
Semiconductor Laser Modulation Response by using Optisystem

Subhrajit Pradhan*

Research Scholar
Department of Electronic Sciences
Berhampur University, India

Rashmita Kumari Panigrahy

Lecturer
Department of Electronic Sciences
Berhampur University, India

Aditya Kumar Sahu

UG Student
GIET, Gunupur, Rayagada, India

Susmita Kumari Panigrahi

UG Student
GIET, Gunupur, Rayagada, India

Priyanka Padhi

UG Student
GIET, Gunupur, Rayagada, India

Abstract

We present a theoretical analysis of the modulation response of a semiconductor laser amplifier. We find resonance behaviour similar to the well known relaxation oscillation found in semiconductor lasers, but for a different physical. The role of the wave guide scattering loss is investigated in detail and is shown to influence the qualitative behaviour of the response. In particular, it is found that in a certain amount of waveguide loss may be beneficial in some cases. Finally, the role of the microwave propagation of the modulation signal is investigated and different feeding schemes are analyzed. The nonlinear transparent waveguide, i.e. an amplifier saturated to the point where the stimulated emission balances the internal losses, is shown to be analytically solvable and is a convenient vehicle for gaining qualitative understanding of the dynamics of the modulated semiconductor optical amplifiers.

Keywords: Laser amplifier, Modelling, Optical modulation, Semiconductor laser.

***Author for correspondence** subhrajit.pradhan@gmail.com

1. Introduction

Semiconductor laser have been the subject of intense research over the past decade or so. The main characteristics of semiconductor laser amplifier compared to other optical amplifiers are perhaps its small size, made possible by the huge gain available in direct bandgap semiconductors, and the fact that it is electrically pumped. The small size and compatibility with semiconductor laser sources and semiconductor detectors offer the possibility of photonic integration and the electrical injection offers the possibility of simple modulation and control schemes. The main application of Semiconductor laser's may be within optical signal processing. It has been demonstrated that cross-gain and cross-phase saturation in a semiconductor laser (the

modulation of the amplitude or the phase of an optical beam passing through the waveguide by injection of a control beam) can be used for various types of signal-processing. Also, coherent techniques such as four-wave mixing (FWM) have been shown to have a remarkable potential. The success of these various schemes can be traced to the large value of the differential gain in semiconductor media; this leads to a large gain for modest injection currents, but also implies that the semiconductor gain medium can be readily saturated. The carrier lifetime of the semiconductor is on the order of several hundreds of picoseconds. This would seem to imply that the characteristic frequencies of schemes relying on the saturation of the carrier density should be of the order of a few Giga hertz at most. It has been recently demonstrated, however, that long waveguides. In this paper, we shall analyze the modulation response of a semiconductor laser amplifier, i.e., the frequency dependence of the amplitude modulation imposed on an injected CW optical beam when the bias current is modulated. This mode of operation has not been dealt with extensively, although it seems important to understand whether Semiconductor laser's can be used as efficient high-speed modulators. Also, switching fabrics based on Semiconductor laser gates rely on current modulation. These may only need moderate switching speeds but the requirements to the turn-on and turn-off times can be severe. We show here that the modulation response of Semiconductor laser displays a number of interesting features. Resonance behaviour, resembling the well-known relaxation resonance in semiconductor lasers, is predicted. Since the cavity feedback is absent, the underlying physical mechanisms are different. We analyze this behaviour in detail and find the waveguide (scattering loss) plays a very important role. This is similar to the case of cross-gain modulation in Semiconductor laser, and the present analysis yields further insight into this behaviour. We show that the case of a transparent waveguide, where stimulated emission exactly balances the scattering losses, is particularly simple to analyze, but it still displays many of the general features of the Semiconductor laser propagation dynamics and is convenient for understanding the underlying physics. It has been demonstrated that at microwave frequencies above 10GHz, the typical electrode geometry of semiconductor lasers and amplifiers yields a large propagation loss, which means that the details of the way the modulation signals are fed to the device becomes important. We analyze different modulation schemes that give qualitatively different results.

2. Simulation and Result

When using a directly modulated laser for high speed transmission systems, modulation frequency can be no larger than the frequency of relaxation oscillation. Relaxation oscillation depends upon both carrier lifetime and photon lifetime.

The relaxation frequency increases with the laser bias current. For the default parameters of our laser rate equation model $I_{th}=33.45\text{mA}$, $T_{sp}=1\text{ns}$, $T_{ph}=3\text{ps}$, and if we assume modulation peak current $I=40\text{mA}$, the corresponding resonance frequency in accordance with the above equation will be 1.3GHz.

$$f_{res} = \frac{1}{2\pi} \frac{1}{(\tau_{sp}\tau_{ph})^{\frac{1}{2}}} \left(\frac{I}{I_{th}} - 1 \right)^{\frac{1}{2}}$$

Discussion of the numerical parameters: bit rate is 1.3Gb/s and sequence length 128 bits, there the time window is about 98.5ns. Samples per bit are 512; therefore the sample rate is 670 GHz. Therefore, default rate is 10MHz.

In figure 2 and figure 3, the influence of the increased modulation frequency above the resonance one on system performance will be demonstrated. In figure 2, 1.3 Gb/s (10Gb/s) transmission is studied. The parameters of the laser rate equations are the default ones ($I=I_B=40\text{mA}$) as previously described.

Clearly, modulation with the frequency well above the resonance one leads to unacceptable system performance. In figure 3 the influence of the bias current on the resonant frequency and therefore on the system performance, for a fixed bit rate will be demonstrated. We use 1.3Gbps transmission keeping all other parameters same and $I_B=20\text{mA}$.

If you compare figure 3 with figure 2 (with 1.3Gbps transmission and $I_B=40\text{mA}$). It is clearly demonstrated that the reduction of the bias current below its threshold leads to a decrease in system performance. In this section we have shown the dependence of the performance of the high speed system on the modulation frequency and the laser bias current.

3. Conclusion

We have investigated the response of semiconductor laser modulation through Optisystem. We have shown, through numerical simulations and approximate analytical treatments, that the modulation response of a semiconductor optical amplifier is heavily influenced by propagation effects. In particular, it was found that a finite amount of waveguide internal loss, due to waveguide scattering or free-carrier absorption, can lead to the appearance of a resonance in the modulation response. Comparison to the case of zero internal loss shows that the loss decreases the response at all frequencies, but not uniformly so. Two different techniques were used for this theoretical study, namely a standard small-signal analysis of the well-known propagation equations as well as description in terms of cascaded amplifiers.

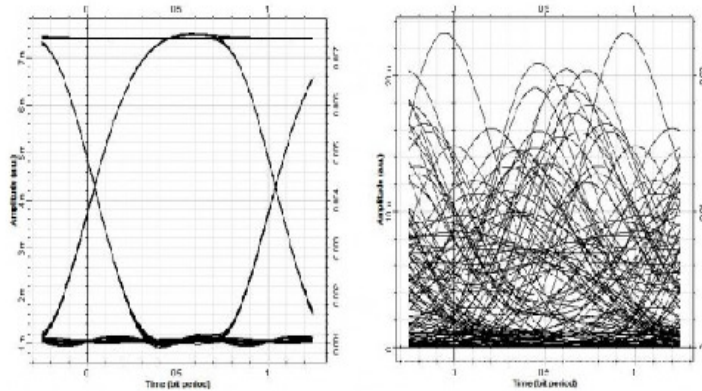


Figure 2: Increase in modulation frequency above resonance

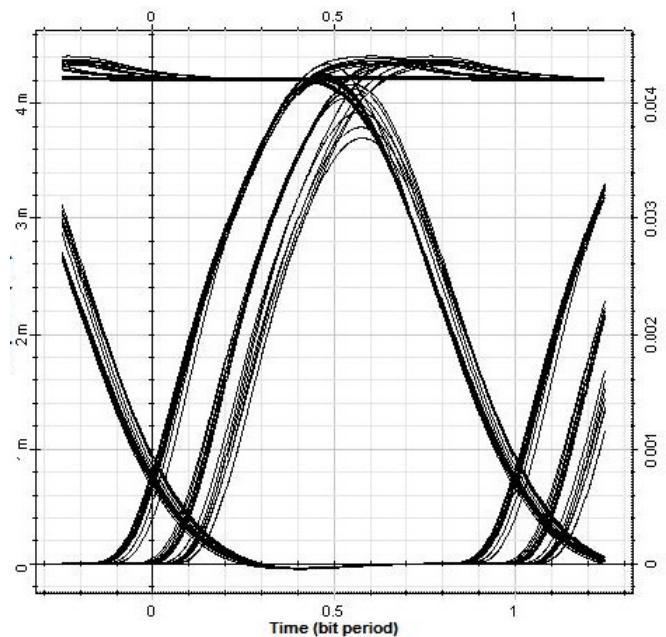


Figure 3: Reduction of bias current

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