STUDY OF WELL BARRIER HOLE BURNING IN QUANTUM WELL BISTABLE LASERS

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ABSTRACT

Quantum carrier capture and release effects on optical bistability in multiple quantum well (MQW) lasers are studied using the well barrier hole burning model. The ratio of carrier capture to release time (η) is varied and the hysterisis width, transient behavior are analysed by simulating the equivalent circuit of MQW bistable laser using circuit simulation program Pspice. The hysterisis width is found to increase with an increase in η. From the time response, improved damping and increased turn on delay are observed in switching characteristics for higher value of η.

***Keywords**: Multiple quantum wells, well barrier hole burning, semiconductor lasers, bistability, hysterisis, circuit modeling*

INTRODUCTION

Optical bistability in semiconductor lasers has received much attention because of its potential application in optical switching and signal processing. It is well established that the presence of an unpumped absorber in the laser cavity can lead to bistability. Introducing quantum wells in the active regions of gain and absorber sections could significantly improve the switching speed and controllability of hysterisis characteristics [1]. It is also found that the conventional single mode rate equations fail to explain the resonance characteristics profoundly, because of non inclusion of factors such as spatial and spectral inhomogenities. Hence well barrier hole burning model is introduced to incorporate the effects contributing to non linear gain [2,3]. MQW bistable lasers are normally analysed by numerically solving the single mode rate equations [1]. In this paper, we have attempted to study the effect of well barrier hole burning in MQW bistable lasers using circuit simulation technique. Circuit simulation method is adopted because of its advantages, such as inclusion of parasitics and device- circuit interactions [4]. The equivalent circuit is also vital for the design of control and driver circuits for laser [5]. The equivalent circuit is simulated for dc sweep and transient conditions using circuit simulation program Pspice.

LARGE SIGNAL MODEL

The bistable laser has two regions viz. gain and absorber sections. For the simulation purpose, we have considered InGaAs - InAlAs MQW structure. This structure consists of 6 quantum wells in the active region having 5 ps capture time. The carrier lifetime in the barrier and in the well is 1ns. The carrier lifetime in the gain section is assumed to be proportional to the carrier density, whereas it is constant (2ns) in the absorber section. The non linear rate equations incorporating well barrier hole burning [2] are included in the gain section of the bistable laser. Since the absorber section is unpumped, the carrier transport and capture effects are neglected. The above modifications are made in the rate equations of ref [1] and given as

$$\frac{dN_b}{dt} = \frac{J}{ed} - \frac{N_b}{\tau_{sb}} - \frac{(N_b - \eta N_w)}{\tau_c} \quad (1)$$

$$\frac{dN_w}{dt} = \frac{(N_b - \eta N_w)}{\tau_c} - \frac{N_w}{\tau_{sw}} - v_g G_g S \quad (2)$$

$$\frac{dN_a}{dt} = -\frac{N_a}{\tau_a} - v_g G_a S \quad (3)$$

$$\frac{dS}{dt} = \xi\,(1-h)\, v_g G_g S + \xi\, h\, v_g G_a S + \beta\xi(1-h)\frac{N_w}{\tau_{sw}} - \frac{S}{\tau_p} + P_{in} \qquad (4)$$

where N_b, N_w and N_a denotes the carrier density in the barrier layer, well region in gain section and absorber section respectively. The rate of gain (absorption) in the gain and absorption regions, G_g and G_a are approximated by a linear function of carrier density [1]

Multiplying the eqns (1)(2)(4) by qV_g and (3) by qV_a and rearranging one gets

$$I = I_{D1} + \tau_{sb}\frac{dI_{D1}}{dt} + \frac{\tau_{sb}}{\tau_c} I_{D1} - \eta\frac{\tau_{sw}}{\tau_c} I_{D2} \qquad (5)$$

$$\frac{\tau_{sb}}{\tau_c} I_{D1} = \tau_{sw}\frac{dI_{D2}}{dt} + \eta\frac{\tau_{sw}}{\tau_c} I_{D2} + I_{D2} + I_{stg} \qquad (6)$$

$$\tau_a\frac{dI_D}{dt} = - I_{D3} - I_{sta} \qquad (7)$$

$$C_p\frac{dP}{dt} = \xi\,(1-h)\, I_{stg} + \xi\, h\, I_{sta} + \beta\xi(1-h)\, I_{D2} - \frac{P}{\tau_p} + P_{in} \qquad (8)$$

TABLE I

Fig.1

Fig.2

Fig.3

where $qV_gN_b/\tau_{sb} = I_{D1}$, $qV_gN_w/\tau_{sw} = I_{D2}$, $qV_aN_a/\tau_a = I_{D3}$ being the spontaneous emission terms included as diode currents.

$I_{stg} = qV_gv_g\, g_g(N_w - N_{og})(1 - \varepsilon S)$
$I_{sta} = qV_av_g\, g_a(N_a - N_{oa})(1 - \varepsilon S)$

are the recombination currents caused by stimulated emission in the gain and absorption region respectively.

$$C_p \frac{dP}{dt} = qV_g \frac{dS}{dt}, \quad C_p = qV_g S_N$$

and $\tau_p = R_pC_p$. S_N is the normalisation constant. The values of the parameters used are given in Table.I

Combining eqns (5) - (8), the large signal equivalent circuit is developed as shown in Fig.1.The modeling approach is similar to the large signal model for bistable lasers [6].

SIMULATION RESULTS

The equivalent circuit is simulated for dc sweep and transient conditions using circuit simulation program Pspice. The simulations are carried out without any external optical injection. (P_{in} equals zero) and τ_{sw} is given the same value as τ_{sb}. The dc simulation shows hysterisis which validates our proposed model. The simulation is done for different values of η. It is found that the threshold current and hysterisis width increase as η increases. The hysterisis characteristics are shown in Fig.2. In the transient simulation , the device is biased near the threshold and an electrical pulse of 10 mA amplitude and 1 ns width is given to the gain section and the switching characteristics are observed. In the time response (Fig.3), the turn on delay and steady state amplitude are found to increase with η. Further, the damping becomes large (reduced relaxation oscillations) as η increases and makes the switching transition smooth.

CONCLUSION

Well barrier hole burning effects are studied in MQW bistable laser diodes by simulating the equivalent circuit incorporating well barrier hole burning model. The hysterisis width and threshold current are found to increase with capture ratio η. Increased damping and turn on delay result for higher η, which is observed from the transient response.

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TABLE I

Parameter	Description	Value
V_g	Volume of gain section	4.69×10^{-11} cm^3
V_a	Volume of absorber section	1.62×10^{-12} cm^3
N_w	Number of wells	6
L_w	Well thickness	90 A°
L	Length of laser cavity	300 μm
L_g	Length of gain section	280 μm
g_g	Gain constant of gain section	1.69×10^{-6} cm^3 s^{-1}
g_a	Gain constant of absorber section	3.38×10^{-4} cm^3 s^{-1}
τ_{sb}	Carrier lifetime in barrier	1 ns
τ_{sw}	Carrier lifetime in well	1 ns
τ_c	Capture time	5 ps
τ_a	Carrier lifetime in absorber	2 ns
τ_p	Photon lifetime	1.87 ps
N_{og}	Transparency carrier density in gain section	1.25×10^{18} cm^{-3}
N_{oa}	Transparency carrier density in absorber section	1.15×10^{18} cm^{-3}
ε	Gain compression factor	2×10^{-17} cm^3
ξ	Optical confinement factor	0.15
β	Coupling coefficient	1×10^{-5}
v_g	velocity of light in medium	8.45×10^{9} cm s^{-1}
R_s	series resistance	5 Ohms
L_{pp}	lead inductance	1 nH
C_{pp}	parasitic capacitance	1 pF
R_{in}	source resistance	1000 Ohms
C_D	diffusion capacitance	10 pF
S_N	normalisation constant	10^{15}
h	ratio of saturable absorption region to cavity length	0.03