Modeling of Transistor Laser Optical Amplifiers under Steady State and Transient Conditions

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***Abstract*- We have explored the possibility of using Transistor Laser as an Optical Amplifier in addition to its normal function as an electronic amplifier. The steady state gain is calculated by assuming different InGaAs Quantum Well thickness within the GaAs base of fixed width thereby changing the capture rate and confinement factor. Clear gin saturation effect is exhibited. Using ODE solver, the gain saturation as a function of time is demonstrated. The linewidth enhancement factor of the amplifier is also evaluated. .**

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I. Introduction

Since the first demonstration of the Transistor Laser (TL) [1], there is growing interest in the study of its inherent properties, as well as finding new application areas of the device [2-5]. Usually a thin Quantum Well (QW) is inserted in the base region of a Heterojunction Bipolar Transistor. The injected carriers in the base are captured by the QW, in which a population inversion occurs leading to stimulated emission. Light emission occurs from a facet of a Fabry Perot (FP) cavity in a direction perpendicular to the direction of flow of base charges. Transistor Laser provides a means for integration of electronic and photonic components. Signal mixing at GHz has been reported in a two input one output structure.

A number of analyses have been reported in the literature [6] to calculate the small signal ac response, large signal response and switching characteristics, based on rate equations for charge carriers, and photon numbers. Since the subject is quite young, a lot of studies, both theoretical and experimental are needed to exploit the full potential of the device.

It occurs to us that the TL may function as amplifiers both in the electronic and optical domain. This configuration, termed as TL Optical Amplifier without the FP resonator, has both electrical and optical signals to be amplified by the device. The input optical signal gets amplified as in a traveling wave semiconductor optical wave amplifier, which is invariably used in present day optical networking. Moreover, it has a key feature in networking application as a converting component in between optical back-bone network and wireless access network. It is thus worth while to examine the performance of such amplifier in the steady state and time domain. The present paper addresses some of these issues. To our knowledge, there is no report on TL based optical amplifiers.

II. Theory

Our starting point in this paper is the rate equations involving capture and escape of carriers in the QW from the injected carriers into the base [6]. We solve these equations first in the steady state. In our approach, the carrier and photon numbers are expressed per unit volume as in Keiser [7]. The steady state solution gives

$$g = \frac{g_0}{1+(P/P_{sat})} \tag{1}$$

where g_0 is the unsaturated material gain coefficient expressed as

$$g_0 = \Gamma a \tau_{QW}\left[\frac{\nu J_0 \tau_{rb}}{qd\tau_{cap}} - \frac{n_{nom}}{\tau_{QW}}\right]; \quad \nu = d/W_b \tag{2}$$

and the saturation output power is

$$P_{sat} = \frac{hfWd}{\Gamma \tau_{QW}} \tag{3}$$

Γ, a and ν are, respectively, the mode confinement factor, differential gain and capture coefficient in QW, W_b is the base width, W and d are the width and thickness of QW, n_{nom} is the threshold carrier density, hf is the photon energy, τ_{cap}, τ_{QW}, τ_{rb} denote, respectively, the time of capture, lifetime in QW and base recombination lifetime. J_0 is the current density in absence of signal. The transient analysis is made by solving the rate equations given in [6] by MATLAB ODE Solver 45.

II. DC Analysis

We first calculate the unsaturated material gain coefficient for different QW thickness d keeping the base width fixed at 100 nm. This changes the values of ν and Γ, which is obtained from the transcendental equation for EM modes in InGaAs sandwiched between GaAs. The plot of g_0 as a function of d for different values of injection current density as a parameter is shown in Fig. 1. The values of parameters are: W_b= 100 nm, $a = 2 \times 10^{-20}\,m^{-2}$, $\tau_{QW} = \tau_{rb} = 150$ ps, $\tau_{cap} = 1$ ps, $n_{nom}d = 10^{16}\,m^{-2}$. The gain shown in Fig. 1 shows a monotonic increase with the value of d. and becomes quite appreciable for larger values of Γ. The modal gain is however quite small for small d, since both ν and Γ are small. A possible way to increase gain is touse MQW in place of SQW. However, the rate equation should be modified and the present simple model needs substantial modification [8].

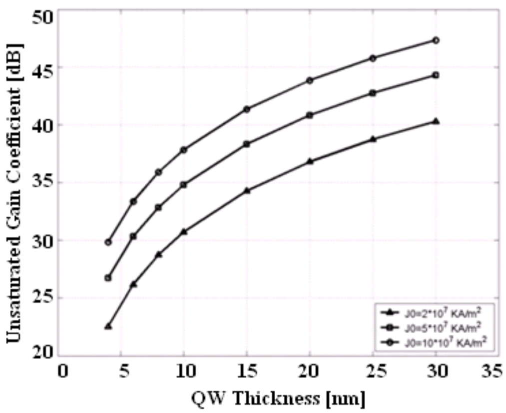

Fig. 1: Plot of unsaturated gain versus QW thickness d for different values of injected current density J_0

III. TIME DOMAIN ANALYSIS

The time dependent rate equations are solved by MATLAB ODE 45 solver using 4th order Runge Kutta method. We give here some representative results.. The variation of total gain as a function of time with application of a short optical pulse of 10 ps duration is shown in Fig. 2. As the pulse amplitude increases, more carriers are involved in stimulated emission at the QW, thereby reducing gain. During the trailing edge of the pulse, the gain shows a proper recovery to its highest saturation value.

The linewidth enhancement factor has been calculated by using analytical expressions for QW developed in [9]. The values are obtained as a function of carrier density at gain peaks. The variation is plotted in Fig. 3.

V. CONCLUSION

We propose in this paper a new application of the transistor laser structure, in which the QW embedded in the base of a Heterojunction Bipolar Transistor acts as an optical amplifier. The material gain coefficient is evaluated for different values of QW thickness and base current density by solving rate equations in the steady state. Some results on transient analysis are given demonstrating gain recovery under short optical pulse. Values of LEF are also obtained. Some other possible applications in current wireless access network are discussed.

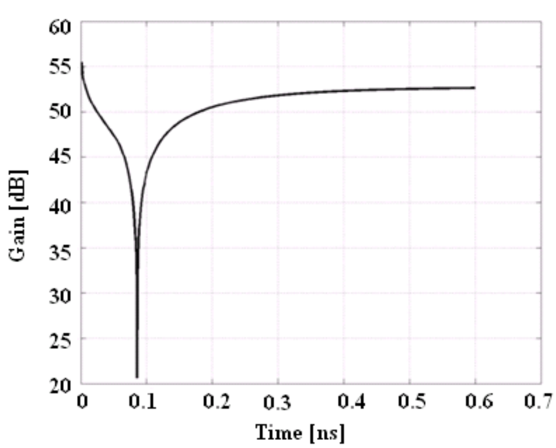

Fig. 2: Total gain as a function of time with the application of short optical pulse of 10 ps pulse width

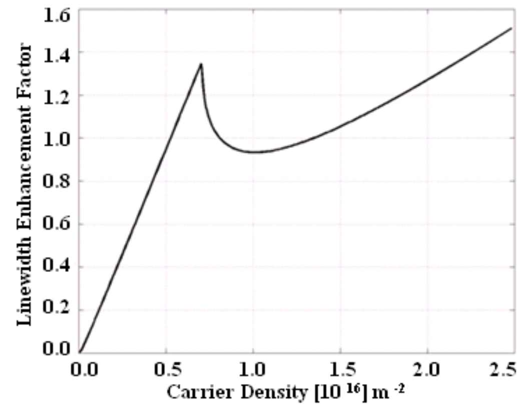

Fig. 3: Line width enhancement factor variation as a function of carrier density at gain peak

VI. REFERENCES

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