Simulation Standard

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RPI VCSEL Model Released in SmartSpice

RPI VCSEL model was developed by Professor Michael Shur and his team from the Rensselaer Polytechnic Institute (RPI) [1]. A release of this model has been implemented within ***SmartSpice***, and can be accessed by setting LEVEL=4 in the diode modelcard.

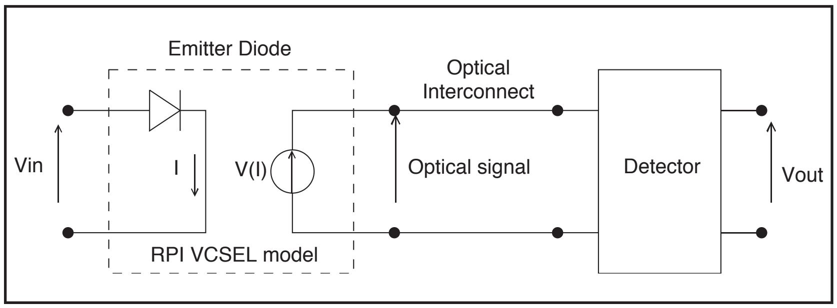

Figure 1. Optical emitter, interconnect and detector.

Mixed Photonic/Electronic Simulation

The optical devices are divided in three parts: emitters (laser diode, LEDs), detectors and interconnects. To provide a Mixed Photonic/Electronic simulation, the photonic signals are described in terms of electrical signals and can therefore be integrated in SmartSpice simulation.

RPI Vertical Cavity Surface Emitting Laser (VCSEL) model is an emitter diode whose optical output power is mapped into an electrical signal. It can therefore be connected to an optical interconnect such as a transmission line. The device is composed of electrical and optical sub-circuits. The electrical sub-circuit is a diode and the equivalent circuit of the device is a current controlled voltage source, as shown in Figure 1.

Model Description

The electric sub-circuit is based on a diode LEVEL=1 Berkeley model. The optical sub-circuit is based on the first order rate equations of semiconductor lasers, as described in [2]:

$$\frac{dN}{dt} = \frac{I}{qV} - \frac{N}{qV} - \frac{v_g \cdot A \cdot \Gamma \cdot (N-N_{tr}) \cdot S}{1 + \varepsilon S}$$

$$\frac{dS}{dt} = \gamma \cdot \frac{\Gamma \cdot N}{\tau_n} - \frac{S}{\tau_p} + \frac{v_g \cdot A \cdot \Gamma \cdot (N-N_{tr}) \cdot S}{1 + \varepsilon S}$$

These equations, involving the carrier density N and the photon density S, describe respectively the electrical properties of a semiconductor laser, and the optical behavior when some photons are produced.

The equivalent circuit of the model is shown in Figure 2.

Idiode, Ileak are diode and leakage currents, Rs is the diode resistance and Cj the junction capacitance. Il, Isp, Ig, Rp, Cp are deduced from first order rate equations (see [1]).

This model allows to simulate optical output power versus input current curves. Due to the strong thermal effects (see Figure 3.), a self-heating sub-circuit has also been added to take into account the thermal leakage current. It leads to an output-power rollover as the input current increases. It has been implemented as an internal node with thermal resistance Rth, thermal capacitance Cth, and thermal excitation Ith.

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INSIDE

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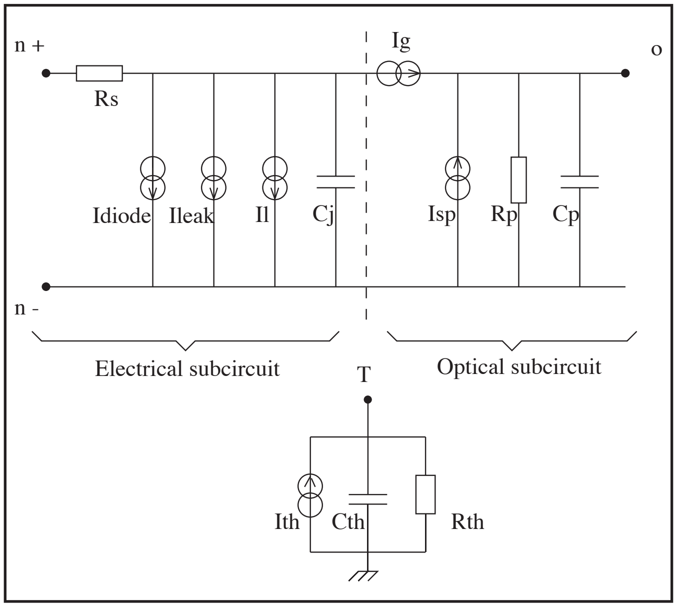

Figure 2. RPI VCSEL equivalent circuit

RPI VCSEL Model and *SmartSpice*

RPI VCSEL model has been implemented as a diode device. The third node is accessible through device declaration:

Dxxx n+ n- o mname ...

n+, n- are respectively anode and cathode of the diode, voltage bias at "o" node is the optical power output in mW. The device can be connected to optical interconnects, such as transmission lines to provide a Mixed Electronic/Photonic simulation.

The model card for RPI VCSEL includes the following parameters:

Optical Equations Parameters

Parameter	Description	Units	Default
DA	Active region depth	m	1.0E-8
TN	Electron lifetime	s	1.0E-9
NTR	Trap density	m-3	0.0
BETA	Spontaneous emission factor	-	1.0
TPH	Photon lifetime	s	1.0
GAMMA	Optical confinement factor	-	1.0
EPS	Gain compression parameter	m3	1.0
G0	Gain slope	m2	1.0
VG	Group velocity	m/s	3.0E8
LAMBDA	Wavelength of optical output	m	8.0E-6
REF	Mirror reflectivity	-	0.99
TOSS	Characteristic temperature of carrier lifetime	K	30
C0	Leakage saturation current	A/m2	1.0E-12
FRAC	Fraction of aluminum	-	0.0
T1	Fitting parameter	s	0.0
IMAX	Maximum saturation current	A	1.0
CM	Saturation knee parameter	-	1.0

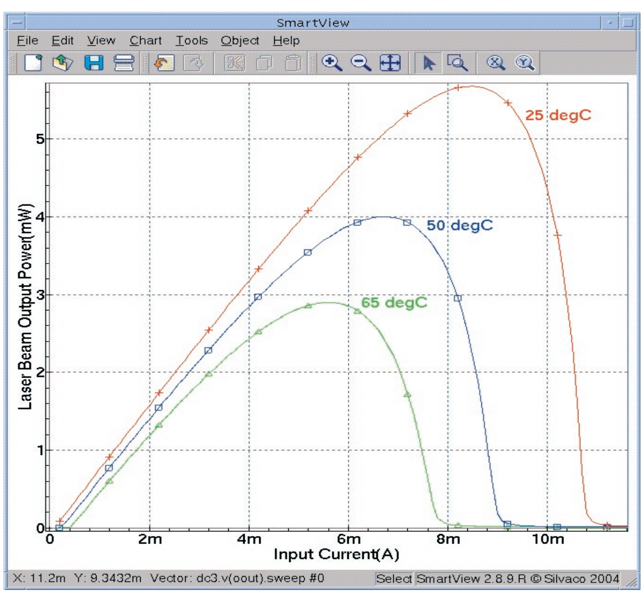

Figure 3. RPI VCSEL P - I characteristics.

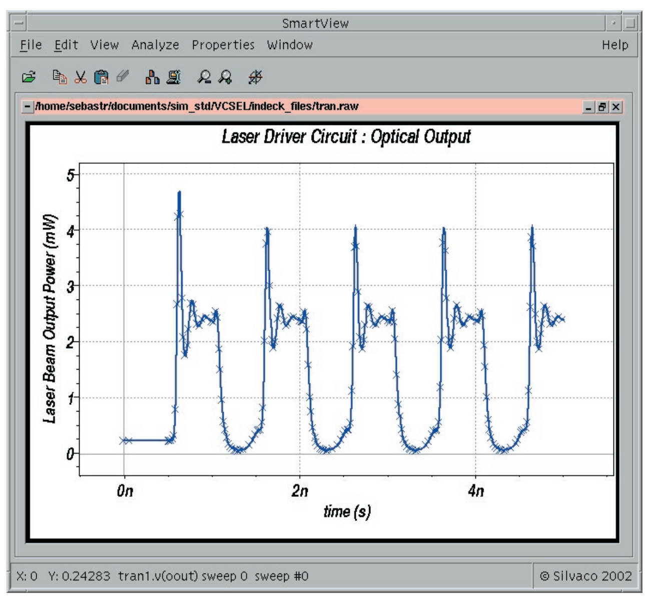

Figure 4. Optical Output of a RPI VCSEL device coupled with a Laser Driver Circuit.

Diode Parameters

Parameter	Description	Units	Default
IS	Saturation current	A/m^2	1.0E-14
TNOM	Parameter measurement temperature	K	TNOM (default)
RS	Ohmic resistance	$Ohm.m^2$	0.0
N	Emission coefficient	-	1.0
TT	Transit time	s	0.0
CJ0	Junction capacitance	F/m^2	0.0
VJ	Junction potential	V	1.0
M	Grading coefficient	-	0.5
EG	Activation energy	eV	1.43
XTI	Saturation current temperature exponent	-	3.0
FC	Forward bias junction fit parameter	-	0.5
BV	Reverse breakdown voltage	V	-5.0
IBV	Current at reverse breakdown voltage	A	1.0E-3
IKF	Forward knee current	A	0.0
ISR	Recombination current	A/m^2	0.0
NR	Recombination current slope	-	2.0
KF	Flicker noise coefficient	-	0.0
AF	Flicker noise exponent	-	1.0

Thermal Sub-Circuit

Parameter	Description	Units	Default
CTH	Thermal capacitance	$J.m^2/degC$	0.0
RTH	Thermal resistance (RTH = 0.0 : no self-heating)	$degC.m^2/W$	0.0

The model supports DC, AC, TRAN and PZ analysis. Bypass calculation and VZERO options have been implemented for a faster simulation when running large circuits. RPI VCSEL model has also been optimized to take advantage of multi-processor machines. Additional outputs have been added in ***SmartSpice*** implementation : SN and NN outputs are photon and carrier densities in the photonic device.

References

[1] J. Deng, M. S. Shur, T. A. Fjeldly, S. Baier, "CAD Tools and Optical Device Models for Mixed Electronic/Photonic VLSI", International Journal of High Speed Electronics and Systems, International Journal of High Speed Electronics and Systems, Invited, Volume 10, No 1, pp. 299-308, March 2000.

[2] R. S. Tucker, " Large-Signal Circuit Model for Simulation of Injection-Laser Modulation Dynamics", IEE Proceedings 128 (1981) 180-184.