A Two Dimensional Analytical Model for Finger Photodiodes

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Introduction

In this work we present a new analytical 2D photodiode model. Our model is capable to predict the stationary as well as the dynamic behavior of different finger photodiode structures. The model is in very good agreement with the numerical results gained with the two dimensional device simulator Atlas/Silvaco. For all relevant carrier distributions within the diode we have found simple analytical expressions. Our model is suitable as circuit simulation model, e.g. for the simulation of high speed fiber-optic systems.

Model

Because the illuminated part of the finger photodiode under consideration consists of a periodic topology, it is sufficient to consider only one of the periodic sections (see fig. (1)) of the structure to characterize the opto-electronic conversion of the diode. We have divided this structure into five quasi neutral regions I to V in addition to the **s**pace **c**harge **r**egion (SCR). We assume that the minority carrier current within the neutral regions is a pure diffusion current. Therefore, for the calculation of the photocurrent we require the minority carrier distribution within the neutral regions. To this end we have to solve the diffusion equation

$$\frac{\partial^2\delta c}{\partial x^2}+\frac{\partial^2\delta c}{\partial y^2}-\frac{\partial\delta c}{D_c\partial t}-\frac{\delta c}{L_c^2}=-\frac{\tau_c g(x)\delta_0(t)}{L_c^2} \qquad (1)$$

within the region I to V. c is the minority carrier density, τ_c, L_c and D_c the lifetime, diffusion length and diffusion coefficient, respectively, of the minority carriers. Applying Laplace-transformation on eq. (1) results in a partial differential equation in x and y. Due to the photo-generation rate and the boundary conditions of regions IV and V we expect no y-dependency of the carrier distributions in these regions. Therefore, we end up with a simple differential equation in these regions which easily can be solved.

To simplify the calculation of the minority carrier distribution within regions I, II, and III we first of all assume that the extension of these regions in the y-direction is large compared to the relevant diffusion length of the minority carriers.

Using the technique of separation of variables we find the minority carrier distribution by first solving the diffusion equation in a regime far away from the dashed vertical lines in fig. (1) which represent the boundary of the SCR. In this regime we again assume the carrier density to be a function of x only. Utilizing this solution we then solve the diffusion equation to come to the y-function of the carrier distribution. As an example fig. (2) gives a comparison of the hole distribution within region I calculated with our model and the simulator Atlas/Silvaco.

For the current contribution of each region to the photocurrent we have to integrate the gradient of the minority carrier concentration along the edges of the SCR.

To calculate the contribution of the SCR to the total current we neglect recombination and thermal generation processes within the SCR. Thus the current contribution of the SCR can by found by integrating the generation rate over the whole depletion region. The temporal variation of the drift current contribution is dominated by the RC time constant of the device. The bulk resistance and the depletion capacity of the diode can be calculated easily and implemented as a RC low-pass filter.

Due to the choice of the photo-generation rate the current contribution of a certain region corresonds to the transfer function of this region. Therefore, the transfer function of the photodiode is given by the sum of the transfer functions of each region multiplied by the transfer function of the RC low-pass filter

Results

Fig. 3 shows the stationary photocurrent of the device calculated with our model in comparison with the results of the numerical device simulator. In one case we have contacted the substrate of the diode which results in a higher efficiency of the diode in the red and infrared spectra compared with the case of the floating substrate.

The frequency responses in fig. 4 presents the results of our model and the device simulator, respectively. The dynamic behaviour of the diode in this case is totally dominated by the RC time constant of the device. For other diode parameters (e.g. doping concentrations, dimensions) or other structures the diffusion in some of the diode regions may not follow the modulated signal resulting in different kinks (cut-off frequencies) of the transfer function.

CONCLUSION

We have developed a two dimensional model of a photodiode which takes care on the transit-time effects due to carrier diffusion. This model is versatile and capable to predict the stationary as well as the dynamic performance of finger diodes of different types and parameters.

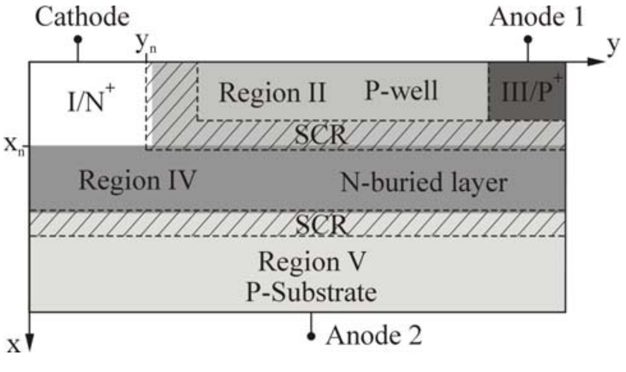

Fig. 1. Modeled section of a NCPWNBL – finger photodiode. The grayscales stand for the different doping concentrations.

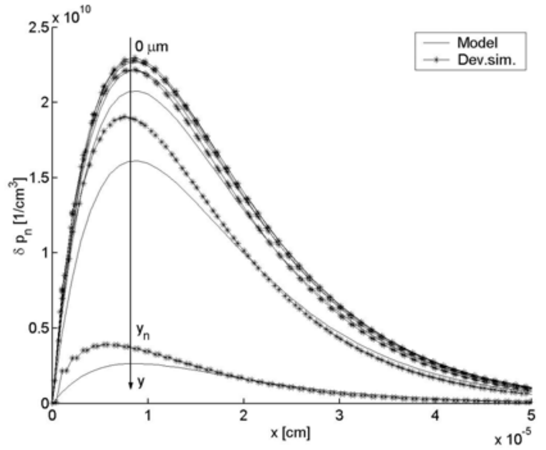

Fig. 2. Hole distribution within region I calculated with our model compared with numerical results.

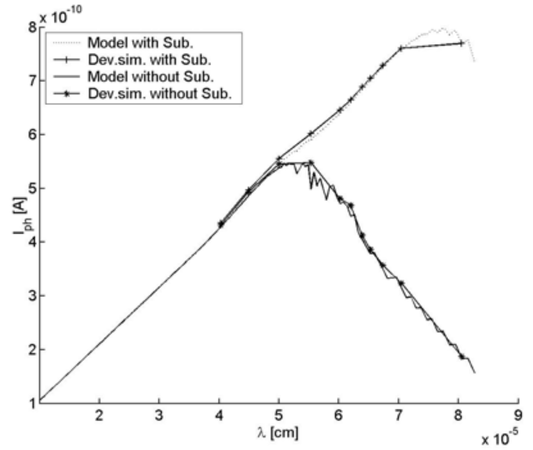

Fig. 3. Stationary photocurrent with and without contacted substrate. Model in comparison with the device simulator.

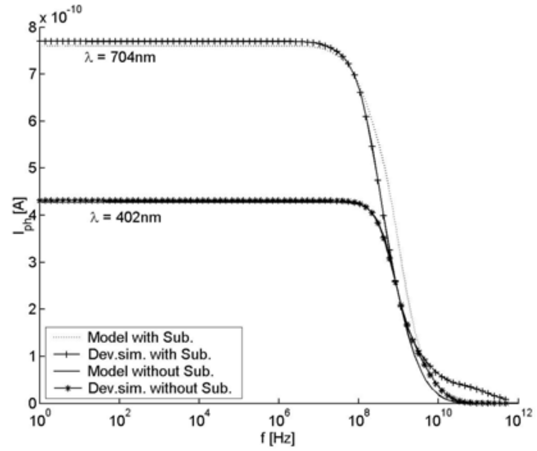

Fig. 4. Frequency responses of the device: model compared with numerical simulation.