Modeling Group

Mission:
Bridge between device and circuit developments

Method:
Surface-potential-based model HiSIM

HiSIM Family:

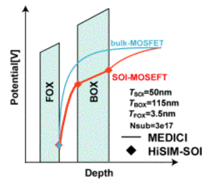
HiSIM for most kinds of MOSFETs down to 45nm
- HiSIM-SOI
- HiSIM-DG
- HiSIM-Varactor
- HiSIM-PD
- IGBT, TFT.....

Objectives

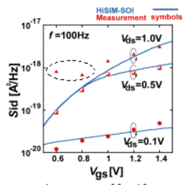
- SOI-MOSFET: Beam-channel transistor
- Photodiode: Optical interconnect

Achievements

HiSIM-SOI: N. Sadachika



Complete surface-potential based model



Accurate prediction of device characteristics

Physics-Based Photodiode Model Enabling Consistent Opto-Electronic Circuit Simulation

HiSIM-PD

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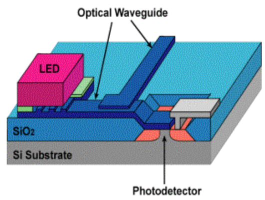
Y. Mizukane, D. Navarro, M. Miyake, N. Sadachika
T. Ezaki, H. J. Mattausch, and M. Miura-Mattausch

Application Areas of Photodiodes

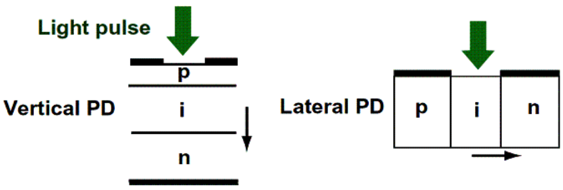
Commercial application:
- Optical sensor arrays with integrated processing circuitry (for e. g. digital cameras)

R & D:
- Opto-electronic integrated circuits (OEICs)
- Prosthetic health care (e. g. artificial eye)



OEIC concept

Photodiode Structures



Modeling Tasks

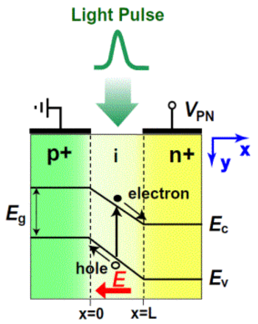
Type \ Appl.	Freq. Domain	Time Domain
Vertical	Most Existing Work†	None
Lateral	Our Previous Work‡	This Work

† e.g. G. Torrese et al., IEEE Mw. Opt. Tech. Lett. 31, 329 (2001);
‡A. Konno et al., SSDM 2004, 946 (2004)

Contents

(1) Time Domain Modeling Concepts and Their Experimental Verification
(2) Circuit-Simulator Implementation Issues
(3) Small OEIC Simulation Results

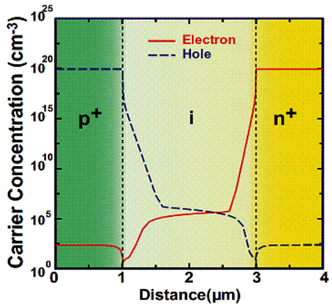
Modeling of Lateral Photodiode



Approximations:

- Homogeneous field E in horizontal (x) direction
- Holes, electrons move to p+, n+ regions instantly
- Negligible recombination in intrinsic region

Negligible Recombination



Main Justification:

- Low carrier concentration in i-region
- Fast separation of generated carrier pairs

Basic Equations

Continuity Eq.: $\dfrac{\partial n(x,y,t)}{\partial t} - \dfrac{1}{q}\dfrac{\partial J(x,y,t)}{\partial x} = G(y,t)$

Current-Density Eq.: $J(x,y,t) = q\mu n(x,y,t)E_x(y)$

Generation Rate: $G(y,t) = \alpha e^{-\alpha y}\phi(t)$

q: elementary charge
μ: mobility
ϕ: photon flux,
α: absorption coefficient
n: carrier number density
J: current density

Derivation of Analytical Solution

Frequency Domain:

$$J(x,t) = \sum_{\omega_j} J_{w_j}(x)\cdot e^{-j\omega_j t}$$

Time Domain:

Coordinate Transformation

$$\xi = \frac{1}{2}\left(t + \frac{x}{v}\right),\quad \eta = \frac{1}{2}\left(t - \frac{x}{v}\right)$$

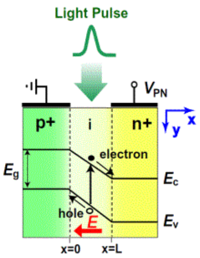
$$I(t) = \alpha q \mu_p W \int_0^\infty dy \int_{t-\frac{L}{\mu_p|E_x(y)|}}^{t} dt' \,|E_x(y)|\, e^{-\alpha y}\phi(t')$$

Field Approximations

$$I(t) = \alpha q \mu_p W \int_0^\infty dy \int_{t-\frac{L}{\mu_p|E_x(y)|}}^{t} dt' \,|E_x(y)|\, e^{-\alpha y}\phi(t')$$

Direction: Horizontal

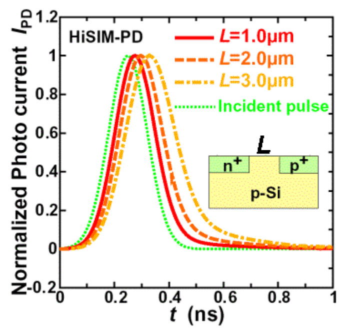
Magnitude in
x-direction: Constant
y-direction: Gaussian



$$E_x(y) = E_0 \exp\left(-\frac{y^2}{D^2}\right)$$

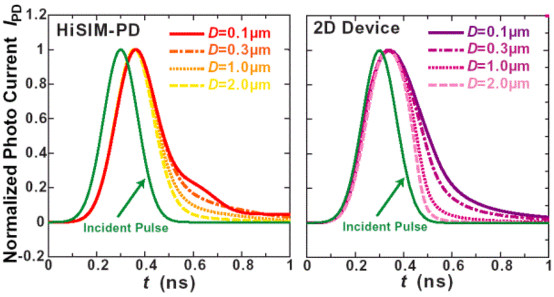
D = Attenuation Length)

Dependence on i-Region Length

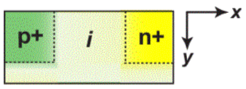


The photo current shifts with i-region length, which correlates well with expectations.

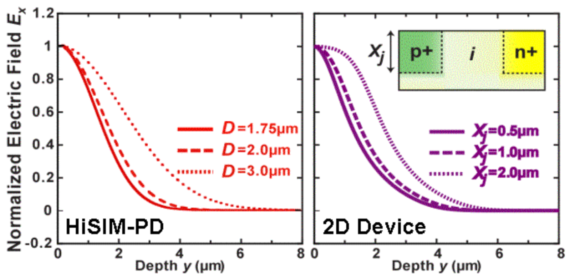
Attenuation-Length Dependence



A small attenuation length results in an extended current tail.

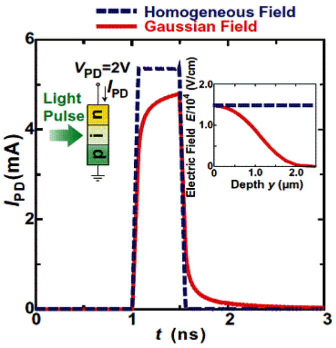


p+, n+ Depth and Field Magnitude



Attenuation-length dependence and p+, n+ depth dependence show correlated behavior.

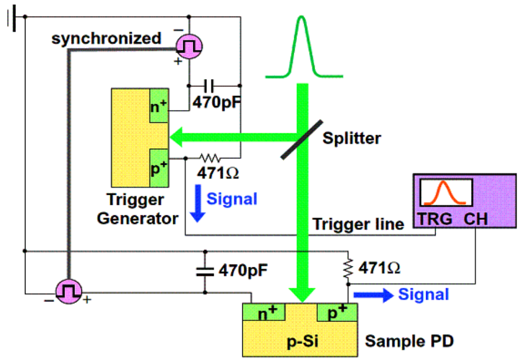
Effect of Field Distribution



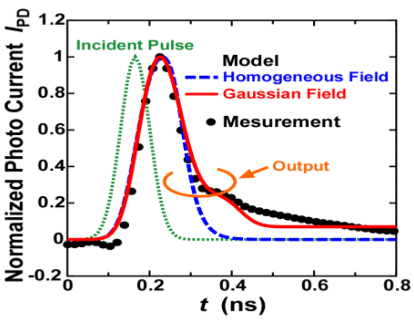
Gaussian distribution causes:

- Slowly increasing current
- Current tail after the light pulse

Measurements for Verification



Measured Photo Current



Good overall agreement of HiSIM-PD results and measured data is obtained.

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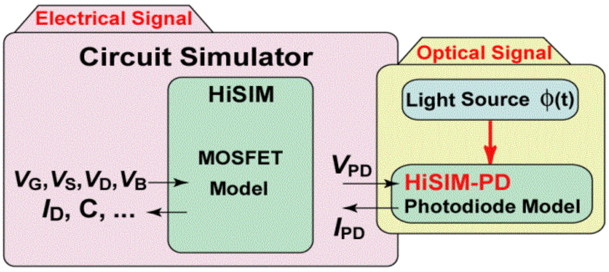
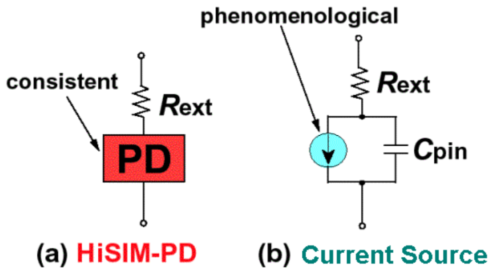
Integration into Circuit Simulator



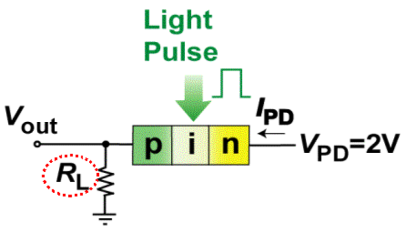
HiSIM-PD receives terminal voltages and responds with corresponding photo currents.

Consistent Simulation Necessity



Is a phenomenological current source model already a satisfactory solution ?

Simulated Test Configuration



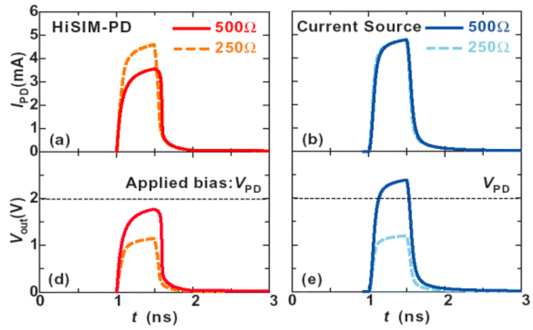
Compared methods:

- HiSIM-PD model
- Current-source model
- 2D device simulation

Tested dependencies:

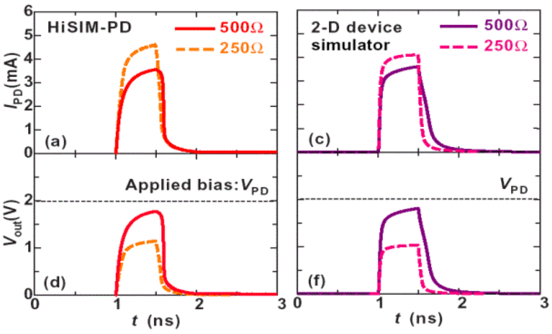
- V_{out} (R_L)
- I_{PD} (R_L)

Comparison with Current Source



HiSIM-PD and current-source results are even qualitatively different.

Comparison with Device Simulator



2-D device simulation verifies the correctness of the HiSIM-PD results.

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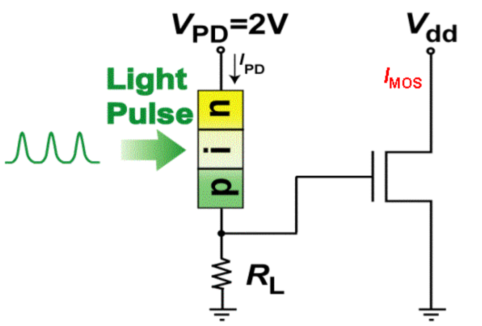
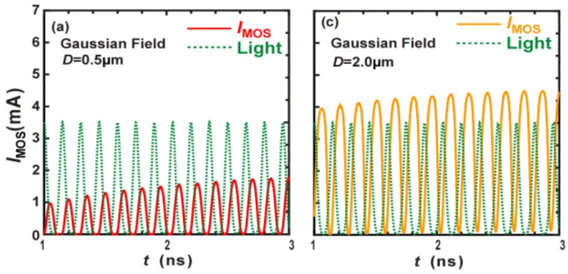
Simple OEIC Test Circuit



Simulation Results of Test Circuit



Expected behavior is correctly reproduced:

- Initial output-current increase as a function of time
- Saturation behavior
- Larger magnitude and faster saturation with increasing attenuation length

Summary

- HiSIM-PD is now ready for OEIC designs.
- Unified compact models for all descendants of the MOSFET are our aim and are being realized step by step.
- Objectives of compact models originally aiming at circuit design are expanded even to device optimization.