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Accurate Prediction of Photocurrent Response for High Performance Optoelectric Circuit Simulation

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1.Introduction

Camera on chip has been on a mass production phase[1,2]. However, to achieve high integration density of optoelectric circuits with a minimum photon flux and reduced applied voltages for such as the artificial-eye application, accurate prediction of the photocurrent response is prerequisite.

We have been developing the photodiode model HiSIM-PD for predicting integrated optoelectric circuits[3]. Our purpose here is to extend HiSIM-PD applicable for integrated circuit simulation predicting generated current response accurately for any operating conditions.

2.Method

We have investigated the photodiode current both experimentally and theoretically. The studied photodiode is shown in Fig. 1 schematically, and the measurement setup is depicted in Fig. 2. We focus our investigation on accurate modeling of the generated photocurrent. For this purpose the device-length L dependence of the photocurrent is studied. Measured results are shown in Fig. 3(a). The feature is that the current peaks rather decrease as the length increases, and the broadening of the current with respect to a laser pulse. The original HiSIM-PD cannot reproduce the characteristics as shown in Fig. 3(b). HiSIM-PD simulates strong current peaks at around t = 5ns for larger applied bias conditions, which is not the case for the measurements.

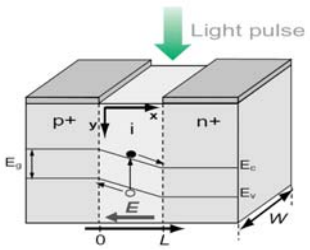

Fig. 1. Schematic illustration of a lateral *p-i-n* photodiode and the energy band diagram across the *p-i-n* structure under reverse bias condition. The electron-hole pair generation due to a light pulse and carrier flows are also shown.

3.Theory and Results

For the model development of the photodiode we have derived three basic equations for compact modeling to be solved (see Table 1)[4,5]. As can be seen in the equations, the equations are written in two dimensions. To derive analytical equations approximations have been introduced. Previously we have considered a constant electric field along the lateral direction and only the distribution in the

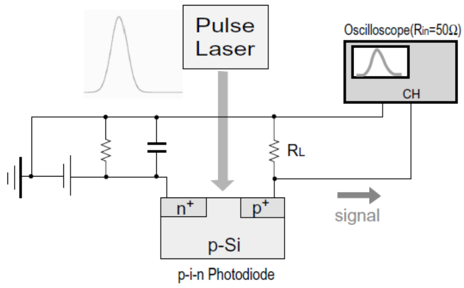

Fig. 2. Measurement system applied. The laser wavelength is 532nm and the full width of half maximum is about 2ns for the studied case. R_L is used for transforming current to voltage signals. The voltage signals are observed by oscilloscope.

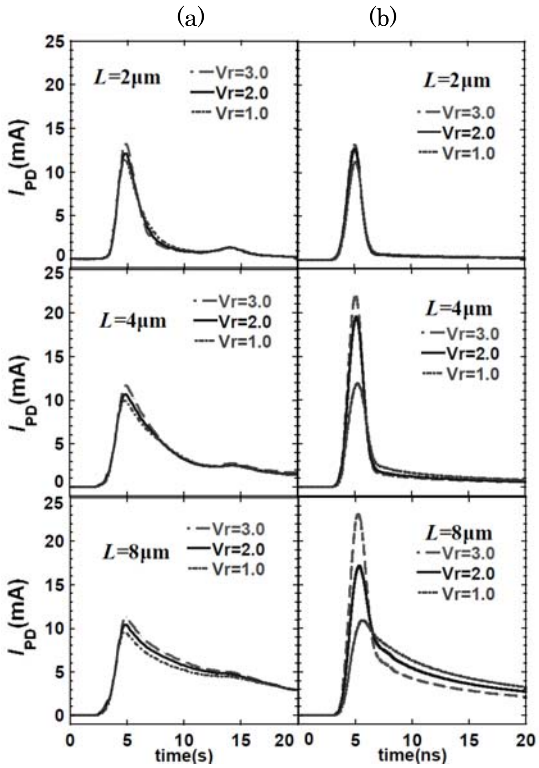

Fig. 3. (a) Measured photocurrent I_{PD}; (b) Calculated I_{PD} with the original HiSIM-PD.

depth direction was considered. Fig. 4 shows 2D-device simulation result of the potential distribution within the device for different L lengths. To describe this field distribution along the length direction, we have extended the model to include two different field regions. One is within the quasi-neutral region and the other is the depletion region where the most potential drop occurs. We have derived an equation for the current induced in the quasi-neutral region by considering the diffusion current (Eq.4) instead of the drift current shown as Eq. 2 in Table 1. The simulation result with the extended model is shown in Fig. 5 for V_r=3V. 2D-device simulation results are depicted together for comparison. The both measurements and simulation results are nearly the same, and are different from the measurements. Contrary to the measurements it is seem that the photo current increases as increases.

Fig. 6 shows a schematic depicting the generated carrier distribution. It is expected that the recombination occurs between electrons generated in the quasi-neutral region and holes generated in the depletion region. 2D-device simulations were performed with the crystal defect with the concentration of 1e12/cm^3. The result is shown in Fig. 7. From this investigation it is seen that the most of the generated carriers are recombined in the depletion region via the recombination cites induced by the crystal defects. This results in the suppression of the peak at t = 5ns.

4.Conclusion

We have improved the circuit simulation model HiSIM -PD by considering the diffusion current within the quasi-neutral region. The model reproduces measured photocurrent of the *p-i-n* photodiode for any device size and any bias conditions. It was found that the reduction of crystal defect is important to achieve high performance circuits without current response delay.

Table 1 :Equation applied for model development

1. Current continuity	$\frac{\partial n(x,t)}{\partial t} - \frac{1}{q}\frac{\partial J_n(x,t)}{\partial x} = G_n(x,t)$
2. Drift current density	$J_n = q\mu_n n(x,t)E(x,t)$
3. Carrier generation rate	$G_n(y,t) = \alpha e^{-\alpha y}\phi(t)$
4. Diffusion current density	$I(t) = \alpha q W\int_0^\infty dy[\int_{t+\frac{x_d}{\mu_n\|E_d(y)\|}}^{t} dt'\|E_d(y)\| + \int_{t+\frac{L-x_d}{\mu_p\|E_q(y)\|}}^{t} dt'\|E_q(y)\|]e^{-\alpha y}\phi(t')$

q: elementary charge, α: absorption coefficient,
G: generation rate, W : device-width, ϕ: photon flux,
n: carrier number density, J: current density, μ: mobility,

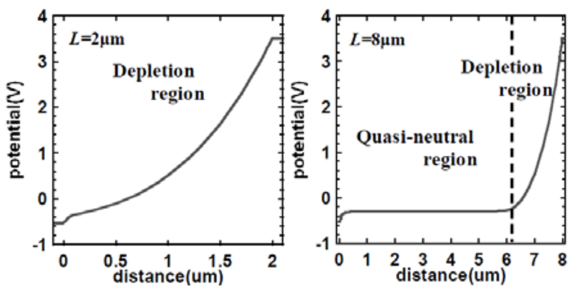

Fig. 4. Potential distribution within the device. It is seen that the depletion width extends the whole L length for the 2µm case. However, the quasi-neutral region occurs for the longer lengths.

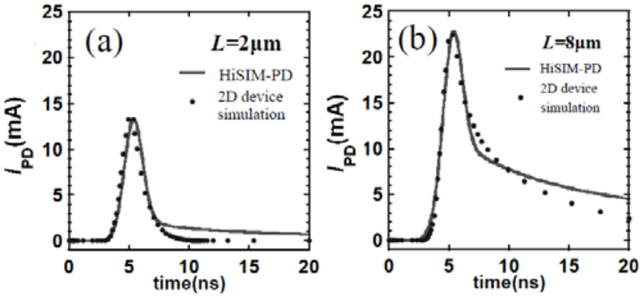

Fig. 5. Comparison of HiSIM-PD photocurrent I_{PD} results with 2D-device simulation results for the different L length of (a)2µm and (b)8µm.

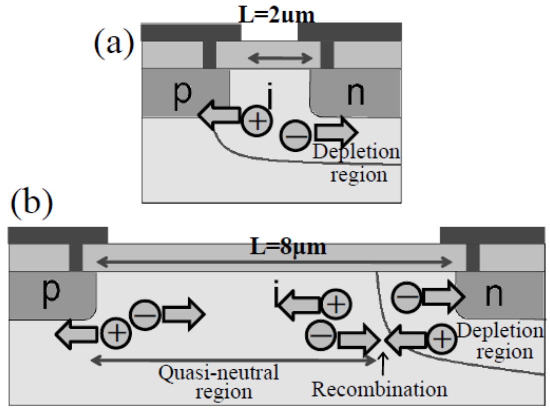

Fig. 6. Schematic of generate a carriers and their movement.

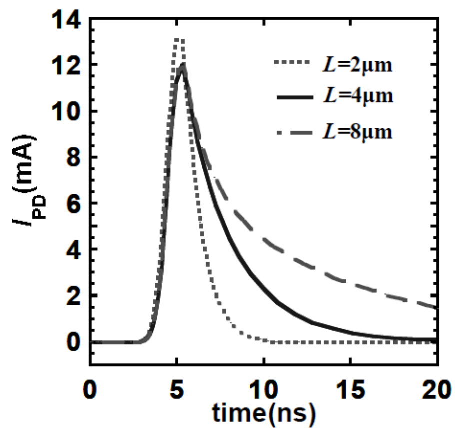

Fig. 7. 2D-device simulated result of photocurrent response with the crystal defect of 1e12cm^{-3} concentration.

Reference

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