VHDL-AMS Model of a VCSEL Emission Module with Thermal Effects

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ABSTRACT

This paper presents a methodology, based on VHDL-AMS modeling, for taking into account the thermal effects of an optical emission module combined with electronic and optic behavior. The thermal transfer is due to the self-heating on one side and the interaction between the components of the other side. This methodology is implemented and simulated with ADVanceMS©.

1. INTRODUCTION

The temperature is an important parameter in any system containing electric, mechanical or hydraulic components. The temperature variation in a system can change its characteristics or its performances and can also disturb its operation, this relates to the type of variation and the applicability.

It's the case for the optical emission module composed of an optical source: Vertical Cavity Surface Emitting Laser (VCSEL) and a driver.

This system is multi-technological (or mixed-technological) type, because it contains electrical and optical interconnected elements. VHDL-AMS language is appropriate to describe such systems, by combining in the description analog objects of predefined nature (technological domains).

2. VCSEL MODEL: THERMAL EFFECTS

1.1 Electro-optical model

The VCSEL operation can be described by the three equations system binding the carriers number, the photon number and the optical phase [1].

$$\frac{dS}{dt} = -\frac{S}{\tau_p} + \beta\frac{N}{\tau_n} + G_N(N - N_0)\frac{S}{1+\varepsilon S} \quad (1)$$

$$\frac{dN}{dt} = \eta_i\frac{I}{q} - \frac{N}{\tau_n} - G_N(N - N_0)\frac{S}{1+\varepsilon S} \quad (2)$$

$$\frac{d\psi}{dt} = -\frac{\alpha_h}{2}\left[G_N(N - N_0)\frac{1}{1+\varepsilon S} - \frac{1}{\tau_p}\right] \quad (3)$$

The different parameters are described in [2] [3].

The output optical power of the VCSEL is expressed by equation 4 [4].

$$P_{opt} = \frac{\eta_d h\nu}{\tau_p}S \quad (4)$$

1.2 Thermal dependence

Different parameters present a thermal dependence what returns the VCSEL output variables thermally dependent.

Moreover, the VCSEL module itself is an essential thermal source provided by self-heating. In order to show this phenomena, two approaches are used.

In the first one a forth thermal equation is added to the equation system [4].

$$C_{Th}\frac{dT}{dt} = UI - P_{opt} - \frac{T}{R_{Th}}$$

This simple equation calculates the temperature which is injected into some parameters. Here there is no way to take into account the thermal behavior of neighbored VCSEL and its neighborhood.

In the second approach, an equivalent thermal scheme is used, based on the electro-thermal analogy as recalled in table 1.

Tableau 1 : Electro-thermal Similarity.

Thermal System	Electrical System
Temperature T (K)	Voltage U (V)
Thermal conductivity λ (W m^{-1} K^{-1})	Electrical conductivity σ(Ω^{-1} m^{-1})
Heat flow P (W)	Current I (A)
Thermal capacitance C_{th} (J K^{-1})	Capacitance C (F)
Thermal resistance R_{th} (K W^{-1})	Resistance R (Ω)

Basically, the propagation of heat in a system can take place in three different ways, convection, heat radiation or heat conduction. Electronic components usually have only heat conduction which is described in a homogeneous isotropic material by the following equation:

$$\frac{\partial^2 T}{\partial x^2} = \frac{c_t \ \rho}{\lambda} \frac{\partial T}{\partial t}$$

In the equation, λ stands for the specific heat conductance, $c_t\,(J \cdot kg^{-1} \cdot K^{-1})$ for the specific thermal capacitance and $\rho\,(kg \cdot m^{-3})$ for the density of the material. T describes the temperature and x the coordinates in the direction of heat propagation.

The unit VCSEL thermal behavior is presented by a π network of first order thermal resistances and thermal capacitances and via thermal ports in addition to the optoelectronic model as shown in figure 1. These ports are Tc, Ts, Tn which indicate respectively the capo, the substrate and the neighbored VCSEL.

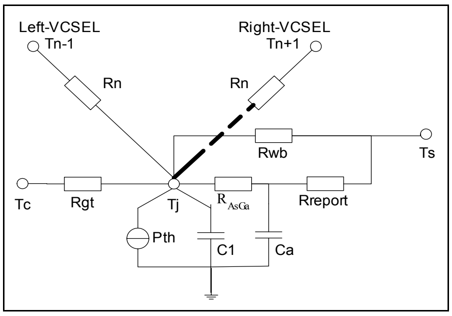


Figure 1 : VCSEL thermal model.

Table 2 recapitulates the various elements of thermal schema equivalent to one unit VCSEL.

Tableau 2 : List of VCSEL thermal element.

Element	Designation
P_{th}	Thermal power
C_1	VCSEL thermal capacitance at the interface active region
C_a	VCSEL thermal capacitance at the interface substrate
R_{AsGa}	VCSEL thermal resistance
R_{wb}	Wire Bonding thermal resistance
R_{gt}	Glop Top thermal resistance
R_{report}	Report thermal resistance
R_n	Neighbor VCSEL thermal resistance

We also note that the VCSEL is in thermal interaction with the whole module as illustrates figure 2 where we show the thermal extraction in the unit VCSEL.

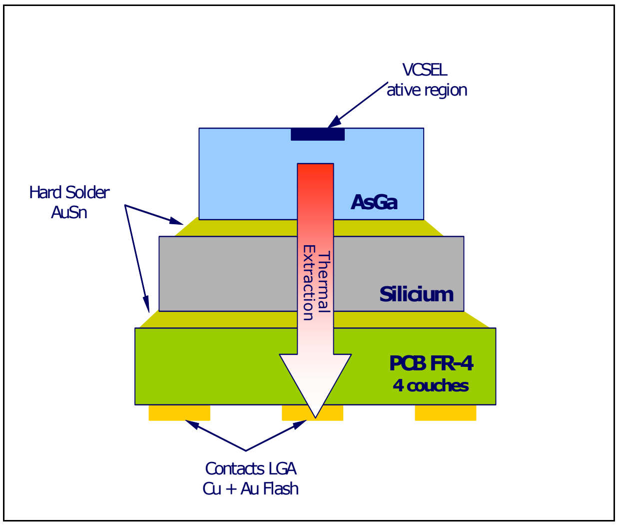
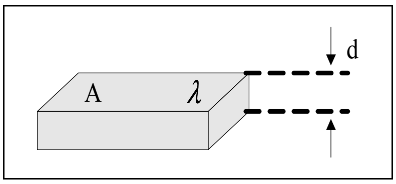


Figure 2 : VCSEL thermal extraction.

The different values of thermal resistances and thermal capacitances are obtained by the equations (5) and (6).



$$R_{Th} = \frac{d}{\lambda \ A} \quad (5)$$

$$C_{Th} = d \ A \ \rho \ c_t \quad (6)$$

where d and A designed the thickness and surface of material which the heat transfer is carried out.

3. DRIVER MODEL: THERMAL EFFECTS

The VCSEL output characteristics depend on characteristics of the current which is applied to it. It's why it makes important to get a good modeling of the command module "the driver".

We have to take essentially into account, besides its electrical behaviour, its thermal influence on the whole emission module which is supposed to be dissipating heat.

Figure 3 shows the CMOS structure of the chosen driver, it's a differential circuit which allows to satisfy required specifications about dynamics of involved electrical signals, because all systematic errors (systematic offset voltage, bias rejection, disturb common mode and are structurally rejected by differential mode.

To each MOSFET is associated a thermal model describing its thermal dependence [6]. The thermal behavior of the driver is described on figure 4, where is shown the self heating effect of MOSFET and the influence of the neighborhood.

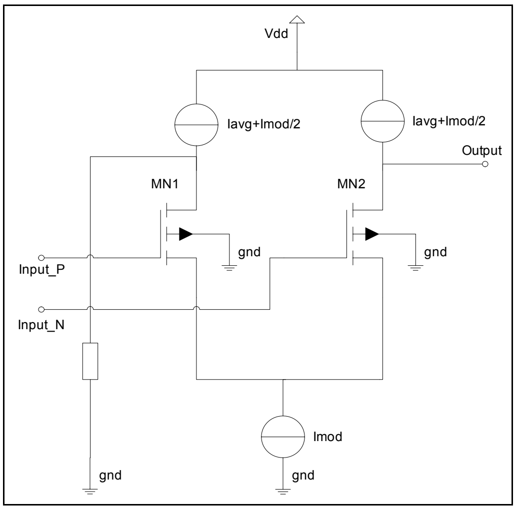


Figure 3 : The Driver Scheme.

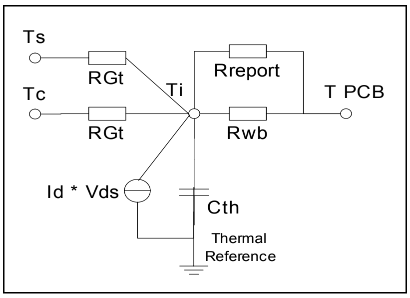


Figure 4 : Thermal model of the Driver.

4. THERMAL PACKAGING

The final protection of a hybrid circuit is obtained by an encapsulation or a coating.

As for the techniques report there are multiple alternatives according to the selected encapsulation procedures, the operation domain and the frequency, the type of the component reported on the layer (wire bonding, flip chip, bean lead...)

Figure 5 presents the thermal packaging model taking into account report and assembly technologies, in which the VCSEL is replaced by its model given by figure 1.

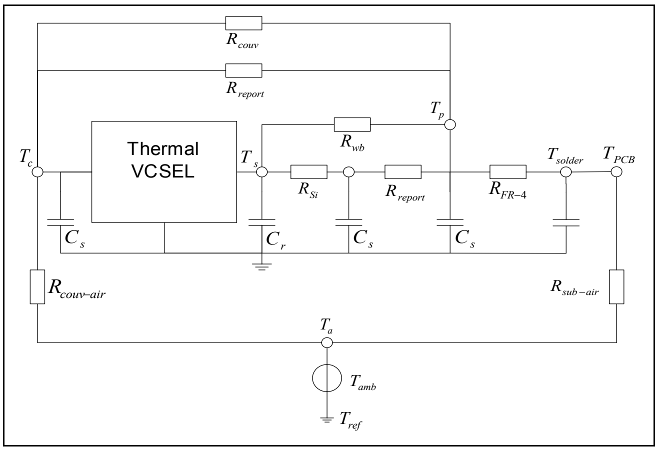


Figure 5 : Thermal Packaging Model.

5. VHDL-AMS MODELING

The VHDL-AMS advantage is that it is multi disciplinary which means being able to model electric, thermal, mechanical and optics effects of a system. VHDL-AMS is appropriate to describe and simulate mixed-technology systems. Thus we present in this paragraph the models written in VHDL-AMS and some simulation results.

First, we present thermal dependence of driver output current, figure 6 and 7 show respectively high and low output currents versus ambient temperatures varying from 238K to 358K.

Secondly figure 8 shows the thermal effects on the emission module: junction-temperature and PCB one are shown, at low and high current injected, simulated at 298K ambient temperature.

At constant ambient temperature the heating effect varies according to the current injected itself versus the temperature.

It is noticed that the temperature difference between the high current and the low current is more important at the junction than at the PCB.

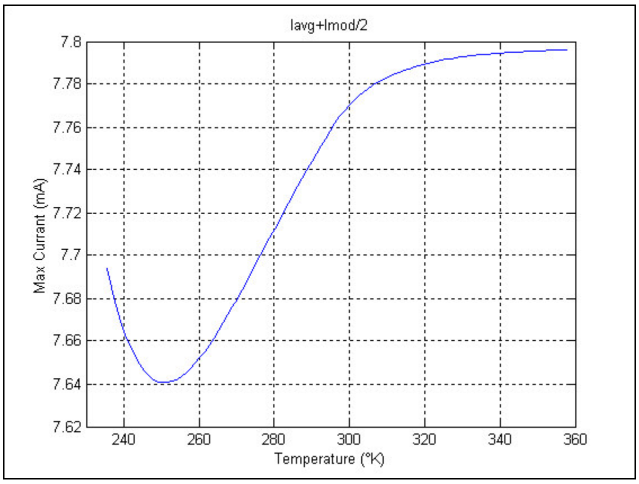


Figure 6: High current vs temperature.

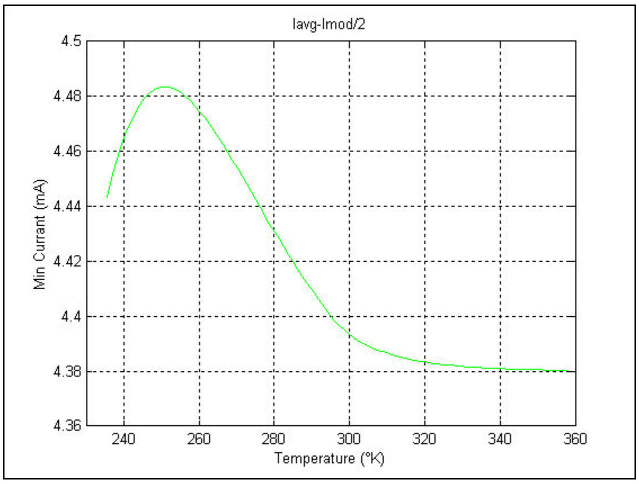


Figure 7: Low current vs temperature.

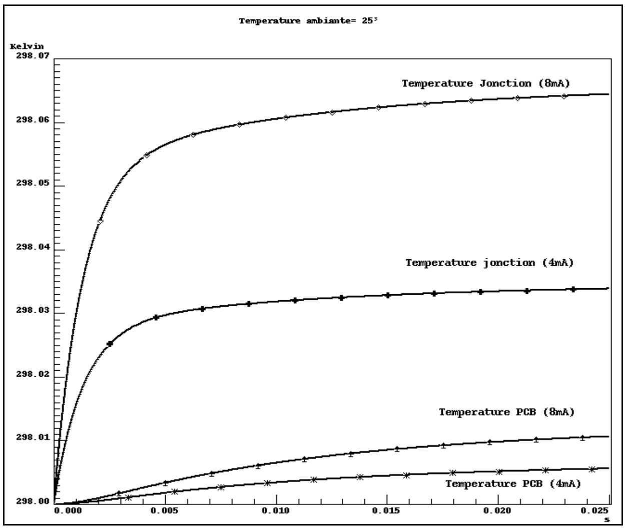


Figure 8 : Different temperature of emission module.

6. CONCLUSION

This paper described the VHDL-AMS modeling of a VCSEL emission module, taking advantage of the language to model multi-technological aspects of the module: here optical, thermal and electrical. The electro-thermal model has been built by considering the analogy between electrical and thermal variables and by using thermal resistors and capacitors in the thermal circuit. Moreover optical aspects have been added into the model. The thermal influence of the neighborhood was also taken into account.

The PCB undergoes the heating of the driver and of the VCSEL but this heating remains less important than that of the two other components.

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