then the coefficients in the coupled equations will be:

$$A=E=\frac{1}{\Delta}\left(\left(L^2-\left(\frac{gL-jdL}{2}s\right)^2\right)-\left(\frac{kLs}{2}\right)^2\right). \quad (12)$$

$$B=D=\frac{1}{\Delta}\left(\left(L-\frac{gL-jdL}{2}s\right)\left(\frac{jkLs}{2}\right)+\right.$$
$$\left.\left(\frac{jkLs}{2}\right)\left(L+\frac{gL-jdL}{2}s\right)\right).$$

$$C_1=G_2=\frac{1}{\Delta}\left[L-\frac{gL-jdL}{2}s\right]Ls.$$

$$C_2=G_1=\frac{1}{\Delta}\left[\frac{jkL}{2}s\right]Ls.$$

For analyzing the photons and carriers interactions, we normalize the carriers' density rate equations like in the equation(13):

$$\mathrm{N}_e^{T+1}=\mathrm{N}_e^T+\frac{\mathrm{L}}{\mathrm{Nv_g trec}}/ \quad (13)$$
$$\left\{\frac{\mathrm{I.trec}}{\mathrm{qALN_{th}}}-\mathrm{A_nN_e^T}-\mathrm{B_n}\left(\mathrm{N_e^T}\right)^2-\mathrm{C_n}\left(\mathrm{N_e^T}\right)^3-\frac{\mathrm{R_{stim}}}{\mathrm{N_{th}}}\mathrm{trec}\right\}.$$

In which $trec=1/\left(N_{th}B+N_{th}^2C+A\right)$ is used for normalizing. We simulate the segments operation by the use of finite difference time domain. At the beginning through solving the speed carrier density in each section along with solving the density rate of the carrier equation the N(z,t) is achieved which help us in calculating the obtained generating coefficient $g_{(m,x)}$ in related section. We assume that input pulse course is much greater than fluctuation course. This hypothesize make us lead toward the regressive waves by finite time domain difference domain method.

We also assume that carriers' distribution and photon density in each section were uniformly; also we use Lax in this matter. In figure (1) we see that when the input signal power increases, the output power increases too, of course to the extent that after that with increase in input power, the output power will be saturated. Thus there is the threshold input power which makes leasing disabled while the input signal power increases from this critical limitation, the output signal power will be saturated. Also while we decrease the input signal power in reversal stage, the output signal will decrease too; and a hysteresis curve will be created that is called a bistability region which is a prerequisite of all optical flip flop.

3.2. Dependence on active region length

The figure (2) of bistability curve (1595nm) for different values of L from the category of 0-1000 with 100 pace with stable coupling rate coefficient of KL=2 is shown. In this hysteresis curve it can be seen that the curve has a good overlap also has a shift with change in region length like quantified bistability property. However those changes from the static view are not that much visible, in a way that we can claim that from the static view the changes in active region length has no effect on hysteresis curve.

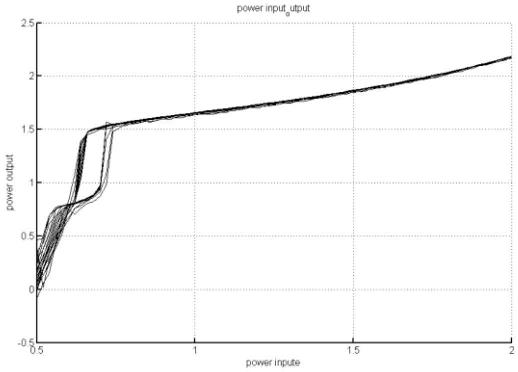

Fig.2.changes of L active region length

4. CONCLUSION

In this article, we described the use of all optical flip flop based on gain clamped semiconductor optical amplifier according to distributed bragg reflectors and analyzed the segment opertation according to output and input power chart, eventually the function of this segment from the static view point based on the physical parameter of the active region length was analyzed and the output power of this flip flop was shown in figure (1) as a function of input power for wavelength of 1559nm, KL=2, and L=600.

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