Analysis of Gain Saturation Characteristics in SOAs for Different Input Pulse Shapes

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Abstract— **This paper presents the gain saturation characteristics for different input pulse shapes in semiconductor optical amplifiers (SOAs). Finite-difference beam propagation method (FD-BPM) is used for simulation and compared the gain saturation characteristics in SOA for different pulse shapes.**

Index terms— **Finite-difference beam propagation method, Pulse shape, Pulse propagation, Gain saturation, Semiconductor optical amplifier.**

I. Introduction

Semiconductor optical amplifiers (SOAs) are the key component for optical amplification and switching at a very high speed because of their small size, a low switching energy, non-linear characteristics and the ability to integrate with other optical devices [1]. The SOAs are not only limited to amplify the short pulses, also used in many functional applications, such as wavelength conversion, optical switching and optical signal processing [2].

The purpose of SOA modelling is to relate the internal variables of the amplifier with external variables, such as output signal power and saturation power. Modified nonlinear Schrödinger equation (MNLSE) is used in pulse propagation models and it includes the SOA non-linearities. The pulse propagation in an SOA is strongly dependent on the input pulse shapes [3-6].

The main objective of this research is to analyze and compare the gain saturation characteristics for different types of input pulse shapes in SOAs for high speed communication systems. This analysis is based on the MNLSE considering the self-phase modulation (SPM), two-photon absorption (TPA), group velocity dispersion (GVD), carrier depletion (CD), carrier heating (CH), spectral-hole burning (SHB), gain spectrum dynamics, and gain saturation in the SOA [3-6].

II. Pulse Propagation Model in SOA

The MNLSE is used for the simulation of optical pulse propagation in SOAs with different input pulse shapes [3-6]. For the pulse propagation, we used the same model and parameters as used in the ref. [4]. We have considered three types of input pulse shapes, such as (i) Secant hyperbolic pulse, (ii) Gaussian pulse, and (iii) Lorentzian-shaped pulse for the simulation of optical pulse propagation and gain saturation characteristics in the SOAs.

Fig. 1 illustrates a simple simulation model for the propagation of optical pulses in an SOA. An optical pulse is injected into the input facet of the SOA, where the input pulse position is at z = 0. The optical pulse is propagated over the length 500-μm of the SOA. Here, τ is the local time, $|V(\tau,0)|^2$ is the intensity (power) of input pulse (z = 0) and $|V(\tau,z)|^2$ is the intensity (power) of the output pulse after propagating a distance z (=500-μm) at the output side of SOA [4].

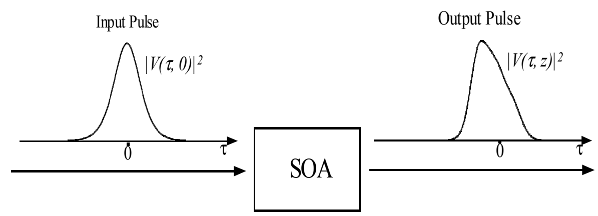

Fig. 1. Schematic diagram for the simulation of optical pulses in SOA.

III. Simulation Results and Discussion

In this section, simulation results of gain saturation characteristics are discussed for different input pulse shapes. For simulation, the parameters of a bulk SOA (AlGaAs/GaAs, double heterostructure) is used [4]. The SOA length is 500μm and propagation step Δz is 10μm.

Fig. 2 shows the saturated gain versus the output pulse energy characteristics for different input pulse shapes; (a) Secant hyperbolic, (b) Gaussian, and (c) Lorentzian. These pulse shapes are Fourier transform limited. The full-width at half maximum (FWHM) of the input pulses are varied from 0.5~10 ps. The saturation behavior is different for short (i.e., <1 ps) and long (i.e., >1 ps) pulses. With the low input pulse energies (i.e., ~0.1 pJ), the gain is unsaturated (i.e., linear gain). Also, when the input pulsewidth is short (i.e., <1 ps) then the gain saturates at low output energies and it is true for all the three pulse shapes. It is observed clearly that the gain saturation is pulsewidth dependent and output energy increases with the increase of pulsewidth. By comparing among the three pulse shapes, it observed clearly that gain saturates at higher output energy for Lorentzian input pulse shape with particular input pulse energy and achieve higher gain for all pulsewidths.

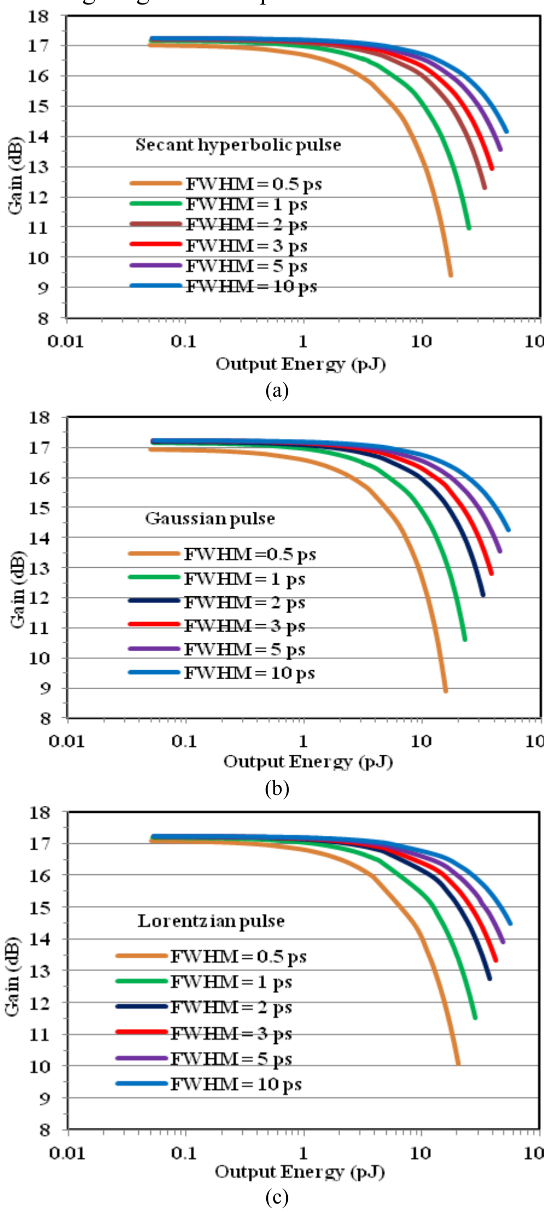

Fig. 2. Gain saturation characteristics with different FWHM for (a) Secant hyperbolic pulse, (b) Gaussian pulse, and (c) Lorentzian pulse.

Fig. 3 shows comparison of the gain saturation among the different input pulse shapes and FWHM; such as (a) FWHM = 1 ps and (b) FWHM = 3 ps. When the FWHM is 1 ps, the corresponding 3-dB down output saturation energies are found 14.08 pJ, 13.89 pJ and 14.42 pJ for Secant hyperbolic, Gaussian and Lorentzian pulses, respectively. The linear gain is very similar for all the pulse shapes because the input pulse energy is low (i.e., ~0.5 pJ). However, when the FWHM is 3 ps, the gain saturation characteristics is very similar (as they overlapped) for Secant hyperbolic and Gaussian pulses with the increase of pulsewidths (>1 ps). For the FWHM of 1 ps and 3 ps, higher output energy has been obtained for the Lorentzian pulse shape.

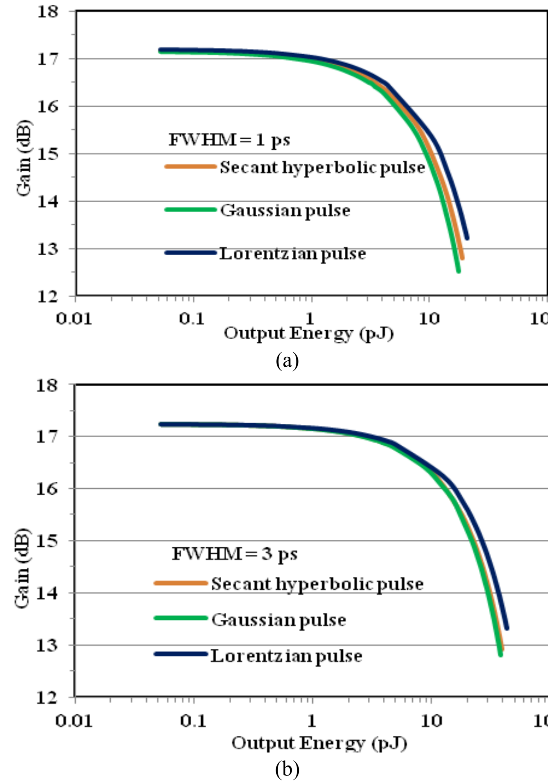

Fig. 3. Gain saturation characteristics comparison for different types of input pulse shapes, when (a) FWHM = 1 ps, and (b) FWHM = 3 ps.

IV. CONCLUSION

The gain saturation characteristics in an SOA are analyzed by using the FD-BPM for different types of input pulse shapes. It has observed that higher saturated output pulse energies were obtained by the Lorentzian pulse shapes for all pulsewidths. The Secant hyperbolic pulse shape reaches to the gain saturation faster than any other input pulse shapes. Moreover, the gain saturation characteristics for Secant hyperbolic and Gaussian pulses are very similar for the pulsewidths of >1 ps.

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