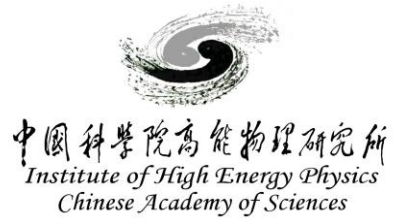
Simulation of 4H-SiC Device Based on DEVSIM



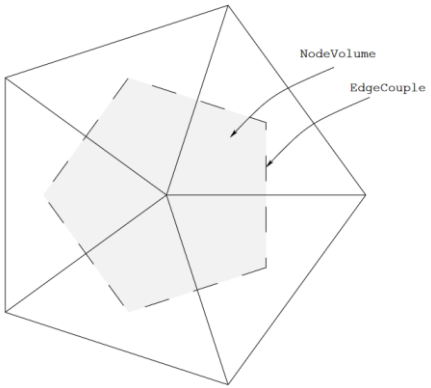
Tao Yang

2022-10-14

Introduction of *DEVSIM*

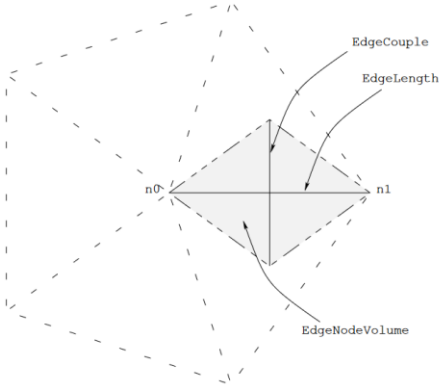
- *DEVSIM* is an open-source semiconductor device simulation software which uses the finite volume method. (Python interface, C++ core) https://devsim.org/
- *DEVSIM* uses the control volume approach for assembling partial-differential equations (PDE's).

Node



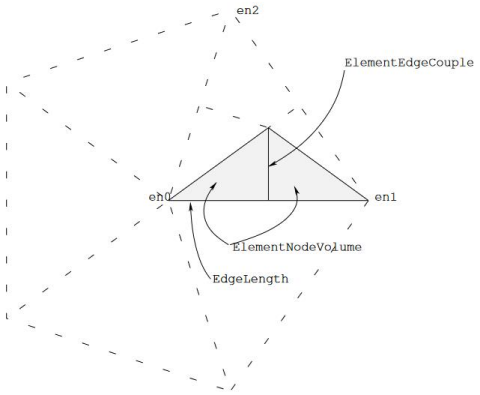
n, p, φ ...

Edge



E ...

Element Edge



$\mu_n(E), \mu_p(E)$ ...

How to Solve the PDEs in *DEVSIM*

$$\frac{\partial^2 \varphi}{\partial^2 x} = -\frac{q}{\varepsilon}(N + p - n) \quad \Longrightarrow \quad \frac{\partial(\varepsilon E)}{\partial x} = q(N + p - n) \quad \Longrightarrow \quad \oint_S \varepsilon E \cdot dS - \int_V q(N + p - n) \quad dV = 0$$

```
for i in (
    ("ElectricField",     "(Potential@n0-Potential@n1)*EdgeInverseLength"),
    ("PotentialEdgeFlux", "Permittivity * ElectricField")
    ):

    n = i[0]
    e = i[1]
    CreateEdgeModel(device, region, n, e)
    CreateEdgeModelDerivatives(device, region, n, e, "Potential")

devsim.equation(device=device, region=region, name="PotentialEquation", variable_name="Potential",
                node_model="PotentialIntrinsicCharge", edge_model="PotentialEdgeFlux",
                variable_update="log_damp")
```

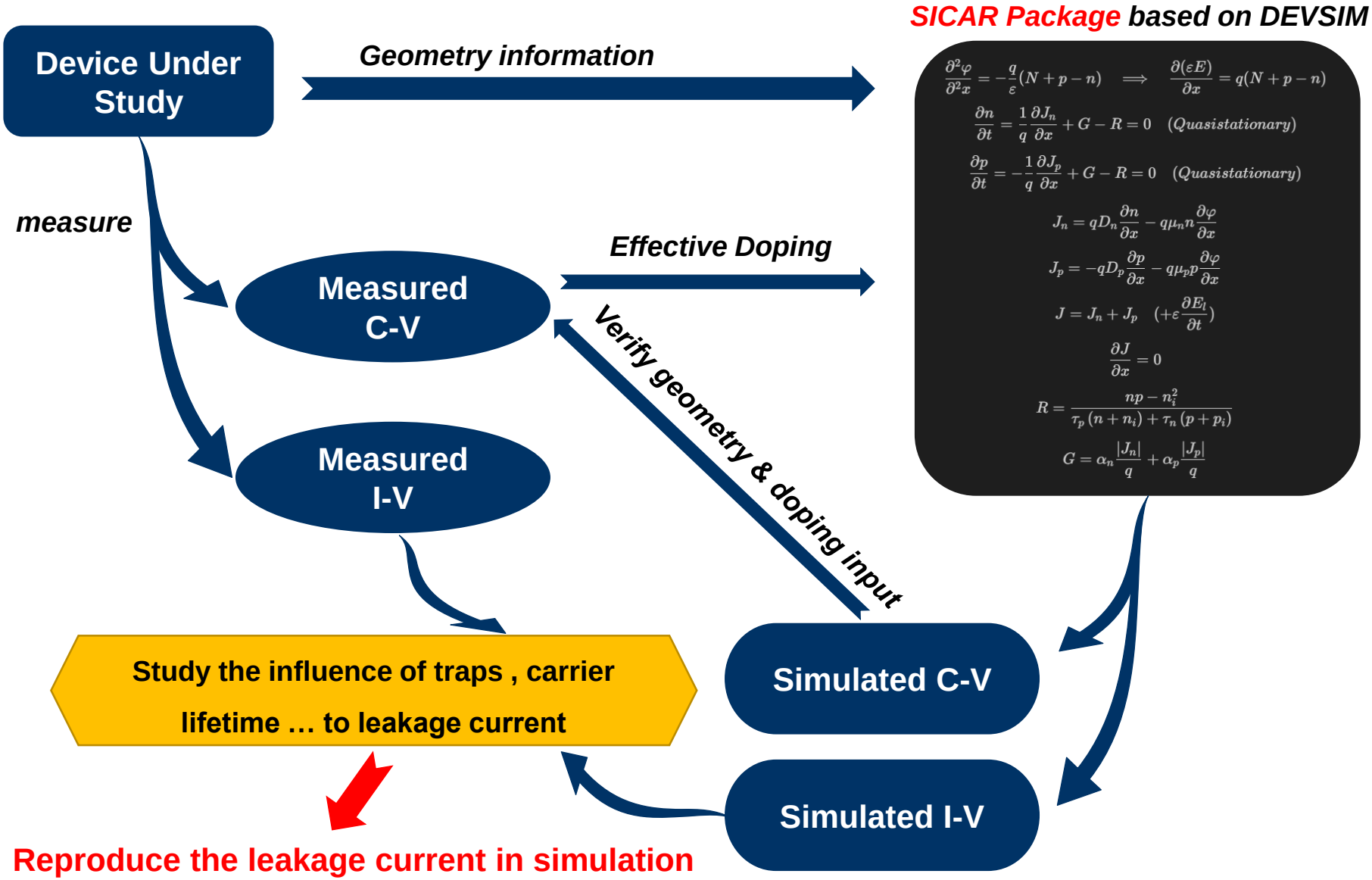
$$\frac{1}{q}\frac{\partial J_n}{\partial x} + G - R = 0 \quad \Longrightarrow \quad \oint_S J_n - \int_V q(G - R) \quad dV = 0$$

```
def CreateECE(device, region, mu_n):
    CreateElectronCurrent(device, region, mu_n)

    NCharge = "-ElectronCharge * Electrons"
    CreateNodeModel(device, region, "NCharge", NCharge)
    CreateNodeModelDerivative(device, region, "NCharge", NCharge, "Electrons")

    devsim.equation(device=device, region=region, name="ElectronContinuityEquation",
    variable_name="Electrons",
             time_node_model = "NCharge",
             edge_model="ElectronCurrent", variable_update="positive", node_model="ElectronGeneration")
```

Simulation Roadmap

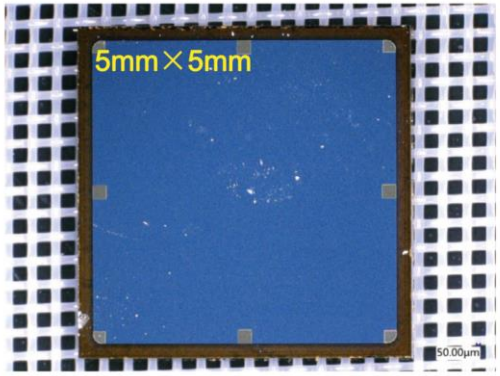


Device Under Study: NJU 100 μm PIN

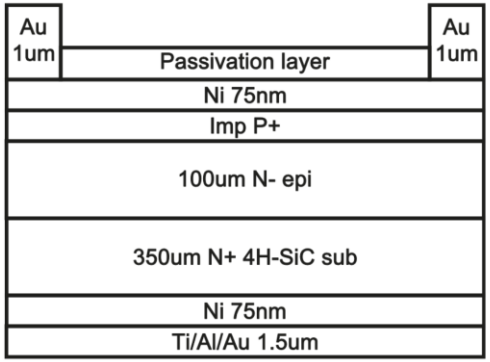
- Choose NJU 100 μm PIN with 5mm*5mm size as device to study.

Geometry

A

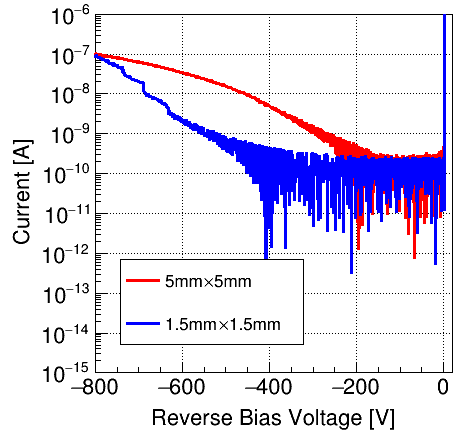


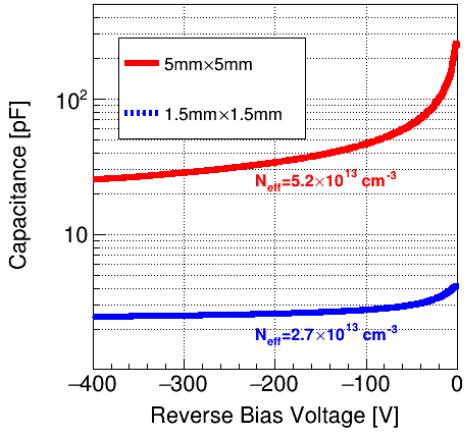
B



10.3389/fphy.2022.718071

I-V & C-V





Custom Parameters of 4H-SiC in SICAR

- **Mobility**

Parameter	3C-SiC		4H-SiC [perpendicular to c-axis]		4H-SiC [parallel to c-axis]	
	Electrons	Holes	Electrons	Holes	Electrons	Holes
μ_{max} [cm^2/Vs]	650	70	910	114	1100	114
μ_{min} [cm^2/Vs]	40	15	40	0	40	0
N_{ref} [cm^{-3}]	1.5×10^{17}	5×10^{19}	2.0×10^{17}	2.4×10^{18}	2.0×10^{17}	2.4×10^{18}
α	0.8	0.3	0.76	0.69	0.76	0.69

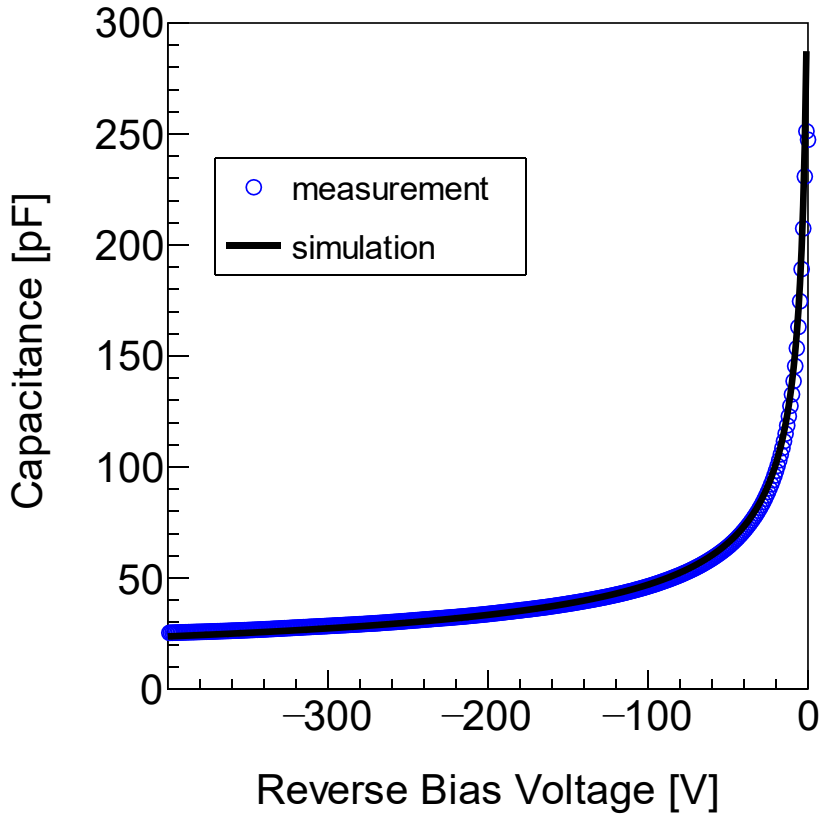
- **Carrier lifetime**

Parameter	SiC	
	Electrons	Holes
τ_{min} [sec]	0	0
τ_{max} [sec]	2.5×10^{-6}	0.5×10^{-6}
N_{ref} [cm^{-3}]	1×10^{17}	1×10^{17}
γ	0.3	0.3
T_α	1.72	1.72
T_{coef}	2.55	2.55
E_{trap} [eV]	0	0

http://www.intechopen.com/books/disruptive-wide-bandgap-semiconductors-related-technologies-and-their-applications/tcad-device-modelling-and-simulation-of-wide-bandgap-power-semiconductors

C-V Simulation of 4H-SiC PIN

- Use custom small ac signal simulation tool of *DEVSIM* to simulate the capacitance of NJU 100 μm PIN.

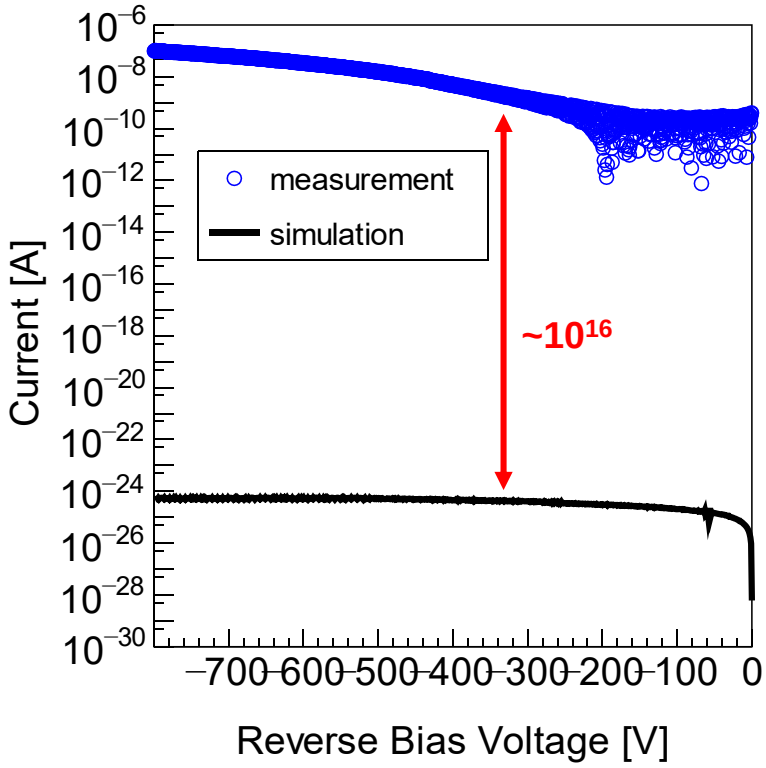


✓ **Good agreement between measurement and simulation!**

✓ **Verify the geometry & doping input to SICAR is correct.**

I-V Simulation of 4H-SiC PIN

- Use custom dc simulation tool of *DEVSIM* to simulate the capacitance of NJU 100 μm PIN.



✓ **Large discrepancy between measurement and simulation!**

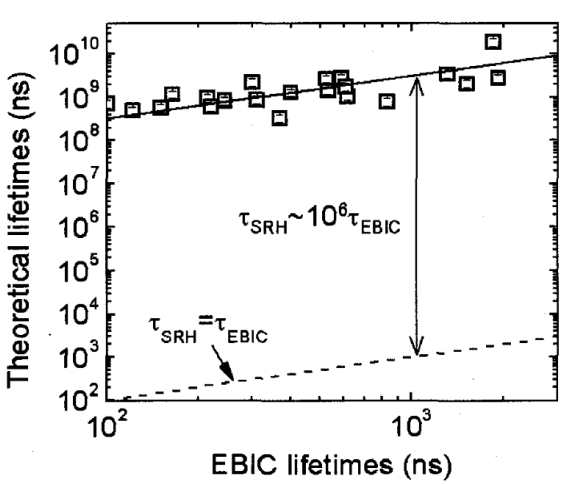
✓ **The influence of Carrier Recombination & Generation to leakage current from defects should be considered.**

Shockley-Read-Hall G&R to Leakage Current

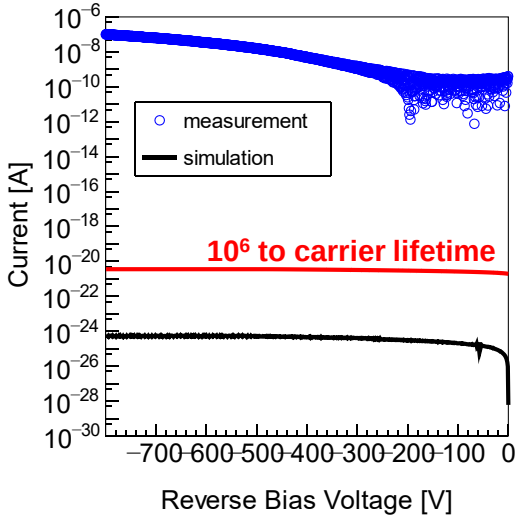
$$R = \frac{np - n_i^2}{\tau_p(n + n_i) + \tau_n(p + p_i)}$$

- Default carrier lifetime:

$$\tau_n = 2.5 \times 10^{-6}\ s \qquad \tau_p = 0.5 \times 10^{-6}\ s$$



Nigam, Saurav, Carrier lifetimes in silicon carbide, PhD Thesis, 2008



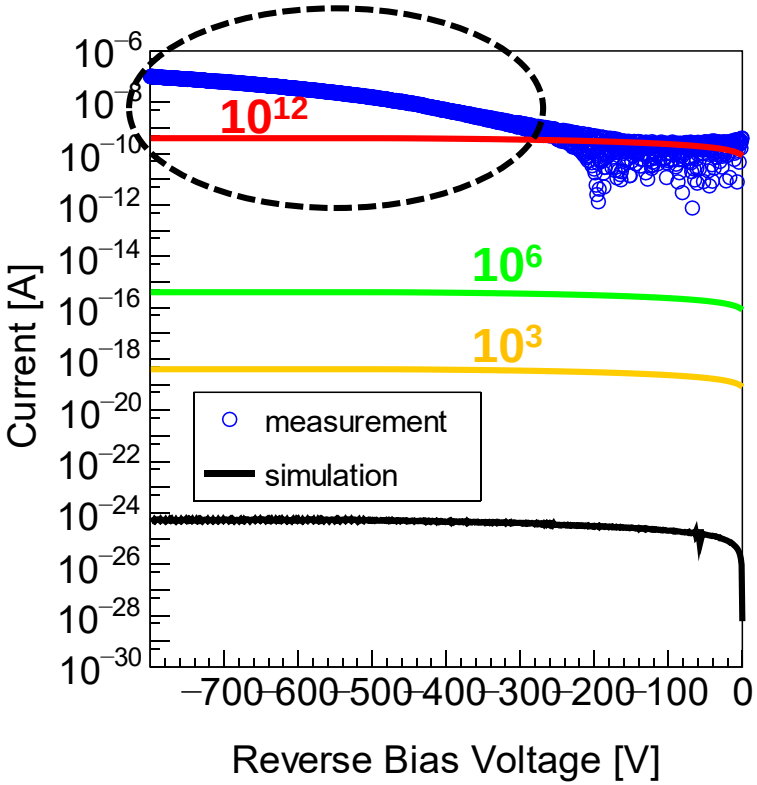
✓ **The SRH is not dominated term of leakage current.**

Bulk Defects G&R to Leakage Current

- Use constant G&R rate to replace the complex traps effects.

$$R_{\mathrm{net}} = \frac{N_0 v_{\mathrm{th}}^n v_{\mathrm{th}}^p \sigma_n \sigma_p (np - n_{\mathrm{i,eff}}^2)}{v_{\mathrm{th}}^n \sigma_n (n + n_1/g_n) + v_{\mathrm{th}}^p \sigma_p (p + p_1/g_p)}$$

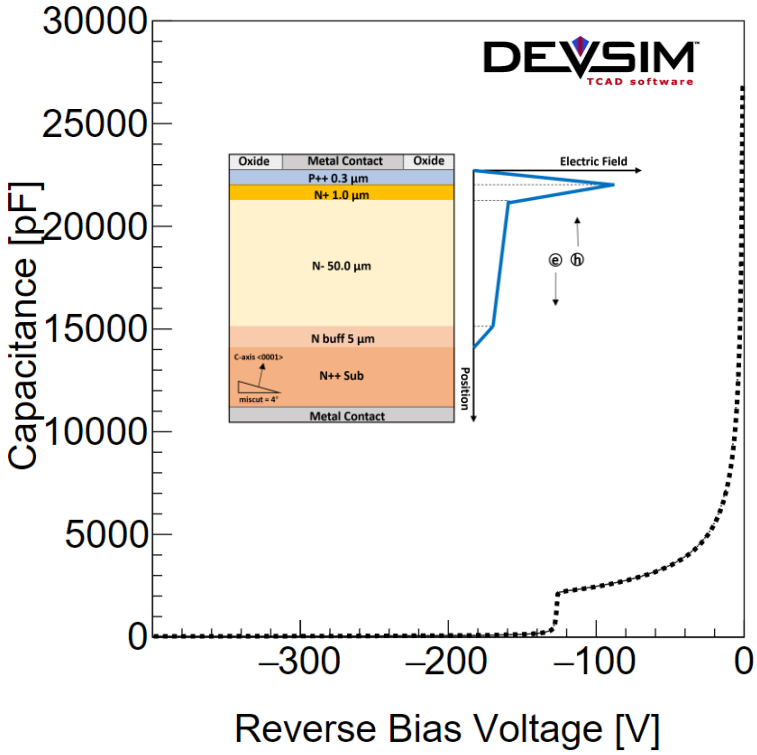
~ Constant

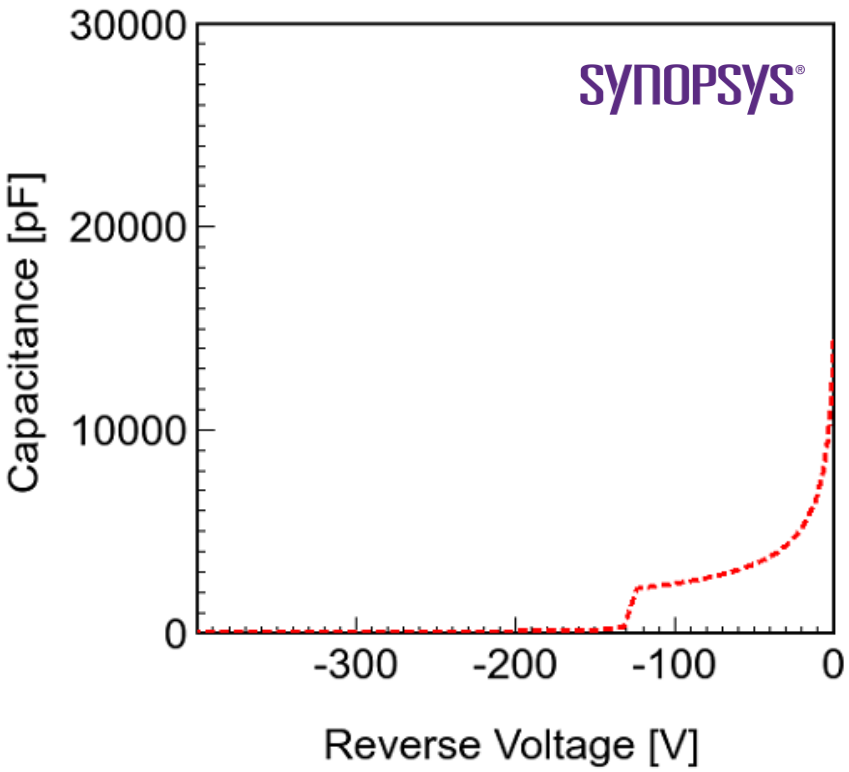


✓ **Same leakage current level when the constant G&R rate is 10^{12} cm^{-3}.**

C-V Simulation of 4H-SiC LGAD

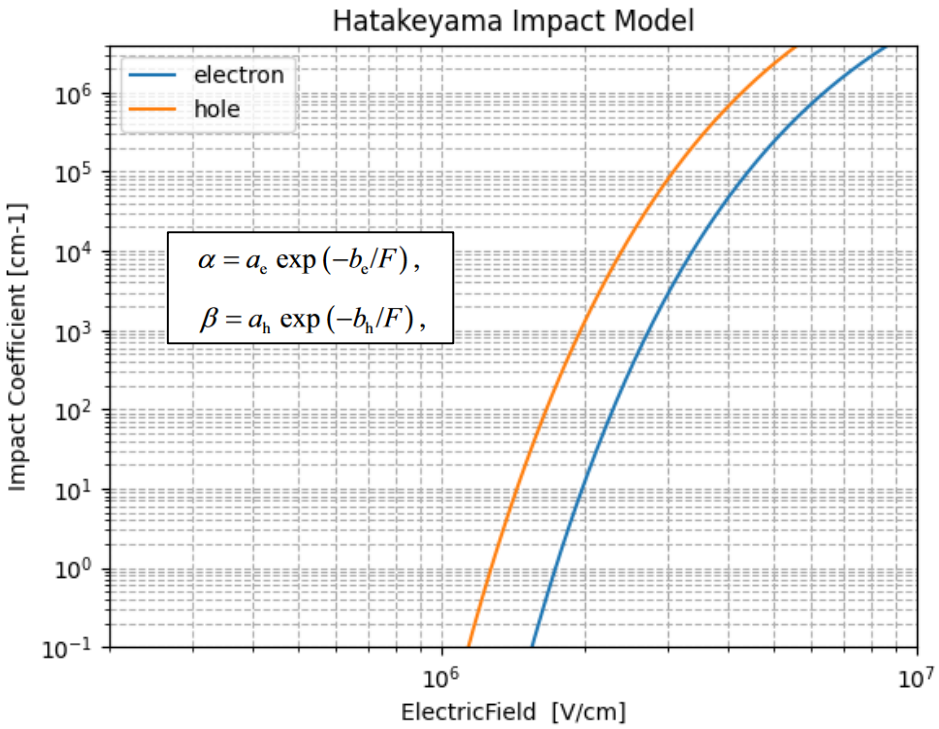
- **Good agreement** between DEVSIM and Synopsys TCAD





Impact Ionization for Breakdown

- To simulate the impact ionization in 4H-SiC device (like 4H-SiC LGAD). The impact ionization model is added in DEVSIM.

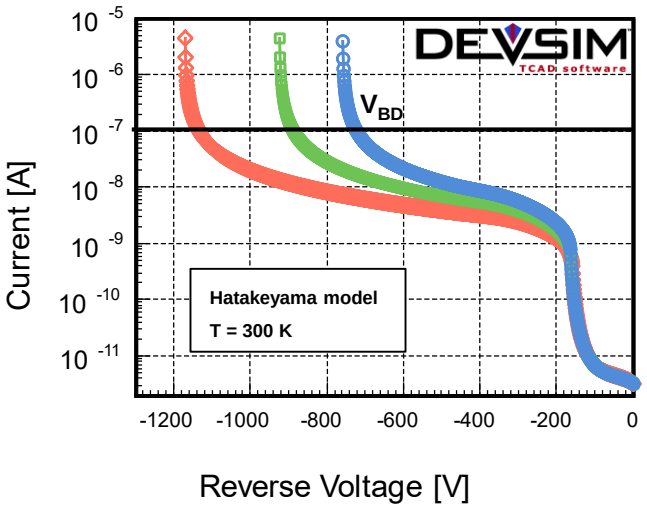


symbol	direction	value	unit
a_e	c-axis	1.76×10^8	cm^{-1}
b_e	c-axis	3.30×10^7	V/cm
a_h	c-axis	3.41×10^8	cm^{-1}
b_h	c-axis	2.50×10^7	V/cm
a_e	a-axis	2.10×10^8	cm^{-1}
b_e	a-axis	1.70×10^7	V/cm
a_h	a-axis	2.96×10^8	cm^{-1}
b_h	a-axis	1.60×10^7	V/cm

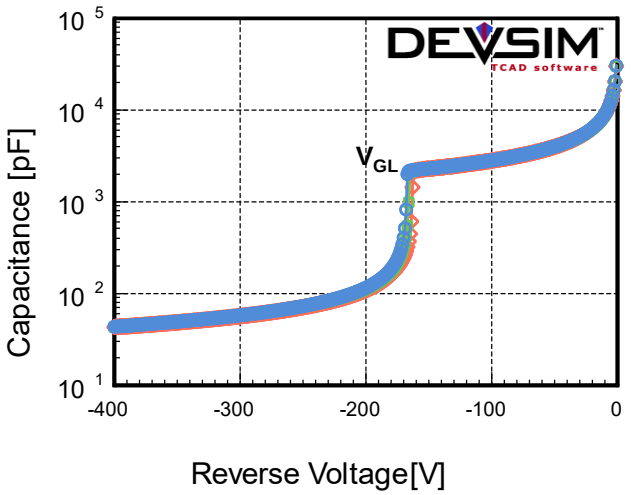
Compare Simulation of 1D 4H-SiC LGAD

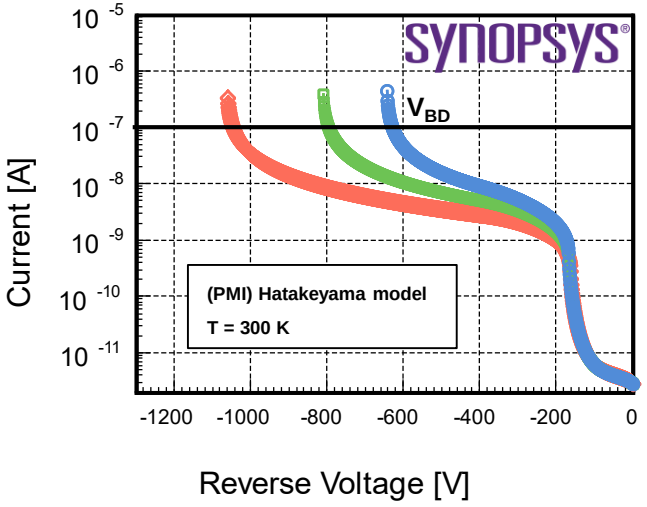
- **Good agreement** between DEVSIM and Synopsys TCAD

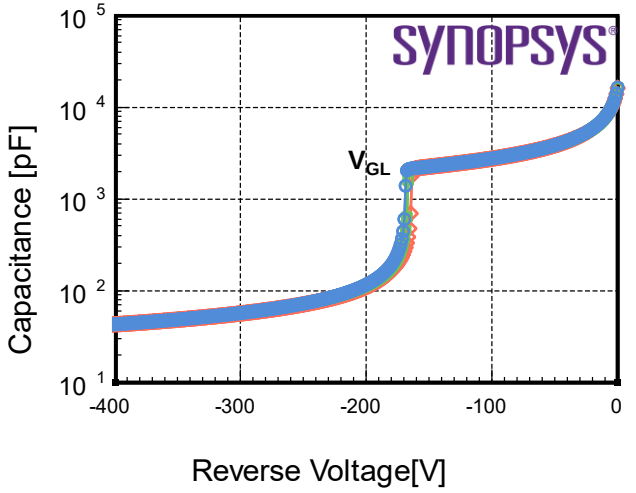
Breakdown Voltage : $\delta V_{BD} < 100$ V



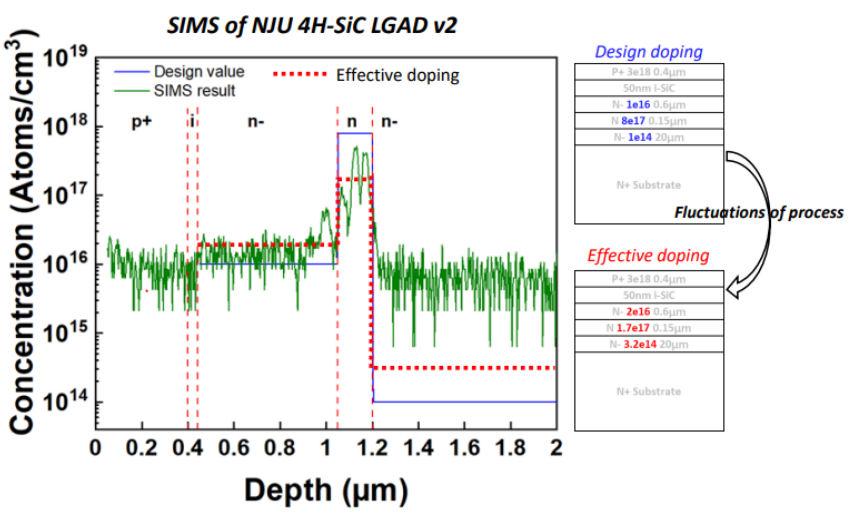
Gain Layer Depletion Voltage : $\delta V_{GL} < 10$ V

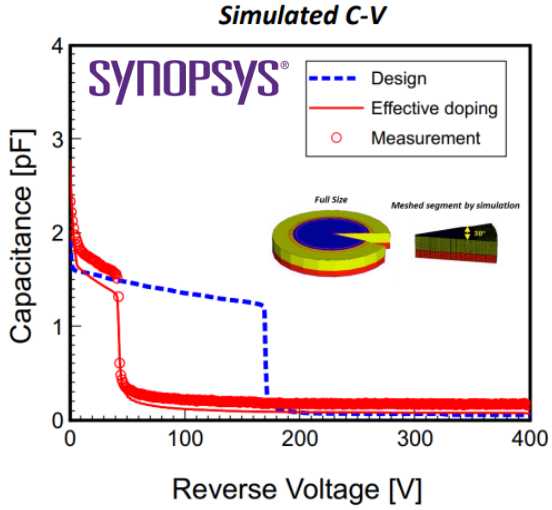


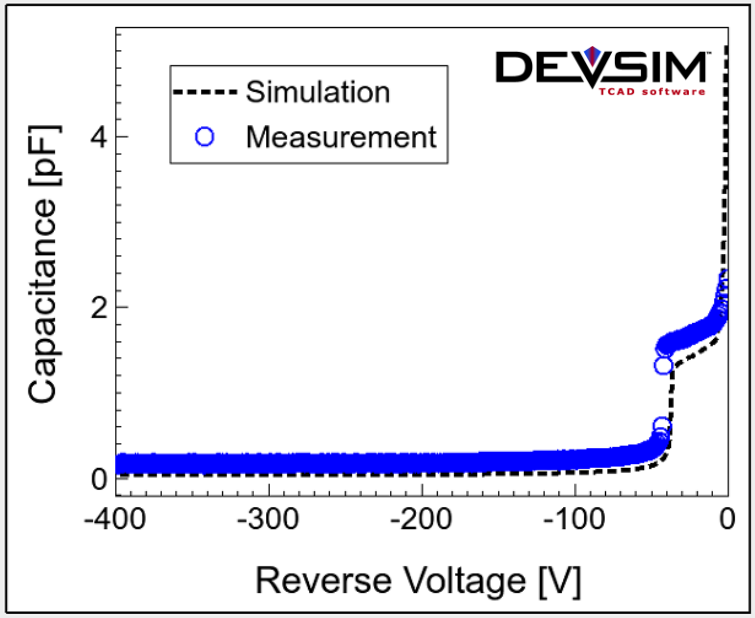


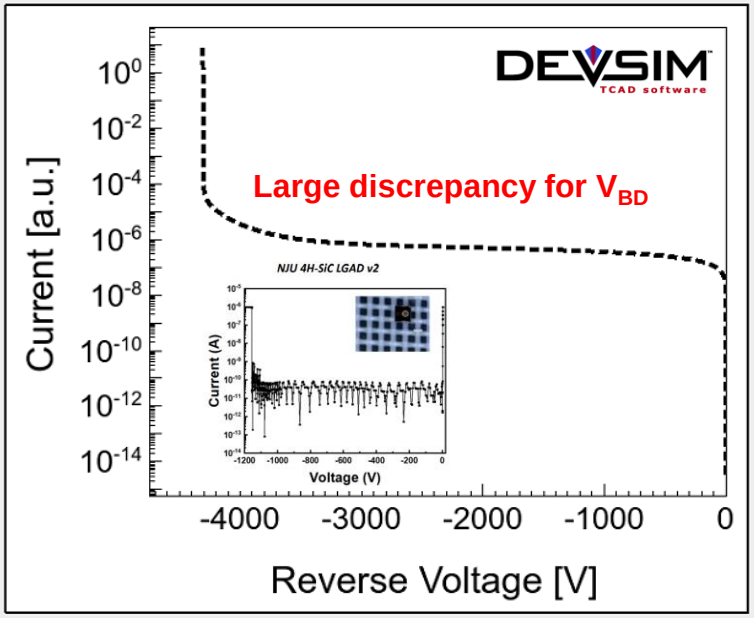


Simulation of NJU LGAD v2

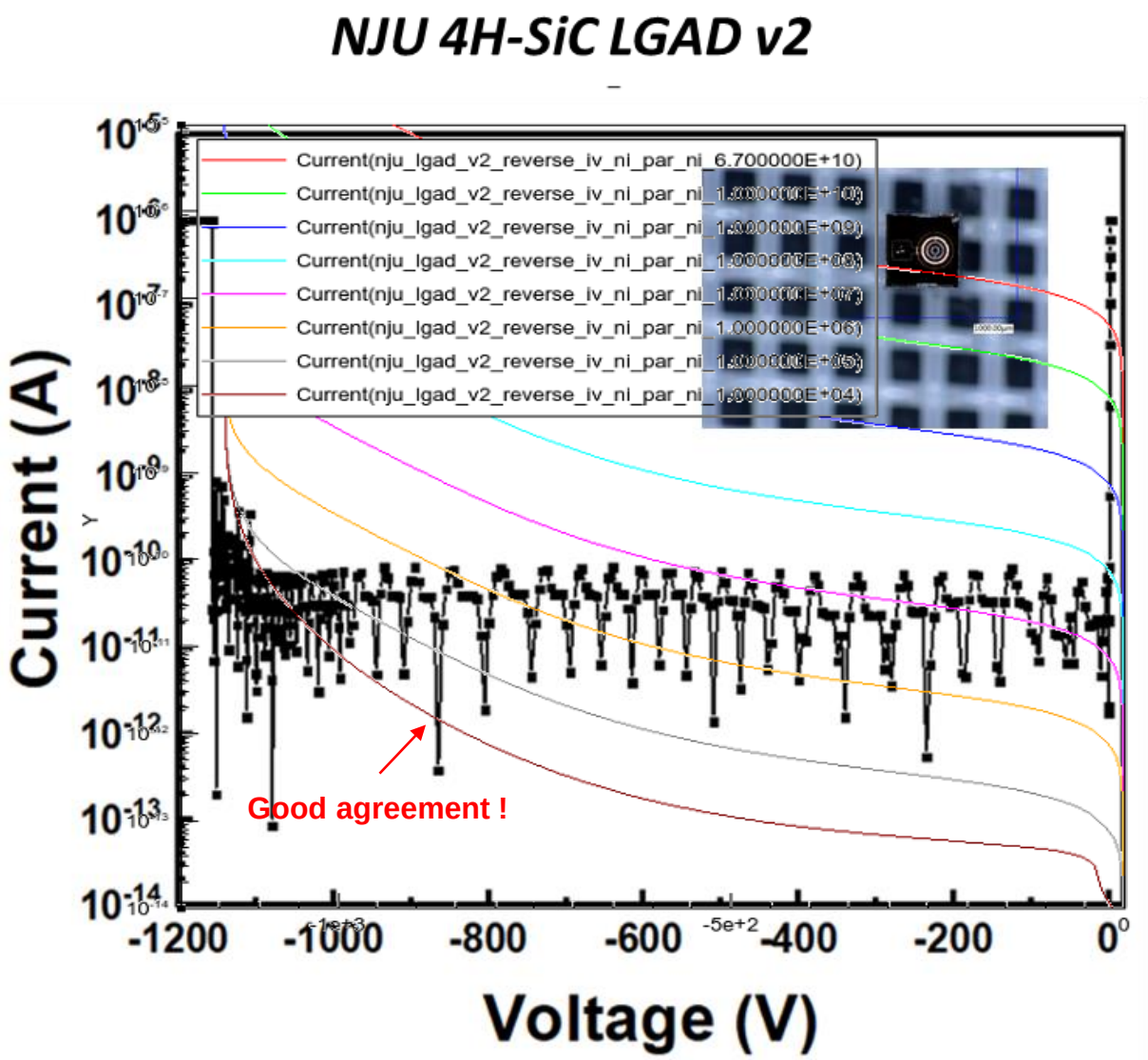








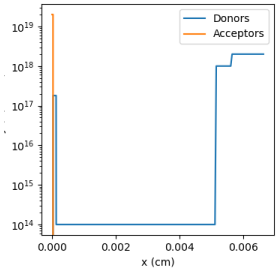
Calibration of NJU LGAD v2 Leakage Current



Extend Simulation 1D to 3D

1D simulation:

Generate 1D mesh set doping profile in DEVSIM.



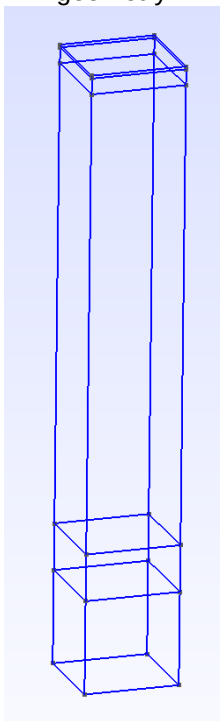
Total based on open-source software !

3D simulation:

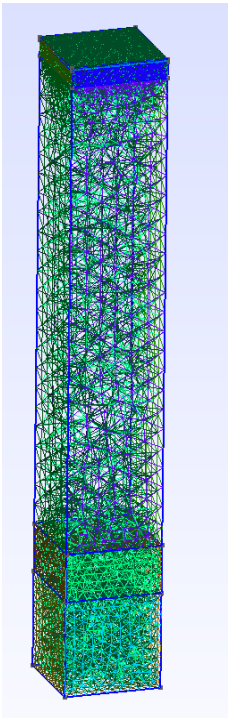
1.Generate 3D mesh file by *gmsh*

https://gmsh.info/

geometry



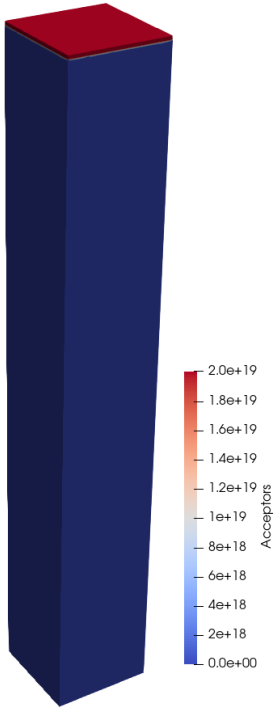
mesh



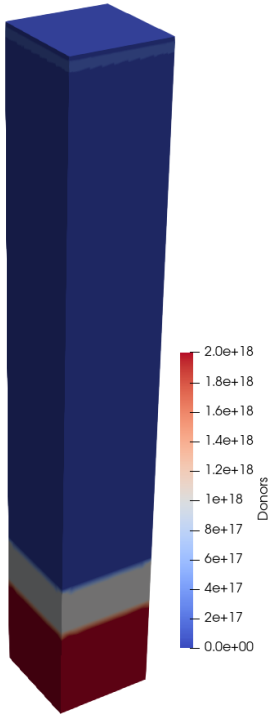
2.Import 3D mesh in *DEVSIM* and set doping profile, visualized by *Paraview*

https://www.paraview.org/

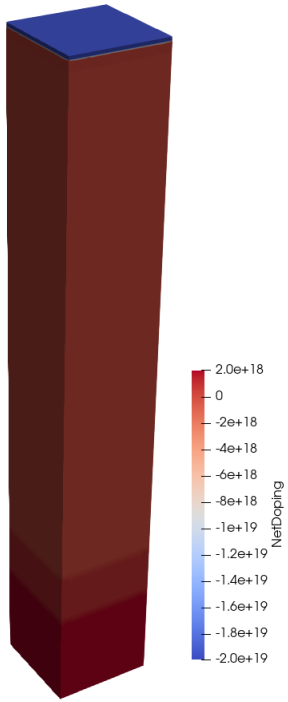
acceptor



donor



NetDoping = donor-acceptor



Present Status and Next :

DEVSIM achieved:

- ✓ Good agreement between measurement and simulation for 4H-SiC PIN.
- ✓ Simulate the breakdown of 4H-SiC LGAD.
- ✓ Technical validation for 3D simulation by DEVSIM

Next:

- ➢ Combine the deep trap levels in DEVSIM to simulate the increasing of leakage current.
- ➢ Develop the functions for 3D simulation to simulate the performance of 3D 4H-SiC LGAD.

Thanks for your attention