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Performance Analysis of Quantum Cascaded Lasers

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Abstract**—**Improving the performance of the QCL through block diagram as well as mathematical models is the main scope of this paper. In order to enhance the performance of the underlined device, the mathematical model parameters are used in a reliable manner in such a way that the optimum behavior was achieved. These parameters play the central role in specifying the optical characteristics of the considered laser source. Moreover, it is important to have a large amount of radiated power, where increasing the amount of radiated power represents the main hopping process that can be predicted from the behavior of quantum laser devices. It was found that there is a good agreement between the calculated values from our mathematical model and those obtained with VisSim and experimental results. These demonstrate the strength of implementation of both mathematical and block diagram models.

Keywords**—**Quantum Cascaded Lasers (QCLs), Modeling, Block Diagram Programming, Intersubband transitions.

I. INTRODUCTION

QUANTUM cascade laser (QCL), is a unipolar semiconductor laser [1,2] based on intersubband transitions in quantum wells with the initial and final states of the electrons are only in the conduction band and therefore have the same curvature in the reciprocal space. A fundamental property of the QCL is that the wavelength is not controlled by the material bandgap but by the layer thickness. For this reason, the emission wavelength of such a laser can be changed without using different semiconductor materials [3,4].

The recent demonstrations of room temperature, high power, distributed feedback (DFB) QC lasers and a long wavelength indicate the great potential of the QC configuration [5]. As a result of this we are concerned with the power characteristics of QCL and its effect on the other element of QCL. Power with wavelength and current density is introduced in a complete form. Here, we establish a model technique that describes the power with other lasing effects. Experimental Setups for measuring the characteristics of QCL are reported [6]. However it is shown difficulties in tuning and cost much. In this work block diagram technique is used to overcome the above mentioned complexity. Models are designed for the lasing properties of QCL devices. We focused here on improving the characteristics of QCLs, by exploiting the parameters that have a large effect on the performance of QCL through our developed models. Block diagram models are implemented by VisSim describing the lasing characteristics of QCLs. Furthermore, proposed mathematical models are evaluated in order to do the same function. This paper is organized as follows: In section *II,* we present the basic assumptions of the model. Proposed Simulator for Quantum Cascaded Laser including Power model is considered in section III. We summarize our results in section IV. Section V is devoted for conclusion.

II. PROPOSED MODELS FOR QUANTUM CASCADED LASER

Here, we simulate the power equations in VisSim environment. The power is modeled in accordance with both wavelength and current density. The selected wavelength is that required for a particular application. In addition, the simulated results were compared with both theoretical results, which evaluated in the Maple package, and the practical published ones. The behavior of these models will be evaluated in the following subsections.

A. Power

A useful measure describing the performance of QCLs is the output power. It is a useful parameter that takes into account the internal efficiency as well as QCLs's different parameters. The optical output power of QCLs is intrinsically high due to the cascading scheme. Because the electrons that have undergone a radiative transition **in** one active region are still present in the conduction band and can be reused in subsequent active regions. The power performance of the lasers shows the validity of the cascading scheme [7]. The emitted power is related to the distance of optical transition between the two lasing states by the following relation [8]:

$$dP = h\ \upsilon\ W_{ij}^{sp}\ \frac{\lambda^2}{8\pi h \upsilon n^2} L(\upsilon)\ \Delta N\ \ I(\upsilon)\ dZ \qquad (1)$$

Where, n, I(ν), h, ΔN and Z denotes the refractive index, intensity of radiation at frequency ν, Plank 's constant, population inversion that due to the optical transition between the states (3 and 2), and distance of optical transition. The above formula was simplified and the resultant expression that describes the relation between the output optical power and the QCLs parameters has a form given by:

$$P = \frac{\left\{ \frac{1}{30000} Q + \frac{200}{3} S + \frac{2}{3} \frac{(j - j_{th}) \upsilon_0 c a h \alpha_m \eta_i}{q(\alpha_m + \alpha_w)} \right\} N_p}{c} \qquad (2)$$

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Where

$$Q = \frac{\sqrt[3]{50}\sqrt[3]{\phi}}{\pi\varepsilon_0 q(\alpha_m + \alpha_w)}$$

$$S = \frac{(\upsilon_o{}^2 - 3\gamma^2)(j - j_{th})2c^2a^2h^2\alpha_m{}^2\eta_i{}^2\pi\varepsilon_0{}^{2/3}\sqrt[3]{50}}{q(\alpha_m + \alpha_w)\sqrt[3]{\phi}}$$

Where a, j, e, α_m, α_w, η_i, T, T_0, c, τ_2, f_0, τ_3, τ_{32} and L_p, denotes the stripe area (cm^2), injected current density (KA/cm^2), electron charge, mirror losses (cm^{-1}), waveguide losses (cm^{-1}), internal efficiency, absolute temperature (^0K),characteristic temperature of the compound material, speed of light, lifetime of state 2, central frequency, lifetime of state 3, lifetime of optical transition between the two states 3 and 2 and length of one period of the QCL structure. A block diagram model has been proposed for the analytical model.

III. SIMULATION RESULTS AND DISCUSSION

The power varies up and down passing by 7.935µm wavelength as Fig. 1 indicates. This figure shows a benefit comparison among practical, Maple program, and simulated results. This value of wavelength is in excellent agreement with the published experimental result [6]. Another remark that can be taken from the underlined figure is the variation of the power with wavelength which takes Gaussian form. Additionally, the emission of the mode is very close to the Bragg wavelength.

Refractive index has an important effect on the power as illustrated in Fig. 2. The high peak power is recorded for the large refractive index and vice versa. We noticed from this figure that as the refractive index is increased, the beam is refracted with small divergence and high coupling occur inside the cavity with small dissipation and consequently better optical confinement is obtained along with high power. Power, N_p, and frequency are plotted in Fig. 3.

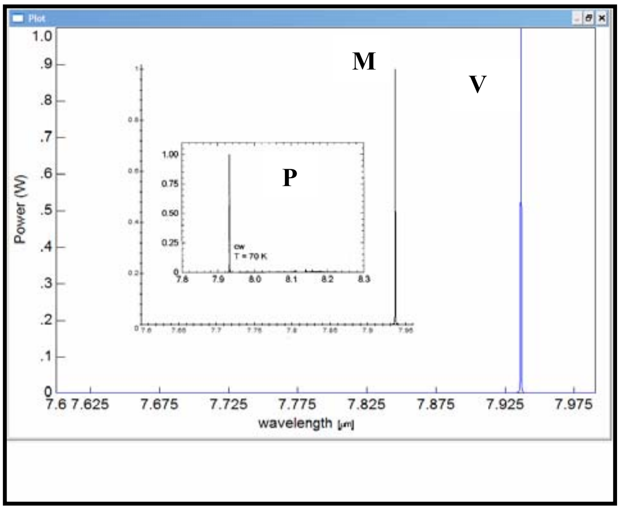

Fig. 1 Comparison between M=analytic (Maple), V=VisSim and P=practical results in [6]

The output power as a function of the current density is illustrated in Fig. 4, at 30^0K. From this figure, the output power increases with the injection current. Because as the injection current increases, the alignment between the periods increases, hence satisfied population inversion and high photons emission are produced. High agreement between our simulated results, Maple results and published practical results are obtained. An important mechanism that can enhance the output power is that associated with waveguide loss. As waveguide losses increase, the dissipated electrons in the transition process within QCL system increase more leading to defect the operation. The small disagreement between practical and theoretical results may be due to the underestimate waveguide losses and Fig. 5 support this concept.

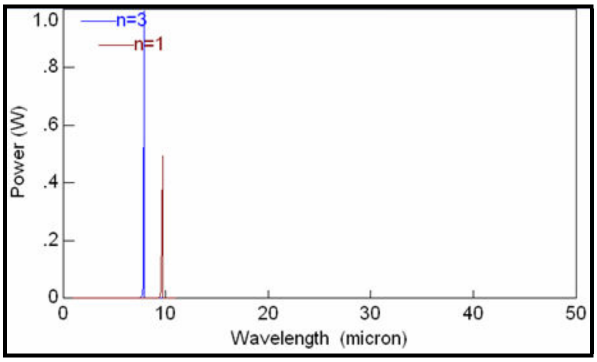

Fig. 2 Power as a function of the wavelength at different refractive index values

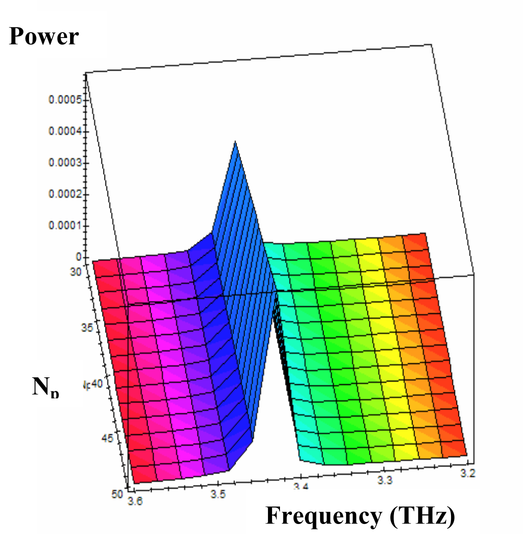

Fig. 3 Relation between power, frequency, and number of periods with

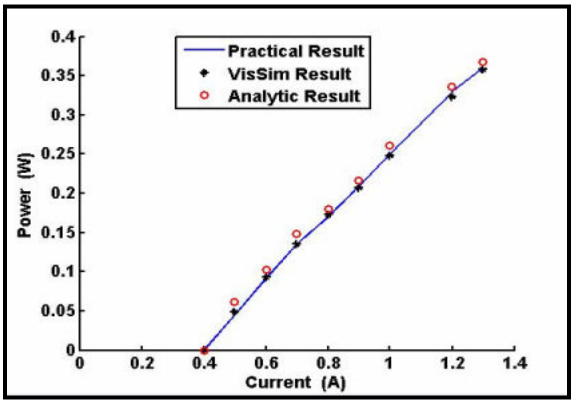

Fig. 4 Relation between current density and power at 30 K, τ_3=1.495ps, α_w=24;α_m=5.59; a=2.925μm, N_p=30 A) VisSim and B) Maple results c) Practical result in [6]

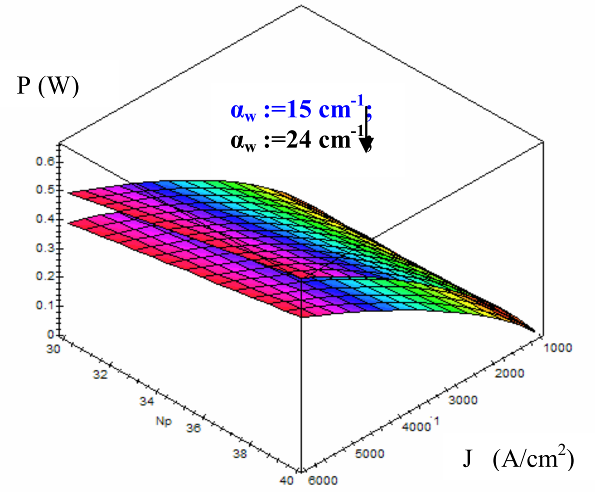

Fig. 5 The emitted power with current density and Number of periods at different waveguide losses, with α_m=5.59 cm^{-1}; z_{ij}=1.9nm, τ_3=1.495ps,τ_{32}=3.1ps, T=30 ^{0}K

IV. CONCLUSION

Our goal is to improve the lasing properties of the QCL. We have proposed block diagram along with mathematical models that capable of covering all critical behaviors of QCL. The performances dependent on different QCLs parameters are illustrated. Additionally, proposed relation that linked emitted power with QCLs parameters is deduced. Our numerical results are compared with the building block diagram model and published experimental results and the coincidence between the two are observed.

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