11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Input and Intrinsic Device Modeling of VCSELs

K. Minoglou[1], E. D. Kyriakis-Bitzaros[2,1], D.Syvridis[3] and G. Halkias[1]
[1] Institute of Microelectronics, NCSR "Demokritos", 15310 Agia Paraskevi, Greece
[2] Department of Electronics, TEI of Pireaus, 12244 Egaleo, Greece
[3] Department of Informatics and Telecomunications, Univ. of Athens, 15784 Athens, Greece

INTRODUCTION

In recent years the Vertical Cavity Surface Emitting Lasers (VCSELs), have emerged and threaten to supplant the standard laser technology in a variety of applications, such as short hull high speed networks and MOEMS. Thus, motivated by the fact that the ability to model VCSELs is critical to the design and analysis of optoelectronic microsystems, we propose a new model scheme that will combine the non-linear behavior of the input parasitics with the intrinsic fundamental device rate equations. A systematic methodology for the model parameter extraction from dc and ac, electrical and optical measurements is also presented and simulation results are compared with the experimental measurements. Simulation and extraction procedures are proved to be very fast while they preserve adequate accuracy.

MODEL DESCRIPTION

The proposed circuit model for a packaged VCSEL is illustrated in Fig. 1. L_0, R_0 and C_0, model the connection to the measurement equipment and inductance L_p with capacitance C_p represent the parasitics of the package-leads as well as the wire-bonds of the package. The intrinsic VCSEL is modeled by a series resistance R_a in shunt with a non-linear capacitance C_j and the combination of a non-linear temperature-dependent current-controlled voltage-source *Einp* with a series resistance R_{int} and an ideal diode D_{vcsel}. Intrinsic voltage drop *Einp* and the intrinsic capacitance of the VCSEL are modeled according to the semi-empirical equation and to the junction diode's equation presented in [1]. The internal device temperature *T,* the carrier density and the photon density, which is equivalent to the output optical power are dynamically calculated using the respective rate equations [2]. Moreover non-linear gain and transparency number and temperature dependent leakage current are included in the model.

Since a circuit simulator is a differential equation solver, the rate equations can be solved with such a tool by mapping the dynamic quantities (i.e. the electron and photon populations) into node voltages, which are dynamically calculated. Working towards this direction, we have implemented all rate equations based on the analysis of Mena [2] in OPSIM™. As an example in fig.2 is presented the equivalent circuit (with the expressions for the circuit elements) that corresponds to the following photon density equation:

$$\frac{dS}{dt} = -\frac{S}{\tau p} + \frac{\beta}{\tau n} No + \frac{Go \cdot zn\left(\gamma_o No - \gamma_1 N1 - \gamma_o Nt \cdot zn\right) S}{1 + \varepsilon S}$$

Where τp, τn, β, No, Go, zn, γ_o, γ_1 and ε are model parameters.

PARAMETER EXTRACTION PROCEDURE

Due to the large number of the model parameters (16 for the input circuit and 24 for the rate equations) a three-step parameter extraction methodology is proposed to estimate them by dividing them into distinct groups. The parameter estimation is achieved by using I-L-V dc characteristics measured at four ambient temperatures and S11 and optical signal ac responses for various bias currents.

In the first step the dc dependent parameters of the input circuit (such as R_{in}, R_{int} and R_a) are estimated using as input to the optimization tool the dc current-light (I-L) characteristics and as targets the measured I-Vs. In the second step, using the previously calculated values, the optimization target is changed to S_{11} vector measurements and the remaining parameters of the input circuit, which influence its ac behavior (such as L_o, R_o, C_o, L_p, and C_p) are estimated. In the above procedures the rate equation that affects the results is only the thermal one, which is used to determine the internal device temperature. Thus, in the third step, the parameters of the carrier and photon rate equations as well as gain, transparency number and leakage current parameters are estimated using as optimi-

ISBN 3-901578-16-1

zation targets the dc I-L characteristics and the ac optical response.

As it is shown in Figures 3 and 4 satisfactory agreement between measured values and simulation results for a commercially availlable VCSEL is achieved using the proposed model and extraction methodology.

Unambiguously, the level of model complexity and the different nature of the parameters (physical, geometrical, fitting values), suggest that methods like sensitivity analysis, classification of the parameters, possible calculation or estimation based on published values can significantly improve the extraction methodology. Currently we are developing the parameter extraction procedure pursuing the goal to be robust and efficient. Up to now the two first steps of the parameter extraction methodology have been successfully completed while the third one needs further refinement due to the increased number of parameters.

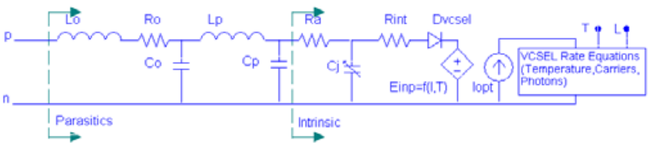

Figure 1 The proposed circuit model of the VCSEL.

$$g_{sp} = \frac{\tau p \cdot \beta \cdot k_f \cdot No}{\tau n \cdot \left(V(m) + \delta_m\right)}$$

$$g_{stm} = \tau p \cdot zn \cdot G_o \cdot \frac{\left(\gamma_o No - \gamma_1 N1 - \gamma_o N_t zn\right) \cdot \left(V(m) + \delta_m\right)}{1 + \varepsilon \frac{\left(V(m) + \delta_m\right)^2}{k_f}} - \delta_m$$

$$C_{ph} = 2 \cdot \tau p$$

$$R_{ph} = 1 \qquad and \qquad S = \frac{\left(V(m) + \delta_m\right)^2}{k_f}$$

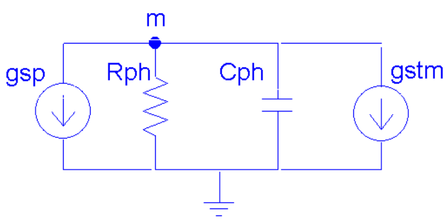

Figure 2 Equivalent circuit for the photon rate equation

CONCLUSIONS

A compact and efficient VCSEL model for the VCSEL that models by means of equivalent circuits the fundamental device rate equations, the thermal effects, the non-linear gain and transparency number functions and the input parasitics elements has been presented. The parameter extraction is based on standard dc and ac measurements and it is achieved by a three-step procedure, which divides model parameters into distinct groups. Simulation results, using the proposed model, present satisfactory agreement with the measurements.

REFERENCES

[1] K.Minoglou,, E.D. Kyriakis-Bitzaros, D. Syvridis, G. Halkias, J.Lightwave Technol, vol. 22, No.12, , pp.2823-2827 Dec. 2004

[2] P. V. Mena et al. J. Lightwave Technol., vol. 17, pp. 2612–2632, Dec. 1999.

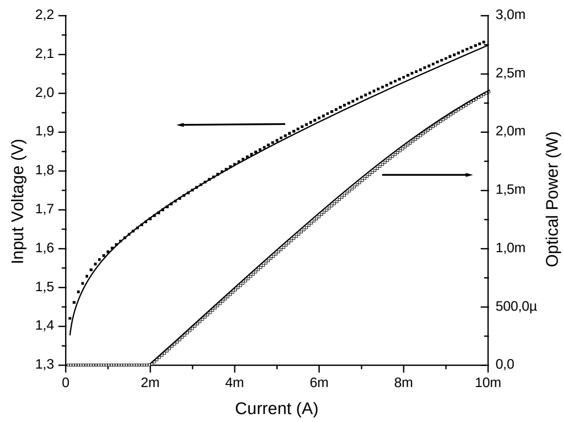

Figure 3 Measured values (dots) and simulated (continuous line) I-V and I-L characteristics at 20ºC

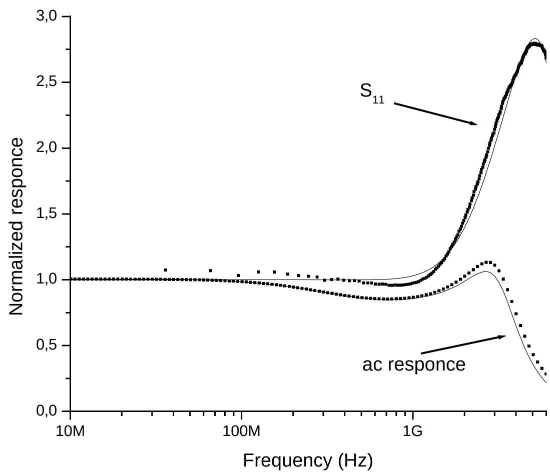

Figure 4 Measured (dots) and simulated (continuous line) S11 and optical ac responses at a bias of 6 mA