

# Opto-electrical model as an assisting tool to design WDM devices in the UV/VIS/NIR

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**Abstract**— Numerical simulations are crucial to validate mathematical models that translate the understanding of the physical mechanisms that occur inside and drive the behaviour of physical systems. In this paper the system is a wavelength selector filter realized by using a double pin/pin a-SiC:H photodetector, modelled as a two connected phototransistors, with several input channels, in the UV/VIS/NIR spectral ranges. Two computer packages including a graphics user interface were designed and programmed within the MATLAB® environment, to perform the numerical simulation tasks using this model. The simulation results showed to be in good agreement with experimental data which corroborates the ability of the presented model and the developed software to mimic the sensitivity behaviour of the proposed system in the UV/VIS/NIR spectral ranges.

**Keywords:** Optoelectronic models; Wavelength selector; Numerical simulations; Photodetectors; MUX/DEMUX device

## I. INTRODUCTION

The simulation is a very important task to understand the physical mechanisms, translated into mathematical models, which occur inside and drive the behaviour of a physical system. To validate these models, numerical simulations are mandatory.

Here the system is a wavelength selector filter realized by using a double pin/pin a-SiC:H photodetector with front and back biased optical transparent conductive oxide (TCO) gating elements. Based on the experimental results and device configuration, a two connected phototransistors differential model made out of a short- and a long-pass filters was used [1] and upgraded to include several monochromatic input channels in the UV/VIS/NIR ranges, each one with a specific bit sequence, to be transmitted and decoded by reading out the generated photocurrent.

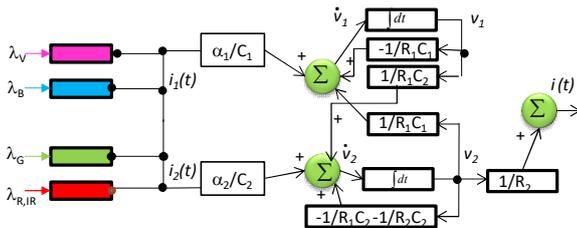


Fig. 1. Block diagram of the model.

The block diagram of the used capacitive active two connected phototransistors model displayed in Figure 1 mimics the system and gives physical meaning to the use of near-ultraviolet steady state illumination to increase the wavelength selecting ability of a double a-SiC/Si pi'n/pin integrated optical active filter, beyond the visible wavelengths (400 nm-900 nm). The resistors ( $R_1, R_2$ ) and capacitors ( $C_1, C_2$ ) synthesize the desired filter characteristics. The input signals,  $\lambda_{IR,R,G,B,V}$ , model the input channels and  $i(t)$  the output signal. The amplifying elements,  $\alpha_1$  and  $\alpha_2$  are linear combinations of the optical gains of each impinging channel, respectively into the front and back phototransistors and account for the enhancement or quenching of the channels due to the steady state irradiation. Under front irradiation:  $\alpha_2 \gg \alpha_1$  and under back irradiation  $\alpha_1 \gg \alpha_2$ . This affects the reverse photo capacitances,  $(\alpha_{1,2}/C_{1,2})$  that determine the influence of the system input on the state change.

The time periodic linearized state equation according to the simplified block diagram of the state model is:

$$\begin{bmatrix} \frac{dv_1}{dt} \\ \frac{dv_2}{dt} \end{bmatrix} = \begin{bmatrix} \frac{1}{C_1} & 0 \\ 0 & \frac{1}{C_2} \end{bmatrix} \begin{bmatrix} i_1(t) \\ i_2(t) \end{bmatrix} + \begin{bmatrix} -\frac{1}{R_1 C_1} & \frac{1}{R_1 C_1} \\ \frac{1}{R_1 C_2} & -\frac{1}{R_1 C_2} - \frac{1}{R_2 C_2} \end{bmatrix} \begin{bmatrix} v_1(t) \\ v_2(t) \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_1(t) \\ i_2(t) \end{bmatrix} = \begin{bmatrix} \alpha_{fr_1} & \alpha_{fr_2} & \alpha_{fr_3} & \alpha_{fr_4} & \alpha_{fr_5} \\ \alpha_{bk_1} & \alpha_{bk_2} & \alpha_{bk_3} & \alpha_{bk_4} & \alpha_{bk_5} \end{bmatrix} \begin{bmatrix} i_{BIT_1} \\ i_{BIT_2} \\ i_{BIT_3} \\ i_{BIT_4} \\ i_{BIT_5} \end{bmatrix} \quad i(t) = \begin{bmatrix} 0 & \frac{1}{R_2} \end{bmatrix} \begin{bmatrix} v_1(t) \\ v_2(t) \end{bmatrix} \quad (2)$$

Results show that the pi'n/pin multi-layered structure acts as data selector in the UV/VIS/NIR ranges.

## II. SIMULATIONS

### A. Simulation software

Two computer packages were designed and programmed within the MATLAB® environment, to perform the task of numerical simulation. Eight input channels are supported in the present version of the software.

The simulation interface programs are twofold:

- Complete signal processing and simulation software named ESTIMA-MUX

- Basic but handy graphics user interface simulation program: OPTO-MODEL-XCH

The complete signal processing and simulation software was developed according to the following eight steps methodology:

1- denoising of the experimental individual and MUX signals when necessary, 2 - gains and estimation of the initial values for the individual peak to peak intensities (pulses), 3 - estimation of the pulses and capacitors  $C_1$  and  $C_2$  for the individual signals, 4 - estimation of the first approximation of the individual pulses contributions to each MUX by using the estimated pulses, 5 – capacitors  $C_1$  and  $C_2$  estimation for each MUX, 6 - estimation of better values for the capacitors  $C_1$  and  $C_2$  by using the updated estimates, 7 - gains correction matrix computation accounting for the loss or increase in gains according to the wavelengths present in each time slot (duration of one bit signal) of the experimental time and the final simulation results, 8 - final simulation computations and plot.

The denoising of the experimental data is optional and performed by using an adapted 1D version of the Non-Local Means (NLM) denoising algorithm introduced by Buades et al. (2005) [2].

The initial values for the individual peak to peak intensities (pulses), gains and capacitors were obtained by using the Matlab® optimization procedure *fminsearch* (Nelder-Mead simplex method) [3], embedding the Matlab® *ode23tb* numerical solver (an implementation of TR-BDF2 which is an implicit Runge-Kutta formula with a first stage that is a trapezoidal rule step and a second stage that is a backward differentiation formula of order 2) to moderately stiff differential equations problems. The objective function to be minimized accounts for sums and maxima of absolute differences of the simulated and experimental currents, root mean square errors of the simulated current, the correlation coefficients between experimental data and simulation and the penalization for pulses lower than a certain predefined threshold.

### A. Simulation Results

Figure 2 presents the resulting plot of a simulation, where the simulated and experimental data are in perfect agreement.

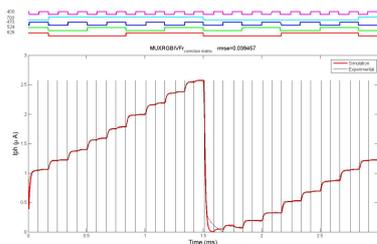


Fig. 2. Example of a resulting plot of ESTIMA-MUX.

A graphics user interface computer program - OPTO-MODEL-XCH -was designed within the MATLAB®

environment, to perform the numerical simulation manually, with no optimization tasks, only the differential equations solver. This interface allows for selecting model parameters and plotting of input bit signals, simulated and experimental photocurrent results.

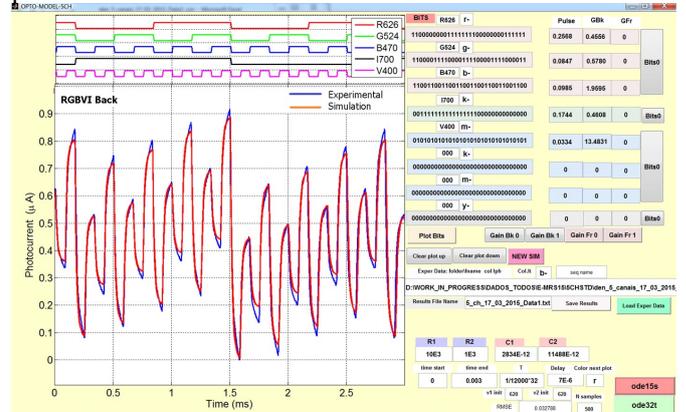


Fig. 3. Example of a five channels simulation with OPTO-MODEL-5CH

Figure 3 presents an example of a simulation using OPTO-MODEL-XCH.

### III. CONCLUDING REMARKS

The opto-electrical model with light biasing control has proven to be a good tool to design WDM devices in the UV/VIS/NIR.

It allows not only to code or to decode transmitted information but also extracting theoretical parameters by estimating the model internal capacitors and optical gains, while solving the linearized differential equations model to attain the simulated photocurrents

A good agreement between experimental and simulated results was achieved which shows the ability of the presented model to simulate the sensitivity behavior of the proposed system in the UV/VIS/NIR spectral ranges.

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