山东高等技术研究院
SHANDONG INSTITUTE
OF ADVANCED TECHNOLOGY

Development of
Simulation Software- RASER

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June 20, 2024

1st DRD3 Week on Solid State Detectors R&D

Outline

- **Introduction of RASER**
- **Simulation of silicon and silicon carbide detectors**
- **Application of planar SiC detectors in beam monitoring**
- **Proposal of SiC AC-LGAD**
- **Summary and Plan**

Introduction of RAdiation SEmi-conductoR(RASER)

- **Induced current:**

$$I(t) = -q\vec{v}(\vec{r}(t)) \cdot E_w(\vec{r}(t))$$

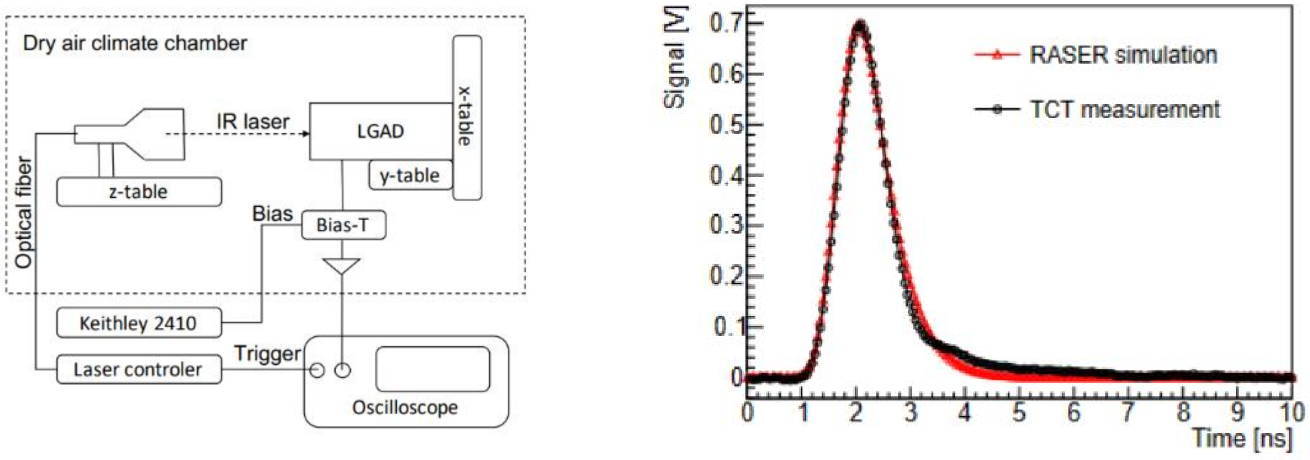
- **Electric and weighting field from Poisson and Laplace equation:** FEniCS → **DEVSIM**

$$\nabla^2\vec{U}(r) = -\frac{\rho}{\epsilon}, \quad \nabla^2\vec{U}_w(r) = 0$$

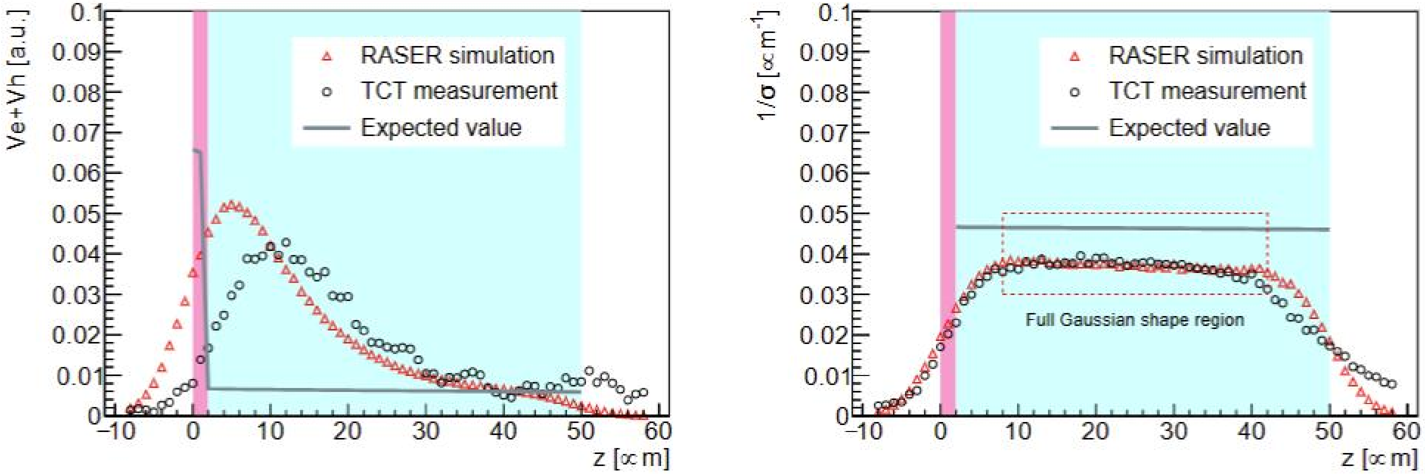
- **Particle incident path and deposition energy distribution: GEANT4**

- **Electronic simulation:** Current sensitive amplifier model → **NGSpice**

Simulation of silicon LGAD



LGAD edge-TCT layout(left) and waveform example(right)

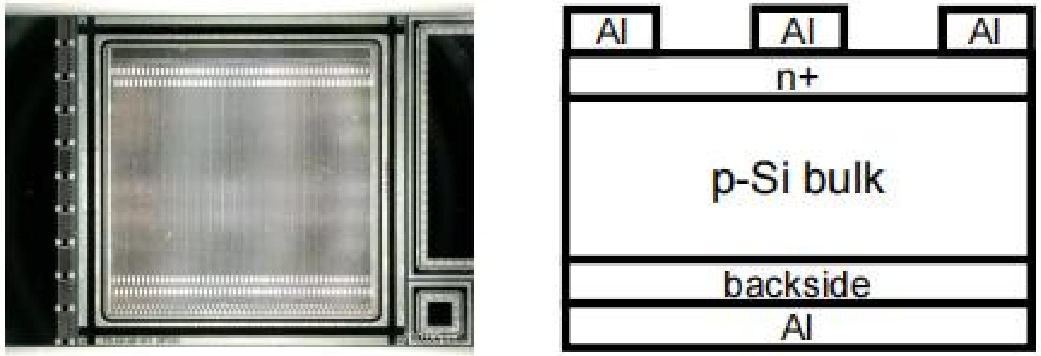


Traditional slope method(left) and carrier diffusion method (right) in LGAD

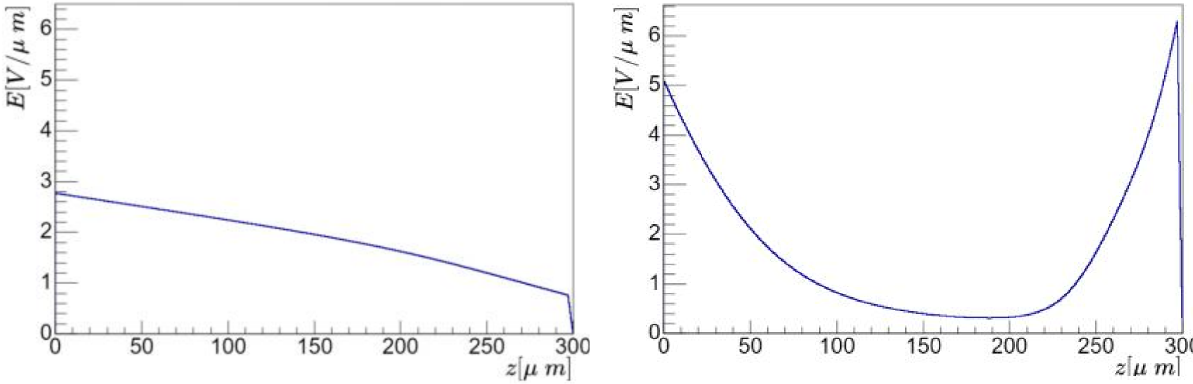
- **Si LGAD simulation implemented in RASER**
- **Construct edge-TCT system based on infra-red laser**
- **Propose a method for evaluating electric field based on carrier diffusion,** $\frac{di_q}{dt}\Big|_{max} = \frac{k_2 \sum N}{\sqrt{\tau^2 v_e^2 + \sigma^2}}$, **significant improvement compared to traditional slope method used in PIN**

<u>Electric Field Measurement by Edge Transient Current Technique on Silicon Low Gain Avalanche Detector</u>, NIMA

Simulation of silicon strip detectors



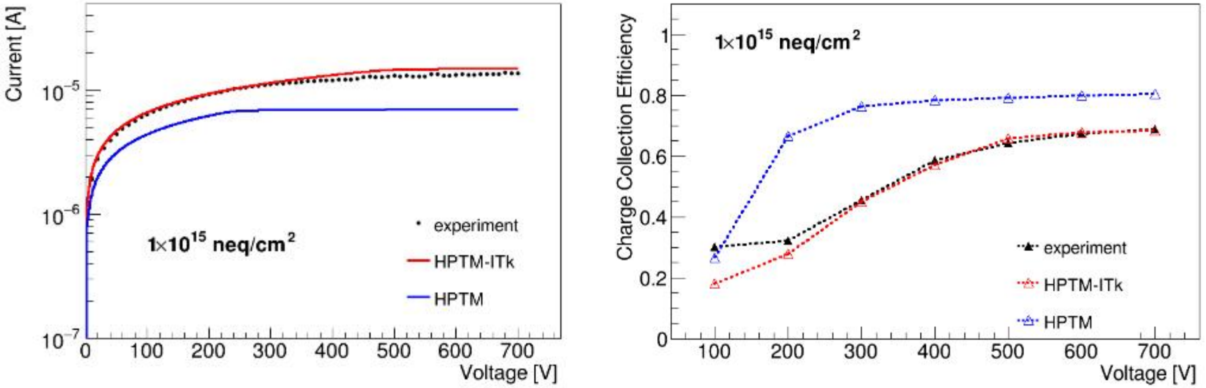
Silicon strip ITk mini sensor(left) and cross section(right)



Electric field of ITk mini sensor before(left) and after(right) irradiation in RASER

Type	Energy	Introduction rate HPTM-ITk	Introduction rate HPTM	$\sigma_e(cm^2)$	$\sigma_h(cm^2)$
Donor	$E_c - 0.1\ eV$	2.0810	0.0497	2.3×10^{-14}	2.92×10^{-16}
Acceptor	$E_c - 0.458\ eV$	1.6504	0.6447	2.551×10^{-14}	1.511×10^{-13}
Acceptor	$E_c - 0.545\ eV$	0.6936	0.4335	4.478×10^{-15}	6.709×10^{-15}
Donor	$E_v + 0.48\ eV$	2.6112	0.5978	4.166×10^{-15}	1.965×10^{-16}
Donor	$E_v + 0.36\ eV$	1.6511	0.3780	3.230×10^{-17}	2.036×10^{-14}

Defect paramaters introduced by irradiation



IV curve(left) and CCE(right) of ITk mini sensor

- **Optimizing the irradiation model parameters, the IV and CCE achieved**

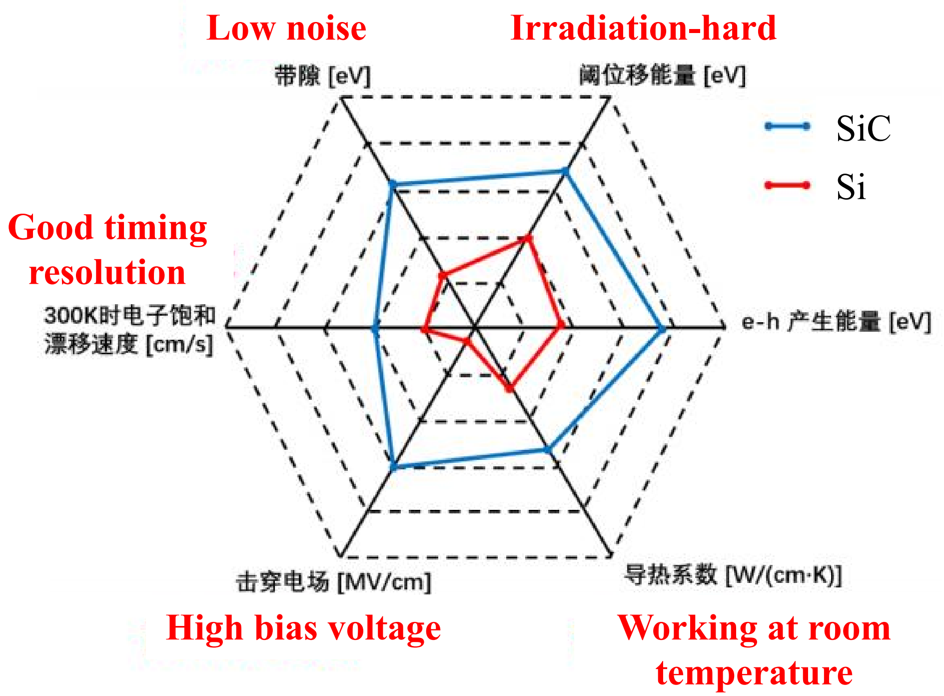
Advantages of silicon carbide

With the increase of collision brightness and detector size, silicon are facing two challenges:

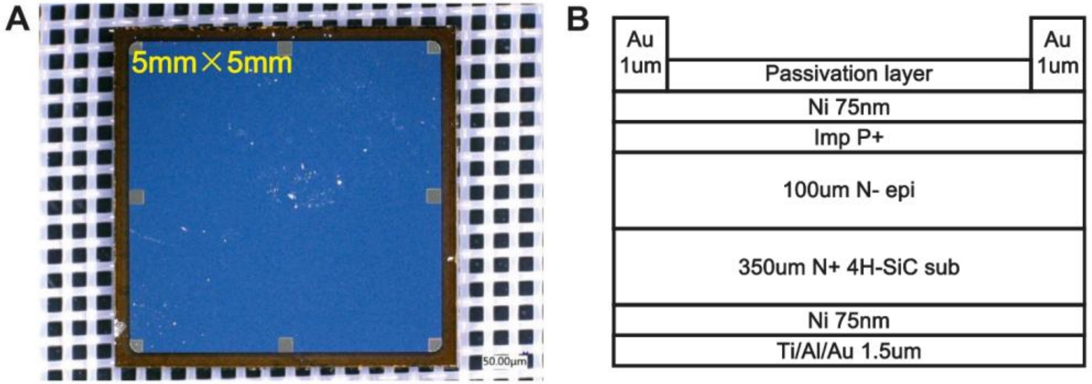
- **Near the limit of irradiation-hard → replace detector regularly**
- **Leakage current increases with irradiation → cooling equipment**

Silicon carbide is expected to achieve breakthroughs in the above two aspects.

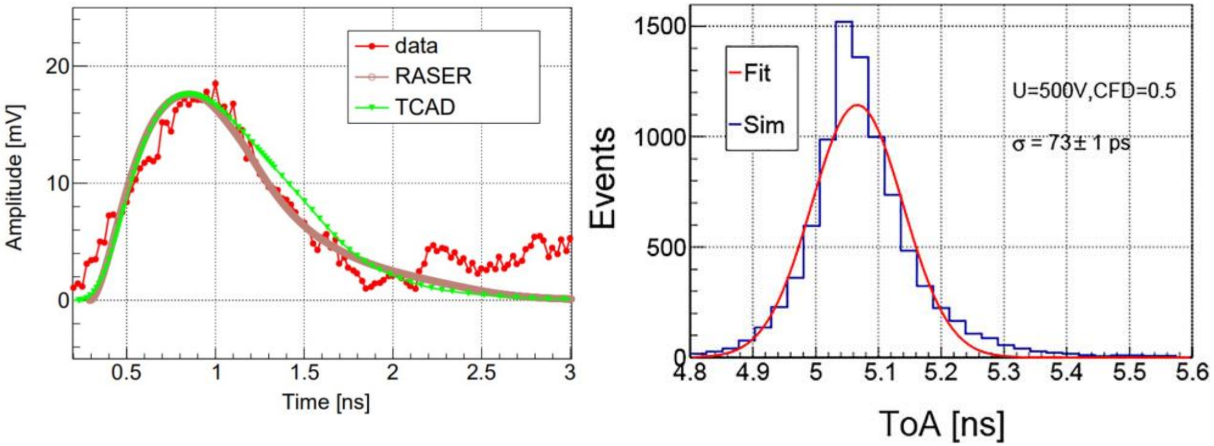
物理量	Si	SiC
Bandgap[eV]	1.12	3.26
Thermal conductivity[W/K cm]	1.5	4.9
Breakdown[MV/cm]	0.3	2.0
Atomic displacement threshold energy[eV]	13	22
Average ionization energy[eV/e-h]	3.6	7.8
Electron saturation drift velocity[cm/s]	1×10^7	2×10^7
Hole saturation drift velocity[cm/s]	0.6×10^7	1.8×10^7



Simulation of silicon carbide detectors



4H-SiC PIN(left) and cross section(right)

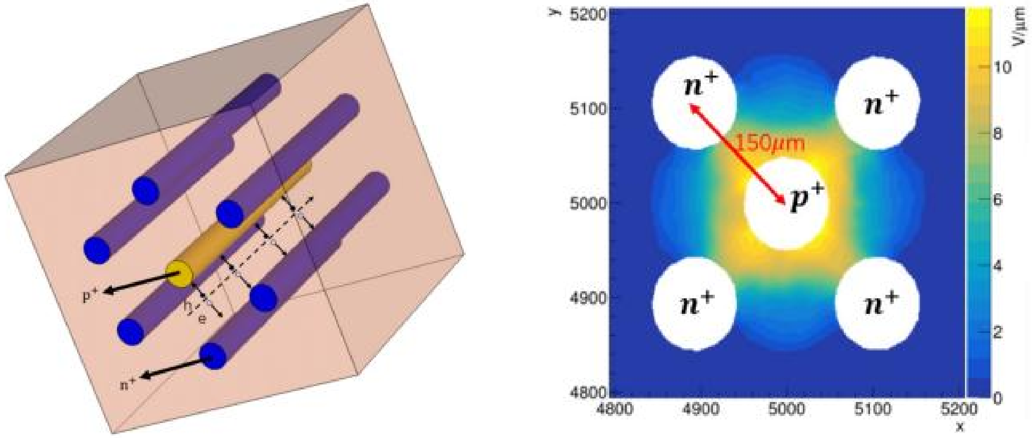


Waveform from RASER(left) and timing resolution(right)

- **4H-SiC PIN detector fabricated by Nanjing University, 100 μm active epitaxy layer**
- **~94ps timing resolution with ^{90}Sr beta source**
- **Wavefrom from RASER validated against experiment result**
- **~73ps timing resolution from RASER simulation**

Time Resolution of the 4H-SiC PIN Detector, Front. Phys.

Simulation of 3D silicon carbide detectors



3D SiC detector(left) and electric field from RASER(right)

- **3D SiC detector simulated in RASER**
- **~25ps timing resolution of 5-electrode SiC detector with ^{90}Sr beta source before irradiation**
- **timing resolution with different thickness, column spacing, number of electrodes**

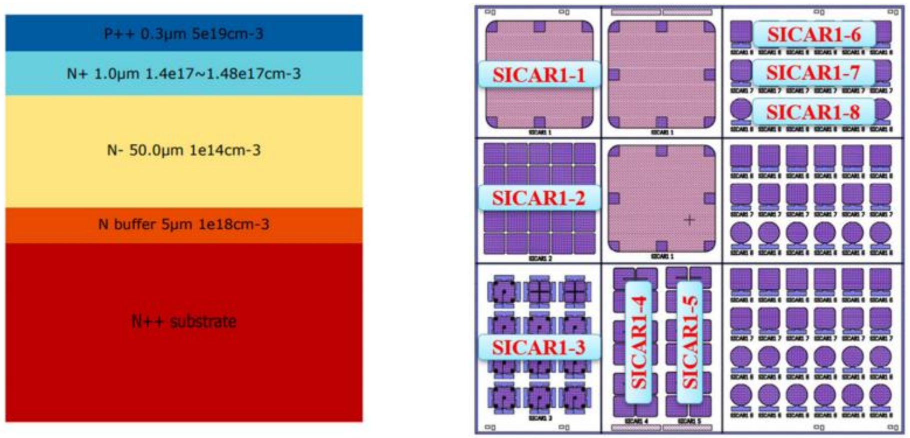
Table 1. The simulation parameters and results for planar 4H-SiC, 3D-4H-SiC-7E, and 3D-4H-SiC-5E detectors with 500 V bias voltage.

SiC Detector Type	Column Spacing (μm)	Thickness (μm)	Rise Time (ns)	Pulse Height (mV)	Time Resolution (ps)
Planar	100	100	0.38	13	77
3D-4H-SiC-7E	50	350	0.29	48	34
3D-4H-SiC-5E	50	350	0.32	53	25

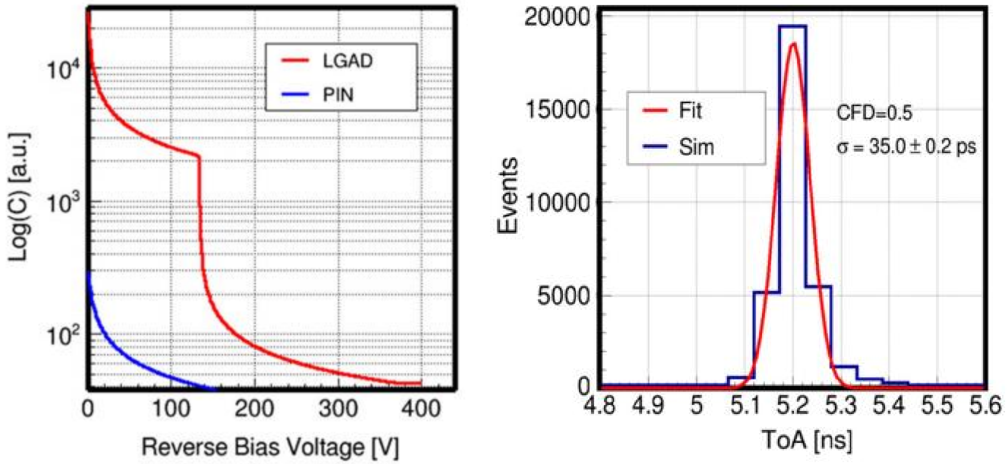
Influence of parameters on 3D SiC detector timing resolution

Timing Performance Simulation for 3D 4H-SiC Detector, Micromachines

Simulation of silicon carbide LGAD



Cross section of SICAR(left) and layout(right)



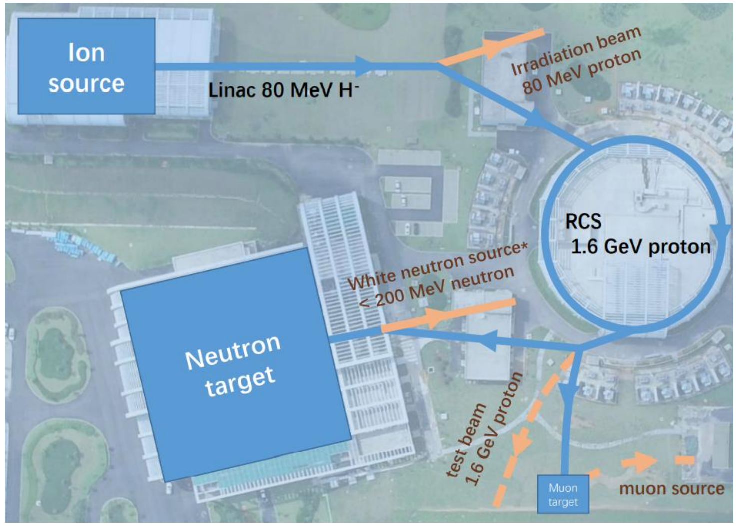
CV curve(left) and timing resolution(right) from RASER

- **Design and fabrication of SiC LGAD completed**
- **IV&CV curve simulated from RASER， depletion ~400V， breakdown ~3700V**
- **800V bias voltage， timing resolution from RASER ~35ps**

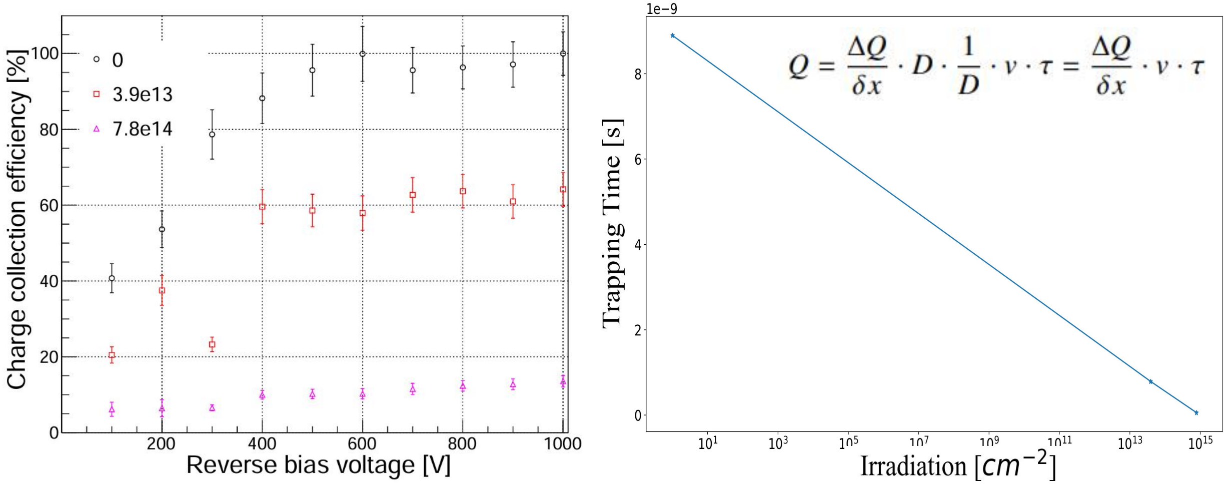
Design and simulation of a novel 4H-SiC LGAD timing device, RDTM

Application of planar SiC detectors in beam monitoring

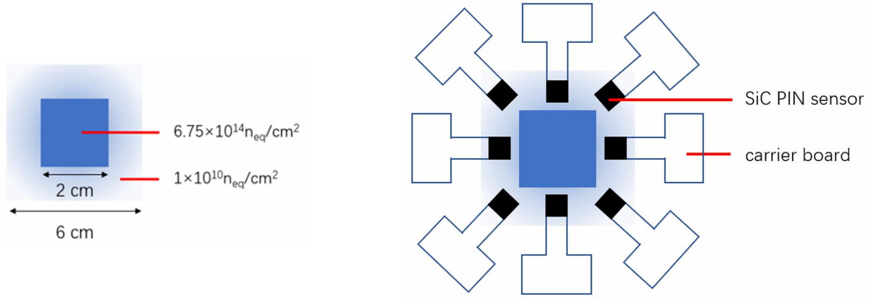
- **A new-built 1.6GeV proton beam line in China Spallation Neutron Source**
- **Beam monitoring system based on SiC detector**



New 1.6GeV proton beam line



CCE(left) and carrier trapping time(right) before and after irradiation



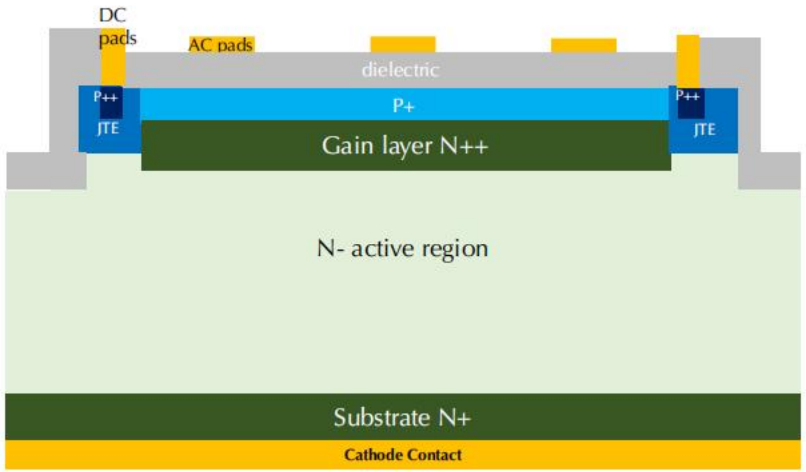
Schematic diagram of beam intensity (left) and detector placement(right)

- **The feasibility of SiC for beam monitoring has been demonstrated through irradiation experiment.**
- **RASER to calibrate SiC for long-term use, with the relationshop between carrier trapping time and irradiation dose.**

Proposal of SiC AC-LGAD

- **SiC AC-coupled strip&pixel LGAD will be add into RASER simulation**

IV&CV curve, spatial and timing resolution...



SiC AC-LGAD structure

Plan:

1. **SiC strip LGAD in RASER**
2. **SiC AC-strip LGAD**
3. **Solution of 3-dimension field**
4. **SiC pixel LGAD in RASER**
5. **SiC AC-pixel LGAD**
6. **irradiation defect**

Summary and Plan

- **DEVSIM and NGSpice update in RASER**
- **Multiple detectors simulated in RASER, including irradiation study**
- **SiC PIN working in beam monitoring system, RASER calibration**
- **Proposal for SiC AC-LGAD**

RASER open-source code

Thanks！