Pulse Compression in Q-Switched Lasers using a Comblike Gain/absorption Structure

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***Abstract*—A novel design for a multi-sections Q-switched laser is proposed to achieve pulse compression. Pulses approximately 1.41 ps wide are generated using a six-sections Q-switched laser. Commercially available software is used to model the Q-switched laser based on traveling wave model theory.**

I. Introduction

Q-SWITCHED lasers are used to generate ultra-short pulses for differing applications ranging from sensing, spectroscopy to free-space communications. Various methods to create Q-switched lasers have been introduced in the literature. Two Examples are: 1) bow-tie structure, which is used to generate picosecond pulses [1] and 2) triple-contact 1.55 μm passive configurations to generate 3-10 ps laser pulses [2]. Also reported is a Q-switched laser based on cavity loss modulation at a sub-harmonic frequency of the fundamental inter-mode frequency spacing [3]. The loss modulation is achieved using ultra-fast variable optical attenuator. The produced pulses width using this method were about 100 ps.

In this work, we propose a scheme to compress the generated pulses of a multiple-sections Q-switched laser by optimizing the width of each gain section. Approximately 1.4 ps pulses are generated using the proposed method. Travelling mode equations are used to model the Q-switched laser as the produced pulses are shorter than 10 ps [2].

II. Traveling Wave Theory

OptiSPICE is an optical simulator based on modified nodal analysis, which includes optical signals. The optical signal at each node is modeled by a slowly varying envelope approximation and is therefore described by:

$$\hat{O}(t) = \sum_{i=0}^{m} \left(\hat{O}_{fi}(t) e^{-i\omega_c t} + \hat{O}_{ri}(t) e^{i\omega_c t} \right) \quad (1)$$

where ω_c is the carrier frequency of the signal, m is the number of modes, and $\hat{O}_i(t)$ are the complex envelopes.

To build a sophisticated distributed waveguide based element that fits naturally into this framework the traveling wave model (TWM) is very appropriate. In such a model an electromagnetic wave propagating through a waveguide with (for simplicity) a single transverse mode can be described by:

$$\hat{E}(t,z) = \hat{E}_f(z,t) e^{i(k_c z - \omega_c t)} + \hat{E}_r(z,t) e^{i(k_c z + \omega_c t)} \quad (2)$$

where $\hat{E}_f(t,z)$ and $\hat{E}_r(t,z)$ are complex envelopes for the forward and reverse propagating fields capturing both the local magnitude and phase of the signals. The carrier frequency and wave number for the signal are given by ω_c and $k_c = n_g k$ where k is the free space wavevector. This is, of course, the same formulation as given in Eq. 1 for an optical signal with the addition of a spatial dependence. By making a slowly varying envelope assumption the equations for the propagation of the envelopes of the two waves with in the waveguide is [4]:

$$\frac{1}{v_g} \frac{\partial \hat{E}_{f,r}}{\partial t} = - \frac{\partial \hat{E}_{f,r}}{\partial z} - i\hat{\beta}(z,t) \hat{E}_{f,r} + i\hat{\kappa}_{f,r}(z) \hat{E}_{r,f} - k_p(\hat{E}_{f,r} - \hat{P}_{f,r}(z)) \quad (3)$$

where $\hat{E}_f$ and $\hat{E}_r$ are the propagating fields in the forward and reverse direction, and $\hat{\beta}$ is a propagation constant that captures effects such as a local perturbation in the effective index or gain/loss of the field. Coupling between the two counter propagating waves is represented by the two parameters $\hat{\kappa}_f$ and $\hat{\kappa}_r$ In some devices dispersion will be a significant effect due to a frequency dependent polarization term. The variables $\hat{P}_f$ and $\hat{P}_r$ represent the polarization response of the material to the forward and reverse propagating fields and will need to be defined by the material response.

One of the advantages of the TWM is its physical nature and the ease with which phenomena can be added to the model. To complete the model of a semiconductor amplifier or a laser, number of effects need to be added[4]. Assuming linear relationships between perturbation of the effective index and the optical gain with the number of carriers above transparency ($\Delta N = N - N_{tr}$), we define a Henry parameter α_H[5] and a differential gain G_0 making the propagation constant,

$$\hat{\beta}(N) = \frac{1}{2} \left[\alpha_H G_0 \Delta N + \delta \right] + \frac{i}{2} \left[g_f G_0 \Delta N - \alpha_l \right] \quad (4)$$

with α_l specifying losses due to scattering and absorption. The definition of $\hat{\beta}$ includes the stimulated emission present in the device. However, spontaneous emission also needs to be included in the propagation equation by adding a stochastic term to the two field equations.

The equation describing the evolution of the carrier density is given by a distributed 1st-order rate equation:

$$\frac{dN(z)}{dt} = \frac{\eta J_d(z)}{q W_l t_l} - G_0(N(z) - N_{tr}) S(z) - \frac{N(z)}{\tau_n} \quad (5)$$

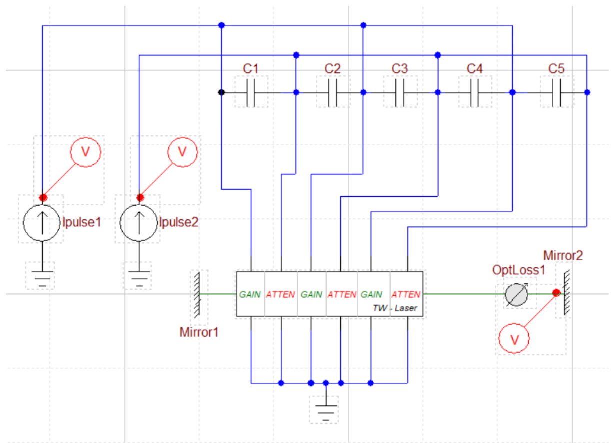

Fig. 1. Schematic diagram of multi-sections Q-switched laser modeled in *OptiSPICE*.

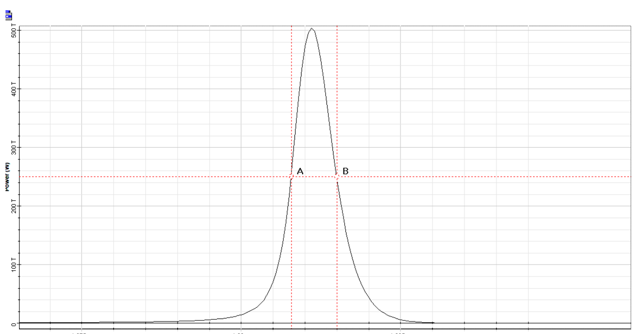

Fig. 2. Generated pulses using six-sections Q-switched laser.

where $J_d(z)$ is the laser current density and τ_n the spontaneous emission coefficient [4].

Finally it should be noted that the presence of mirrors at the device facets place a boundary condition on the two fields:

$$\hat{E}_f(0) = \hat{R}_l \hat{E}_r(0) \text{ and } \hat{E}_r(L) = \hat{R}_r \hat{E}_f(L) \tag{6}$$

where $\hat{R}_l$ and $\hat{R}_r$ are the reflectivities of the two facets.

Equations 3-6 therefore comprise a basic distributed model of the amplifier or laser. They describe both the temporal and spatial evolution of the laser operation and capture a diverse set of optical phenomena including longitudinal modes, distributed photon/carrier densities and laser chirp. Using this model for Q-switching configurations, it is possible to use multiple contacts to the TWM structure and biasing them either as gain or loss elements.

III. Results and Discussions

A multi-contacts Q-switched laser at 1550 nm is modeled in a commercially available software *OptiSPICE* using a traveling wave laser model. The multiple-sections of the Q-switched laser are alternating pieces of gain and absorption sections. The length of each gain section is varied to control the achieved laser pulse widths. Fig. 1 shows the schematic diagram of the Q-switched laser modeled in *OptiSPICE*. For a six-sections Q-switched laser with alternating gain and absorption sections with the lengths specified as 8, 6, 5, 4, 2, 8 μm, 1.41 ps laser pulses are generated. The generated pulses of the Q-switch laser have repetition rate of about 1 GHz. The length of the absorption section is generally higher than that of the gain sections. As a result, instability in the continuous wave operation of the laser due to nonlinear dependency of gain and absorption on carrier density occurs [6]. The gain and absorption sections are controlled using different current sources producing Q-switching [7]. The active medium of the laser is driven using 150 mA DC current for the gain sections and -180 mA for the absorption sections. Table I describes the values of the different parameters used. Fig. 2 presents a plot of a single pulse generated from the six sections Q-switched laser.

TABLE I
Parameters for multiple-sections Q-switch laser.

Parameter	Value	Unit
Gain FWHM	3.5×10^{12}	
Transparency carrier density	1×10^{18}	cm^{-3}
Reflectivity of mirrors R_1, R_2	32%	
Electron lifetime	1×10^{-9}	s
Attenuation coefficient	0	cm^{-1}
Spontaneous emission factor	0.3×10^{-5}	
Volume of active strip	1.5×10^{-10}	cm^3
Length of device	300	μm
Width of active strip	5	μm
Depth of active strip	10	μm
Confinement factor	0.4	
Group refractive index	3.5	
Photon lifetime	3.055	ps

IV. Acknowledgements

This research was supported in part by NSERC and Optiwave Inc.; their support is gratefully acknowledged.

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