Investigation of input pulsewidth, medium loss and gain effect on the output pulse characteristics of semiconductor optical amplifiers

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Abstract: *We have analysed the output pulse characteristics of semiconductor optical amplifier (SOA). They can be modified due to the variation of input parameters, such as, gain, input pulsewidth and internal loss imposed by the medium. In our model, the effect of self-phase modulation (SPM) has taken into consideration to improve the accuracy of simulation results. The proper output pulse characteristics can be achieved by controlling the mentioned parameters. We used a simplified nonlinear Schrodinger equation (SNSE) to model the behaviour of SOAs. The SNSE is solved using the finite-difference beam propagation method (FDBPM).*

1. Introduction

Currently, semiconductor optical amplifiers (SOAs) have significant practical interest in data communication applications because of their small size, high optical gain, low input power requirement, faster response time, large bandwidth and compatible optoelectronic characteristics [1-4].

The main objective of paper is to investigate how internal loss of the propagation medium affects the shape and spectrum of the optical pulse being amplified and is organized as follow; Section 1 is introduction; Section 2 is Theory and Simulation. Section 3 is simulation results and discussion and finally the conclusions are in Section 4.

2. Theory and Simulation

2.1 Theory

The following three equations called simplified nonlinear equations describe the behaviour of pulses that propagate through the amplifier and the temporal variation of amplifier's gain [5]

$$\frac{\partial P}{\partial z} = (g - \alpha_{int})P \quad (1)$$

$$\frac{\partial \Phi}{\partial z} = -\frac{1}{2}\alpha g \quad (2)$$

$$\frac{\partial g}{\partial \tau} = \frac{g_0 - g}{\tau_c} - \frac{gP}{E_{sat}} \quad (3)$$

where α_{int} is medium internal loss, $g_0 = \Gamma a N_0 (I/I_0 - 1)$ is small signal gain, Γ is confinement factor, a is differential gain coefficient, I is injection current, $I_0 = qVN_0/\tau_c$ is transparency current, q is the electron charge, V is the active volume, N_0 is the carrier density required for transparency, τ_c is the carrier lifetime, $E_{sat} = h\omega_0\sigma/a$ is saturation energy, $\sigma = wd/\Gamma$ is mode cross section where w and d are medium width and length, respectively. We have applied the FD-BPM scheme to solve the above three equations [3, 6-7].

2.2 Simulation

The SOA waveguide can be divided into M equal sections. The mentioned set of equations should be solved in each section. The output pulse of the M^{th}section is the amplifier's output pulse [3]. Relation between the powers of propagating pulses in two adjacent sections is as the following equation

$$P(z+\Delta z) = \frac{1+(g(z)-\alpha_{int})\frac{\Delta z}{2}}{1-(g(z+\Delta z)-\alpha_{int})\frac{\Delta z}{2}} P(z) \quad (4)$$

3. Results and Discussion

3.1 Pulse Shape

In the following simulations, L=250μm and $E_{sat} = 10pJ$. Carrier lifetime τ_c is taken $200\,ps$, $G_0 = \exp\,(g_0L)$ is the unsaturated single-pass amplifier gain, which is usually between $0dB - 40dB$. LEF is in the range of $3-8$ [5] and α=5. In the case of Gaussian input pulse, Fig. 1 and Fig. 2 Show the output pulse shapes for different internal losses. It has shown clearly that the temporal output pulse shapes in Fig. 1 are more asymmetric and compressed further. This is due to the effect of SPM.

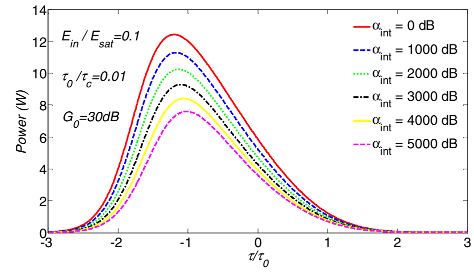

Fig. 1. The output pulse shape for various of medium losses, for this case, the Gaussian input pulse energies are: $E_{in}/E_{sat} = 0.1$, $\tau_0/\tau_c = 0.01$. Output power decreases by increasing the internal losses.

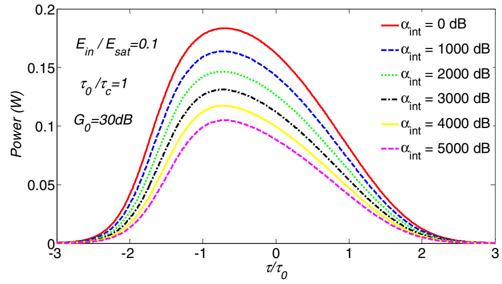

Fig. 2. The output pulse shape for various of medium losses. Here, the Gaussian input pulse energies are: $E_{in}/E_{sat} = 0.1$, $\tau_0/\tau_c = 1$. Output power decreases by increasing the internal losses.

Furthermore, it should be noted that the higher internal loss, leads to more symmetric output pulse shape. This is because the propagated pulse experiences lower influence by the saturation phenomena.

3.2 Pulse Spectrum and Chirp

Fig. 3 and Fig. 4 show the normalized spectrum of the pulse shapes as in Fig. 1 and Fig. 2, respectively.

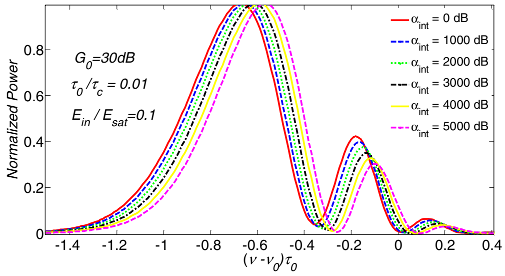

Fig 3. The output pulse spectrum corresponding to the pulse shapes shown in Fig. 1. Medium loss causes a blue shift in spectrum.

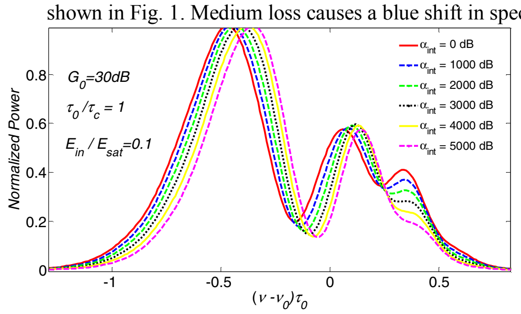

Fig. 4. The output pulse spectrum corresponding to the pulse shapes shown in Fig. 2. Medium loss causes a blue shift in spectrum and the gain recovery impact can be seen on the spectrum.

It has shown that the output spectrum widths are broadened due to the increase of input pulsewidths. The output chirp imposed by SOA is shown in Fig. 5 and 6.

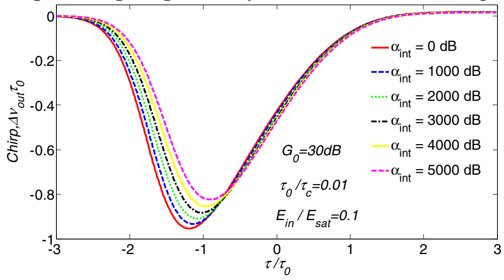

Fig. 5. The output pulse chirp for variety of medium loss values in the case of Gaussian input pulse while its energy and width satisfy $E_{in}/E_{sat} = 0.1, \tau_0/\tau_c = 0.01$. Output chirp decreases for higher medium losses.

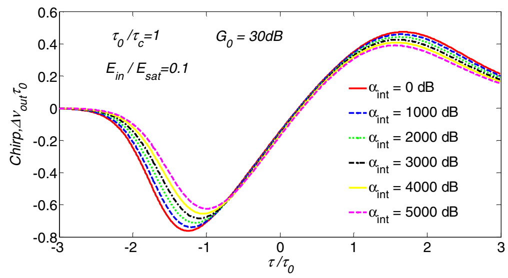

Fig. 6 The output pulse chirp for variety of medium loss values in the case of Gaussian input pulse while its energy and width satisfy $E_{in}/E_{sat} = 0.1, \tau_0/\tau_c = 1$. Output chirp decreases for higher medium losses.

In Fig. 5, for picoseconds pulses, due to the effects of carrier depletion, negative chirp imposed to the entire amplified pulse. As the pulsewidth increased to the tens of picoseconds (as shown in Fig. 6), negative chirp only imposed on the leading edge of the amplified pulse that is the same behaviour which happened for the shorter input pulses. But the trailing edge, experiences positive chirp. This is because the gain can recover to its initial value.

4. Conclusion

In this work, the effects of gain, input pulsewidth and medium internal loss are analysed in detail on the output pulse characteristics of SOA. It has shown that the output power decreased when internal loss increased and its shape became broader for a wider input pulsewidth. The output spectrum experienced a blue shift when the internal loss is increased. It also became broader for the wider input pulsewidth. Furthermore, the chirp imposed to the output pulse was negative for a shorter input pulsewidth and decreased when the internal loss increased. But, for wider input pulsewidth, the chirp experienced both positive and negative values. The output pulsewidth was also sensitive to internal loss, input pulsewidth and gain. Based on our simulation results, we concluded that the output pulse characteristics could be modified by controlling the medium internal loss, gain and the input pulsewidth.

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