Optical power model of a laser bar diode

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Abstract. This article proposes a modelling method for laser diodes optical output power including its dependency on temperature. The device used for this study is a 40 W Monocrom's diode, with 808 nm wavelength emitted light and with a 19 emitters CS mount laser bar, mounted using the patented Monocrom's clamping method. The aim of this study is to propose a Pspice modelling of the laser diode device, mainly focusing in the optical output power variation with the temperature and allowing its computer simulation. Also to setup a characterization system to obtain the necessary parameters values for the optical model mathematical expressions. Therefore, the article explains the proposed method for the optical output power model generation of the laser bar diode and how its parameters values are obtained, an optical output power measurement setup and its calibration, the obtained Pspice model and its simulation, and the characterization system that allows to obtain the necessary parameters with short rise up time current slopes. Finally, evaluation of results and related conclusions are exposed.

1. Introduction

A Pspice or any other modelling method allowing computer simulation of the optical output power of a laser diode device in its control driver, including its dependency on temperature, is useful because laser diode devices increase temperature during the laser effect provoking the decrease of the optical output power and its efficiency. In those industrial applications where the optical output power need to be constant different methods are used to achieve this purpose, either keeping the temperature constant or readjusting the laser diode current with photodiodes based feedback circuits [10]. Simulation can prevent laser diode devices working outside save margins. Laser diodes can be destroyed in case of its usage outside the recommended working conditions. This article is describing an example of Pspice model generation and parameters measurement in case of a Monocrom's CS mount laser bar diode, using a patented clamping method. The novelties of this work are the optical output power modelling proposal considering temperature variations, which includes the mathematical model and related hypothesis validation, the proposed Pspice optical power modelling schema and the characterization system for temperature dependent parameters measurement.

2. Modelling method
2.1 Laser diode electrical model

For the electrical behaviour modelling of the laser diode, Pspice existing libraries and model are used. Those include the Shockley equation (1),[1],[2] for the current/voltage (Ild/Vld) laser diode response curve at forward bias where laser effect takes place. Main parameters are the saturation current (Is), the parasitic resistance (Rs) and the emission coefficient (N), also known as ideality or quality factor. Is and Rs are calculated using pairs of values obtained from the measured Ild/Vld response curve and applying equation (1). N=1 in forward bias and in a good diode [1]. $Vt = kT/q$ is the thermal voltage (25 mV at 25 ºC)

$$Ild \sim Is \cdot e^{\frac{Vld - Ild \cdot Rs}{N \cdot Vt}} \text{ or } Vld = ln\frac{Ild}{Is} N \cdot Vt + Ild \cdot Rs \tag{1}$$

For the electrical response dependency on temperature, Pspice diode models are already including the variation of the saturation current with the temperature as expression (2),[5]. Necessary parameters are Gap energy (EG) and saturation current temperature exponent (XTI). EG parameter depends on semiconductor

material and also related with the emitted light wavelength. Its value is obtained from tables. In this case this is an AlGaAS 808 nm laser diode, and according [4], EG value is 1.55. XTI, saturation current temperature exponent, has a value of 3 in a diode and this value is used as default by the Pspice diode model libraries.

$$Is(T) = Is \cdot e^{[(\frac{T}{Tnom}-1)\frac{EG}{N \cdot Vt}]} \cdot (\frac{T}{Tnom})^{\frac{XTI}{N}} \tag{2}$$

2.2 Laser diode optical model

Laser diodes optical output power variation is modelled as Popt/Ild chart shows in Fig.1 and as expression (3), [3]. It is a simple model based in two straight lines where the optical output power (Popt) is 0 when the current at the laser diode is lower than the threshold current (Ith, current laser effect and emitted light starts from), and if higher, Popt increases linearly with the current increase with a relation SE = ΔPopt/ΔId (W/A) known as Slope Efficiency (SE) or Differential Efficiency (η_D).

$$Popt = 0, \text{if } Ild \leq Ith;$$
$$Popt = SE \cdot (Ild - Ith); \text{ if } Ild \geq Ith \tag{3}$$

Also in this Fig.1 it is shown how the Slope Efficiency (SE) depends on temperature. Its value decreases linearly with the temperature increase. This linear decrease is a hypothesis, based on mid-high output laser diodes specifications like [11]. Hypothesis is that SE(T) value is SE1 (SE at a temperature T1) plus the temperature increment (T-T1) multiplied by the SE decrease ratio with the temperature ΔSE/ΔT (5). Ith increases exponentially with the temperature according theoretical expression (4),[3]. Both Ith(T) and SE(T) behaviours have been confirmed with measurements in a climatic chamber of a 8 W, 808 nm single emitter laser diode (WSLX808008) [7], same type of the ones mounted in the laser bar. Measured charts are shown in Fig.2. Based on that, the optical output power model and its variation with the temperature can be written based on the following expressions, where Ith(T1)=Ith1, Ith(T2)=Ith2, SE(T1)=SE1, SE(T2)=SE2.

threshold current (T) $\quad Ith(T) = Ith1 \cdot e^{\frac{T-T1}{T0}}$ $\hfill (4)$

slope efficiency (T) $\quad SE(T) = SE1 + (T - T1) \cdot (\frac{SE2-SE1}{T2-T1})$ $\hfill (5)$

optical power (T) $\quad \begin{cases} Popt(T) = 0, \text{ if } Ild \leq Ith(T) \\ Popt(T) = SE(T) \cdot (Ild - Ith(T)); \text{ if } Ild \geq Ith(T) \end{cases}$ $\hfill (6)$

using (4),(5) in (6) $\quad Popt(T) = \left(SE1 + (T - T1)\left(\frac{SE2-SE1}{T2-T1}\right)\right)(Ild - Ith1 \cdot e^{\frac{T-T1}{T0}}) \text{ if } Ild \geq Ith(T)$ $\hfill (7)$

where from (4) $\quad To = \frac{T2-T1}{\ln Ith2 - \ln Ith1}$ $\hfill (8)$
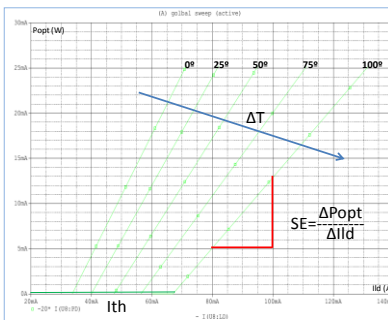

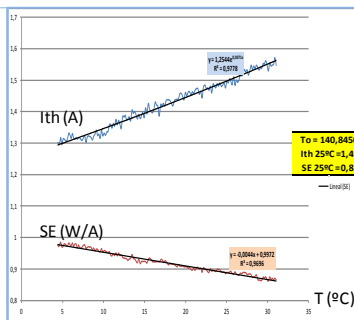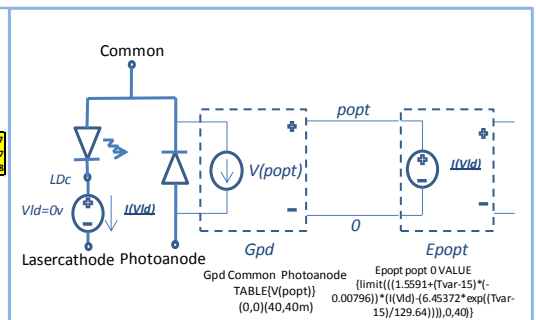Fig 1. Popt/Ild and SE(T)   Fig 2. 8W laser diode Ith(T), SE(T) charts   Fig 3. Popt Pspice model

2.3 Optical output power modelling schema in Pspice.

Pspice modelling of the optical output power is based on the proposed model schema shown in Fig.3. The model uses two diodes in common anode configuration, common pin for laser diode's anode and photodiode's cathode. Current through the laser diode I(Vld), obtained from a serial voltage source, is used as control input of a voltage controlled voltage source (Epopt). It is in this source's transfer function where the optical output power model expression and its variation with the temperature (7) is introduced as:

Epopt popt 0 VALUE {limit(((SE₁+(Tvar-T₁)·((SE₂- SE₁)/(T₂-T₁)))·(I(Vld)-(I$_{th1}$·exp((Tvar-T₁)/To)))),0,max)} (9)

A second voltage controlled current source (Gpd) is used to linearly convert the optical output power V(popt) into photodiode's current. This conversion ratio corresponds to the used photodiode's sensitivity.

3. Model parameters measurement and Pspice model program

3.1 Electrical model parameters Is, Rs. Measurement and calculation

Ild/Vld relation chart of the laser bar diode device at 25 ºC is measured in DC mode and shown in Fig 4. Using its values (i.e. 20 A/2.2 V and 10 A/1.88 V) and equation (1), Is=2E-26 and **Rs=3E-2** are calculated. Pspice nominal temperature is 27 ºC [5]. Using (2), **Is(27ºC)=2.93857E-26** is calculated. Those values are introduced in the electrical Pspice model and simulated results (Fig.5) and measured values at 25 ºC are compared, confirming that Pspice model uses expressions (1) and (2) and calculated parameters are correct.
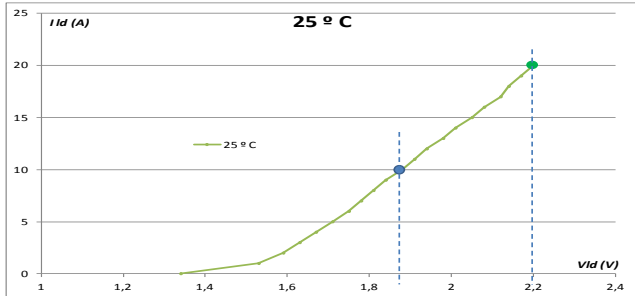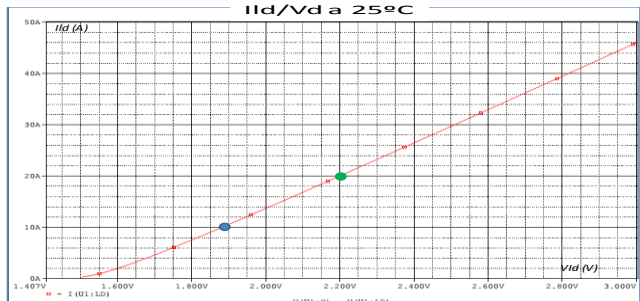

Fig 4. I/V chart at 25 ºC

Fig 5. I/V Pspice simulation at 25 ºC

3.2 Optical output power measurement setup and calibration. Popt/Vpd vs. Ild

Laser diode's optical output power measurement setup (Fig.6) allows stable measurements avoiding any effect due to laser beam directionality. It includes a light integration sphere, a photodiode (Thorlabs PDA100A-EC [9]), an spectrometer to control temperature drifts supervising emitted light spectrum, and a data acquisition card controlled with LabView for photodiode voltage (Vpd) and laser diode current (Ild) measurements, which is the relation to be measured. Voltage at the photodiode needs to be converted to optical power. This calibration (Popt/Vpd) is done using a thermal optical power meter. Vpd and Popt vs. Ild in DC and values used for calibration are shown in Fig.7. This setup allows to obtain Popt/Ild relation with short rise up time current slopes.

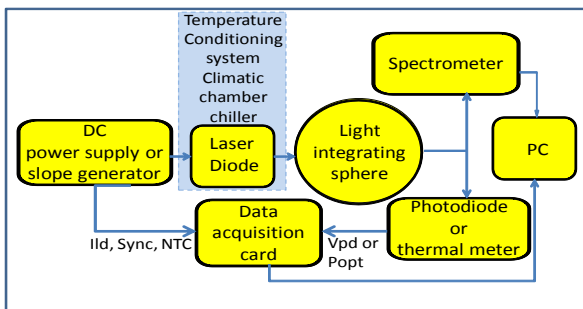**Fig 6 Measurement system setup**

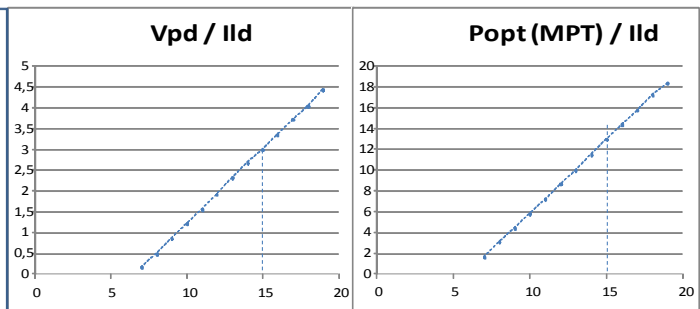

Fig 7. Photodiode Vpd(V) and Thermal meter Popt(W) versus Ild(A)

3.3 Optical output power model parameters measurement. Ith(T), SE(T)

Ith and SE values at two different temperatures need to be measured according expressions (7) and (8). With the proposed measurement setup, Popt/Ild relations of the laser bar diode are obtained at 15 ºC and 25 ºC in DC mode. Fig.8 shows Popt/Ild charts at 15 and 25 ºC and Ith and SE related values at each temperature.

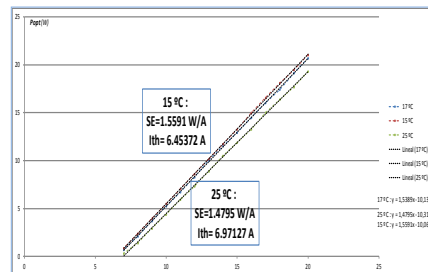**Fig 8. Popt/Ild charts. Ith, SE values @ 15 & 25 ºC**

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* MONOCROM UNIXIPS LASER BAR DIODE
.param Tvar 25
.SUBCKT unixips Lasercathode Common Photoanode
Dlaserdiode Common LDc laserdiode
Dphotodiode Photoanode Common photodiode
Vld LDc Lasercathode
Eopopt popt 0 VALUE {limit(((1.5591+(Tvar-15)*(-0.00796))*(I(Vld)-
   (6.45372*exp((Tvar-15)/129.63)))),0,40)}
Gpd Common Photoanode TABLE {V(popt)}(0,0)(40,40m)
.model laserdiode D (T_ABS={Tvar}) IS=2.93857E-14 N=1 RS=0.03
   BV=2 IBV=10u EG=1.55 XTI=3
.model photodiode D CJO=5p BV=15 IBV=10u
.ends
```
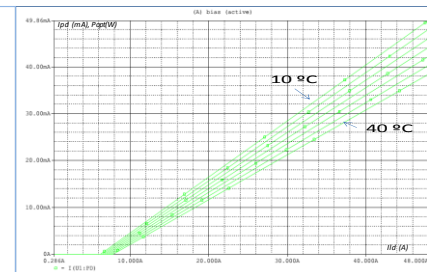
Fig 9. Pspice model of the laser bar diode

Fig 10. Simulation result at 10-40 ºC (each +5 ºC)

3.4 Pspice program of the laser bar diode and simulation results

With SE and Ith values at 15 ºC and 25 ºC, To = 129.63 K (8) is calculated and expression (7) to be finally introduced in the model is : **Popt(T) = 1.5591+(T-15)*(-0.00796))*(Id-(6.45372*exp((T-15)/129.63)).** Pspice model program and simulation results at 10 up to 40 ºC, every 5 ºC are shown in figures 9 and 10.

4. Characterization system using short rise up time current slopes

Obtaining Popt/Ild response curve and Ith and SE parameters with just a few µs laser diode current slope avoids p-n junction temperature increase and related errors in the measurement. Monocrom's DAE-20050 laser driver [6] is used to control the laser bar diode current generating a slope of 20 µs, and a high speed acquisition card, the NI PCI-6115 [8] of 10 Ms/s, 12 bit resolution per channel and external synchronism, for Vpd and Ild data acquisition. Same is done with the WSLX808008 single emitter laser diode device from Wavespectrum [7]. Oscilloscope waveforms (Fig.11) and Popt/Ild response curves of laser bar (Fig.12) and single emitter (Fig 13) diodes are shown. Single emitter results are matching manufacturers device test report (Ith=1.5 A at 25 ºC) validating the characterization system. But Ith and SE parameters cannot be obtained in case of the laser bar diode because of the rounded shape response to this 20 µs rise up current slope.

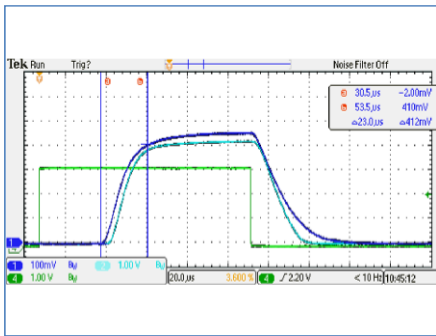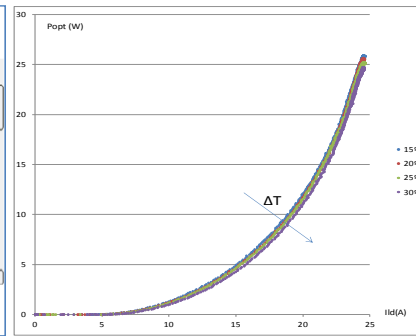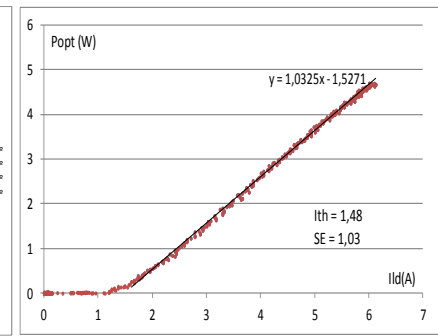**Fig 11. Vpd – Ild 20 µs rise time pulse**   **Fig 12. Laser bar Popt/Ild 15,20,25 & 30 ºC**   **Fig 13. Single emitter Popt/Ild chart**

5. Conclusions

An optical output power model including temperature dependency of a laser diode has been proposed. The hypothesis about the optical power slope efficiency variation with temperature and the existing theory of the threshold current dependency on the temperature, both used in the mathematical modelling, have been confirmed with measured results in a climatic chamber. Another contribution is the proposed Pspice schema for the optical output power modelling including its temperature dependency. Modelling method and related Pspice program have been implemented in a 40 W, 808 nm laser bar diode, and its simulation results are obtained in the device`s operational temperature range. Also it has been proven the feasibility of the characterization system to obtain the relation of the laser diodes optical output power response to a short rise up time current slope, avoiding any possible heating effect in the measurement of the temperature dependency parameters necessaries for the model. This characterization system has been validated with a single emitter 8 W laser diode. Unexpected behaviour is observed in case of the 40 W laser bar diode response curve at short rise up time current slopes that needs further investigation.

6. References

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