DRD3

Research on graphene-optimized silicon carbide detector

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The 2nd CERN DRD3 workshop

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Advantages of 4H-SiC

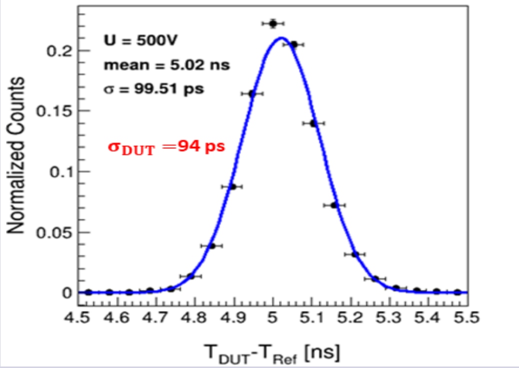
Characteristic	Si	4H-SiC
Eg (eV)	1.12	3.26
Thermal conductivity	1.5	4.9
$E_{breakdown}$ (V/cm)	0.5	3
Saturated electron velocity (cm/s)	1×10^7	2×10^7
ionization energy for e-h pair (eV)	3.64	7.8
displacement energy	13	21.8

- High radiation hardness
- Low dark current
- high temperature resistance
- High saturated carrier velocity -> fast response

Our team's work

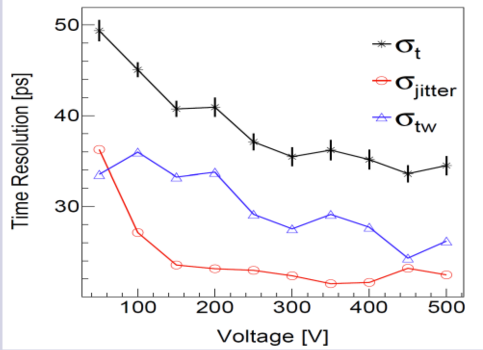
Good time resolution of 4H-SiC detector

100 μm 4H-SiC PIN for MIPs (measurement)



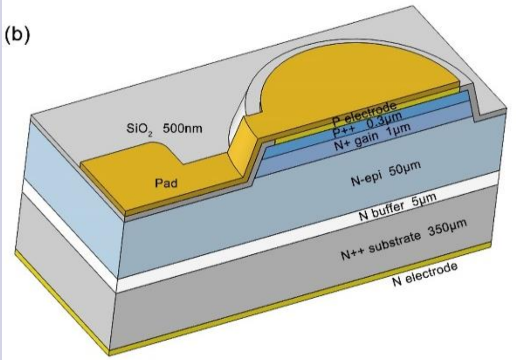
https://doi.org/10.3389/fphy.2022.718071

3D 4H-SiC Detector for MIPs (simulation)

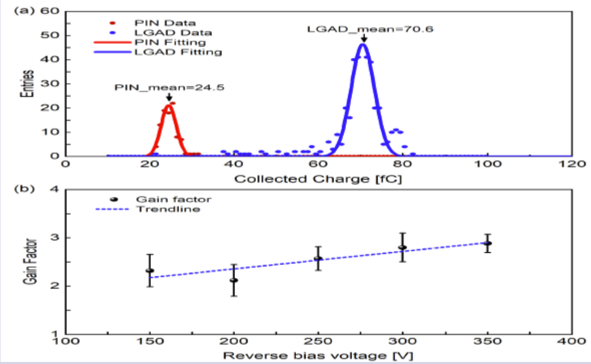


https://doi.org/10.3390/mi13010046

4H-SiC LGAD

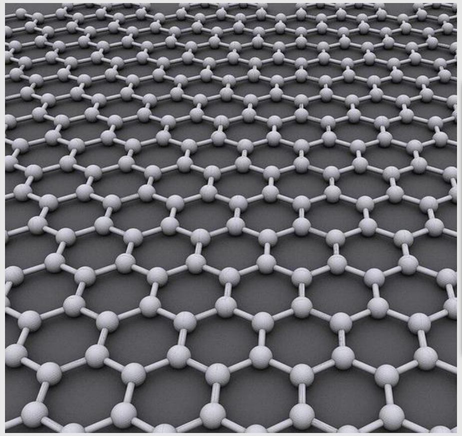


Corresponding author



https://ieeexplore.ieee.org/document/10701498

Advantages of graphene



Graphene advantages

- High thermal conductivity (5300W/m·K)
- High carrier mobility (15000 $cm^2 V^{-1} s^{-1}$)
- Radiation resistance

Graphene Particle detector field

- **Low temperature ohmic contact.**

（reduce the contact barrier between metal and SiC）

- **Used as an electrode**
- **Improve charge collection uniformity**
- **Increase charge collection rate**

WG6 research goals <2027	
	Description
RG 6.1	Development of small cell 3D diamond detectors (cages / interconnects, base length 25 μm) and possible exploitation of impact ionization
RG 6.2	Fabrication of large area SiC and GaN detectors, improve material quality and reduce defect levels.
RG 6.3	Improve tracking and timing capabilities of WBG materials
RG 6.4	Apply graphene and/or other 2D materials in radiation detectors, understand signal formation.

Table 11: WG6 research goals in the period 2024 - 2026

graphene-optimized silicon carbide detector

Graphene/PIN **Graphene/LGAD**

Epitaxial structure of 4H-SiC PIN

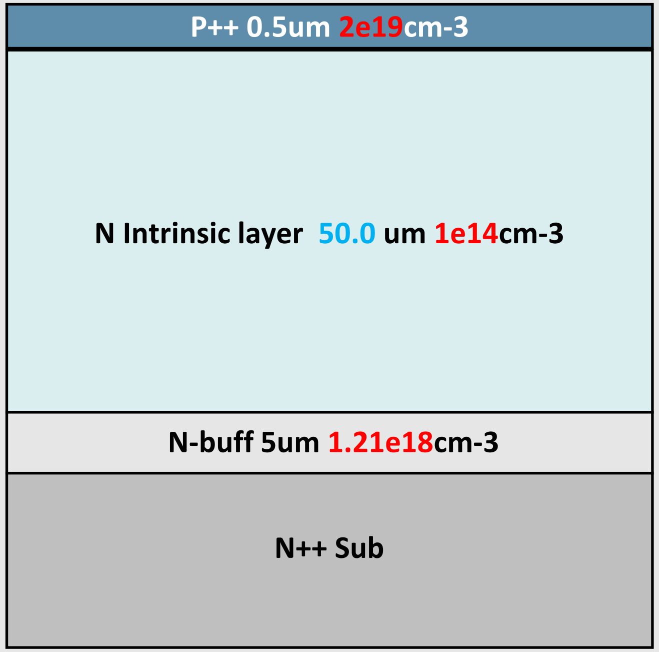


Fig.1 Epitaxial structure（designed）

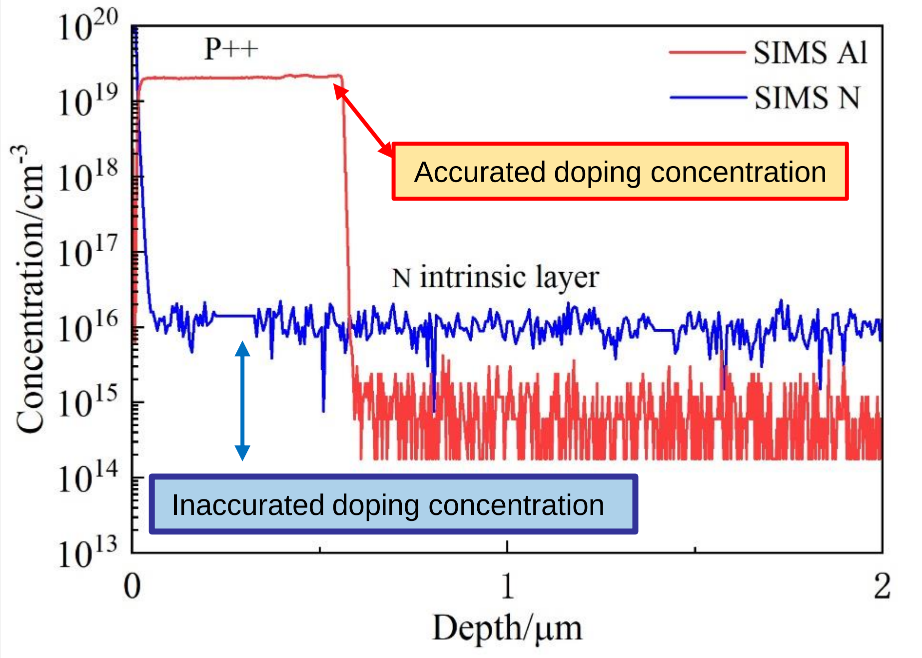
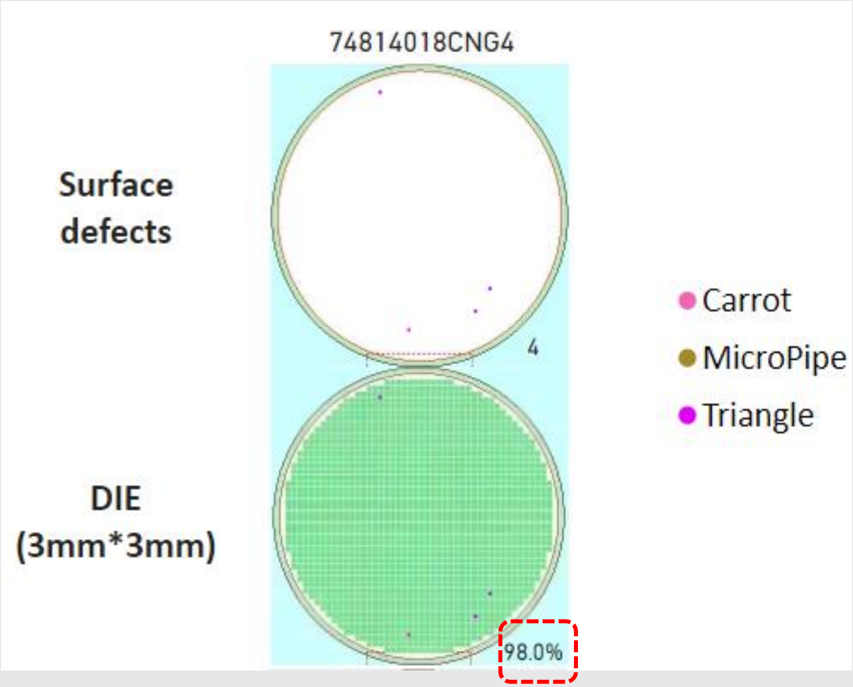


Fig.2 Secondary ion mass spectroscopy (SIMS) measurement results



Doping concentrations of the P++ layer meets the design requirements. Epitaxial wafer has a good quality.

Micro machining processes

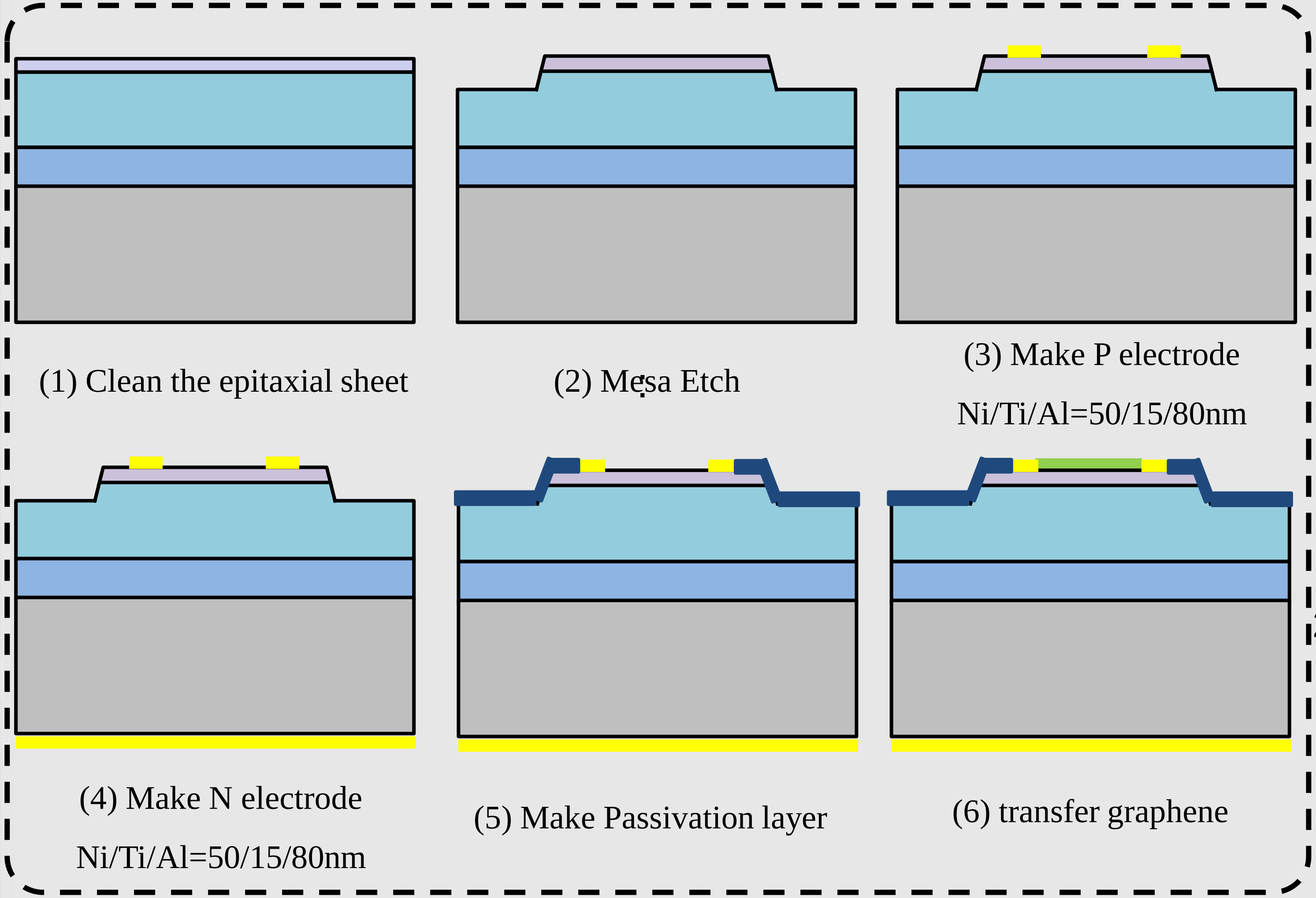


Fig.1 Micro machining processes

Key technologies of Gra/4H-SiC PIN

- Edge Termination：Mesa Etch
- Transfer of graphene (defective)
- P type ohmic contacts

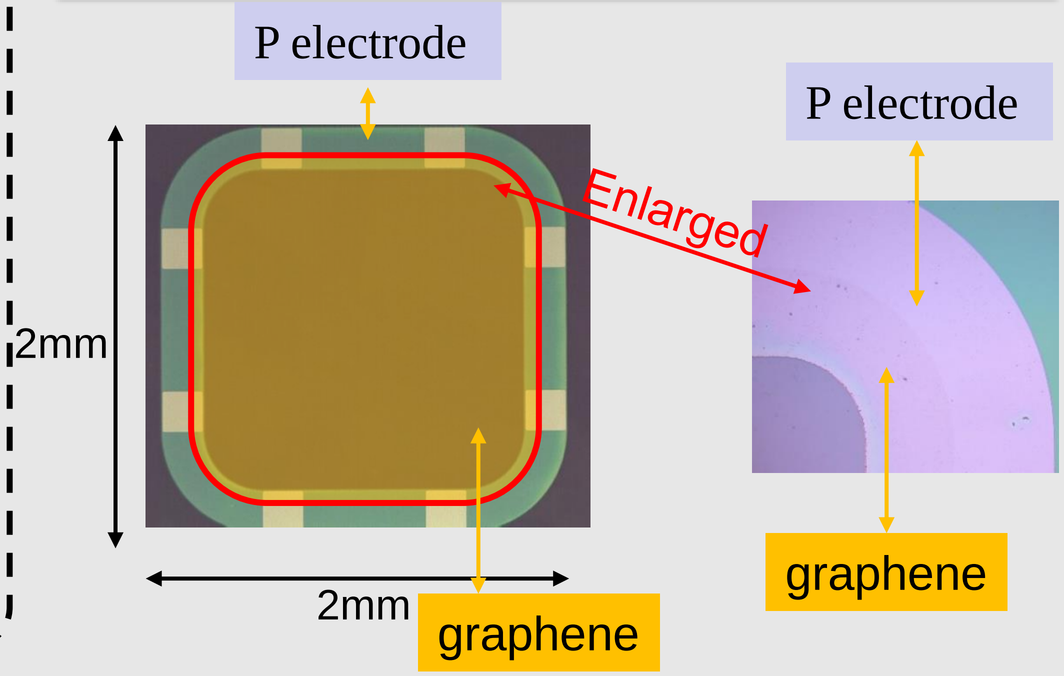


Fig.2 Graphene /4H-SiC PIN detector

Electrical performance analysis

- Leakage current （Current limit: 105μA , measure at room temperature）

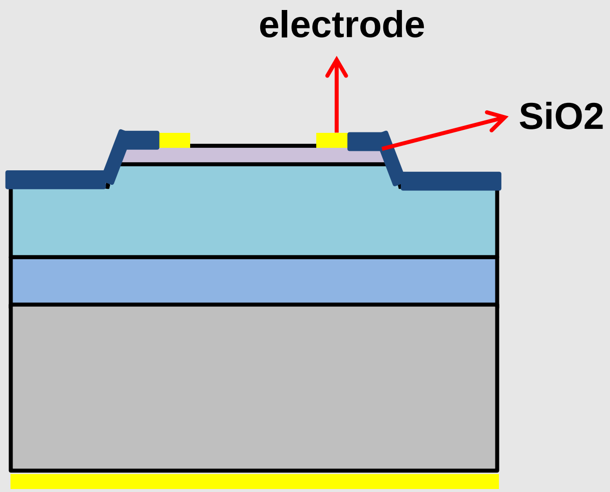


Fig. 1 Ring electrode PIN

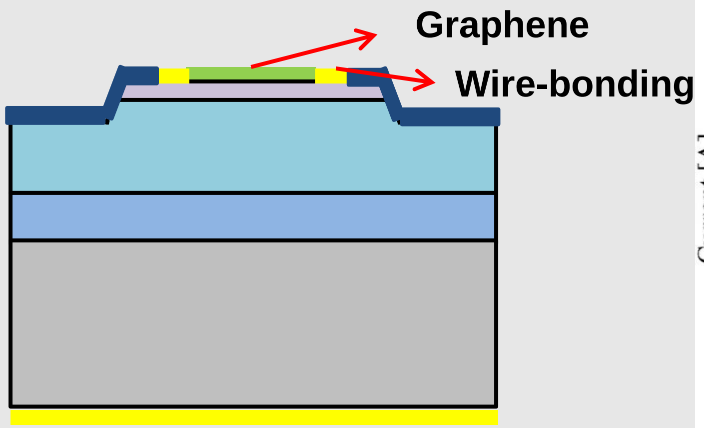


Fig. 2 Graphene/Ring electrode PIN

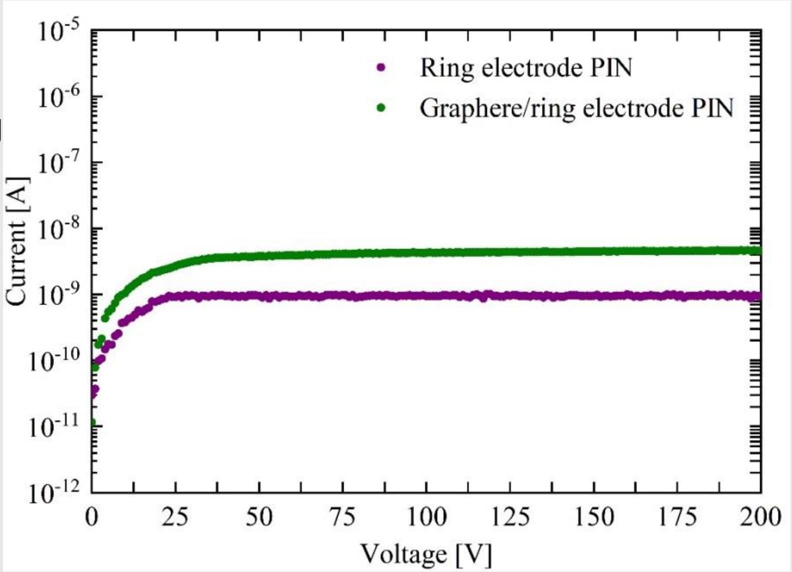


Fig. 3 I-V curves

	Ring electrode PIN	Graphene/Ring electrode PIN
Leakage current	1nA	3nA
Leakage current density	25nA/cm²	75nA/cm²

Electrical performance analysis

- Capacitance （Current limit: 105μA , measure at room temperature）

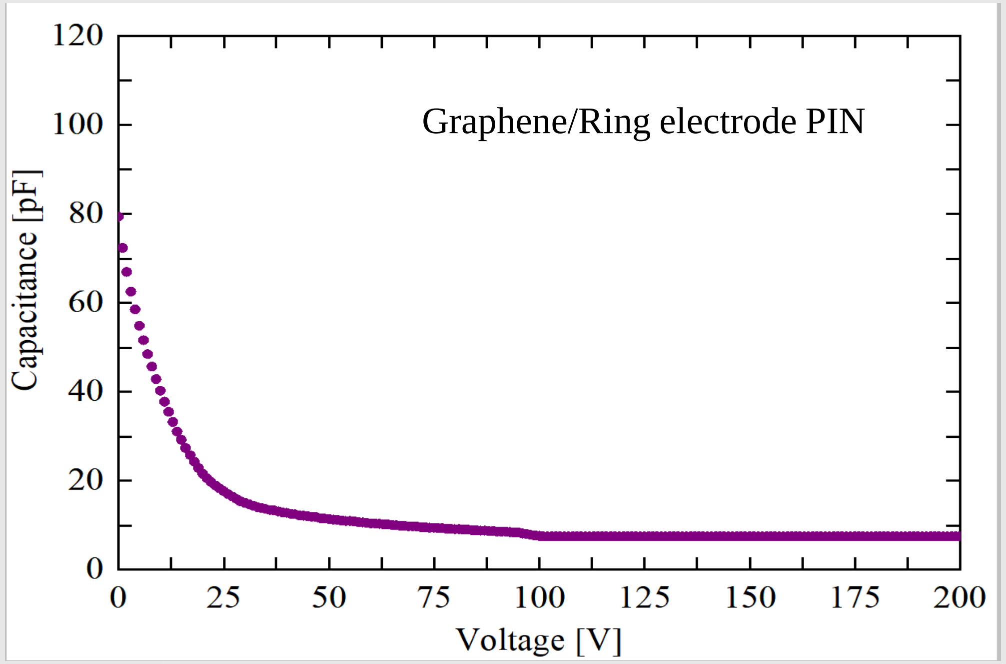
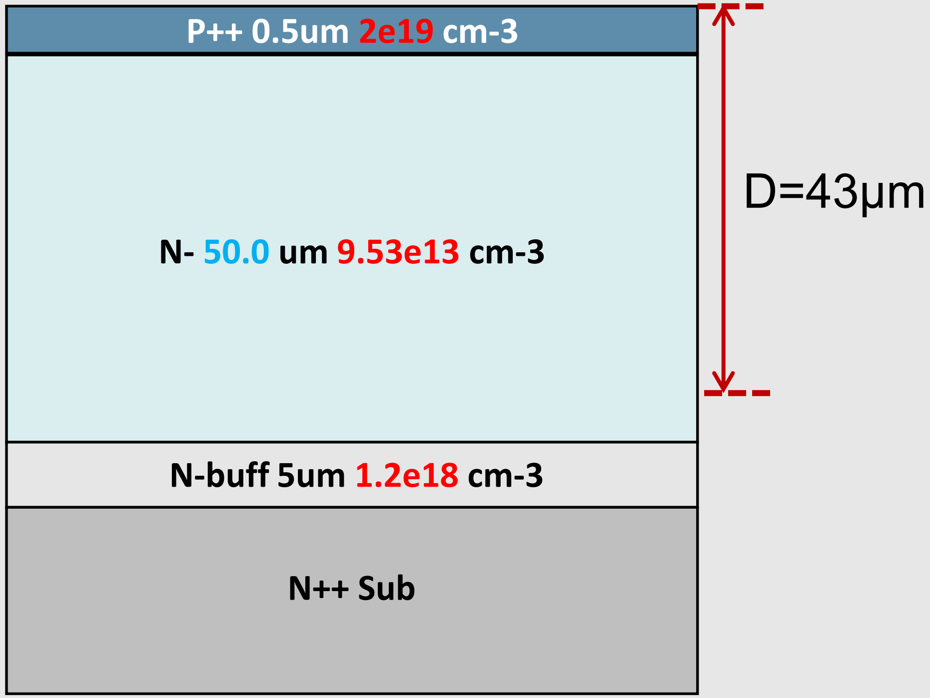


Fig. 1 C-V curve

Depleted depth (D)	43um
Intrinsic layer doping concentration	9.53e13cm^{-3}



Epitaxial structure

Effective doping concentrations of the intrinsic layer meets the design requirements.

Experimental setup for α particle measurement

- ^{241}Am radioactive source, 4H-SiC detector, Electronic board
- High voltage source (keithley 2470), Low voltage source (GPD-3303SGWINSTE)
- Oscilloscope(Tektronix10GHz).

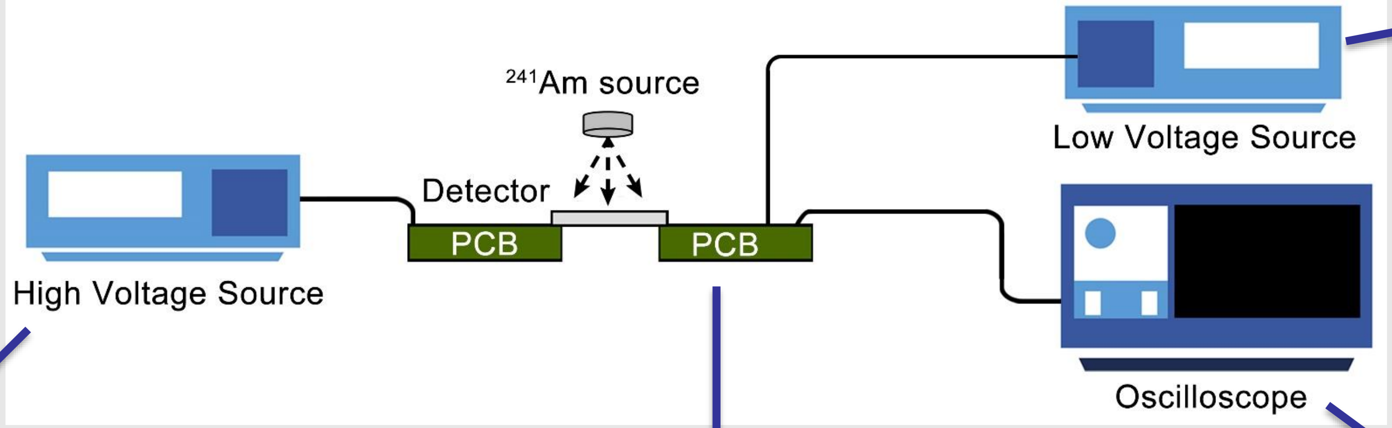
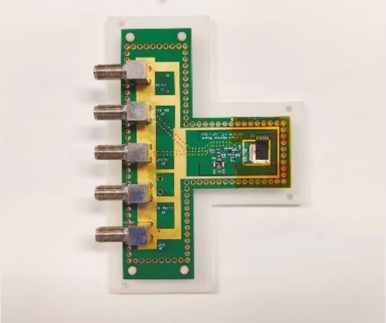
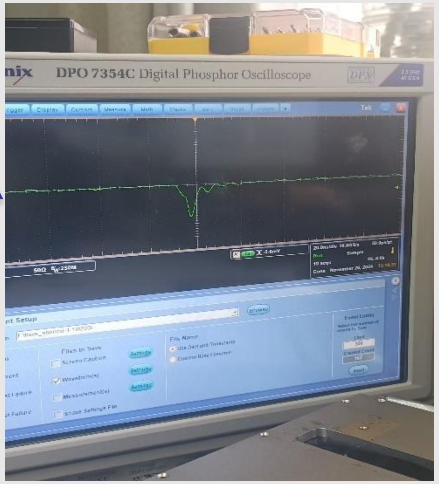
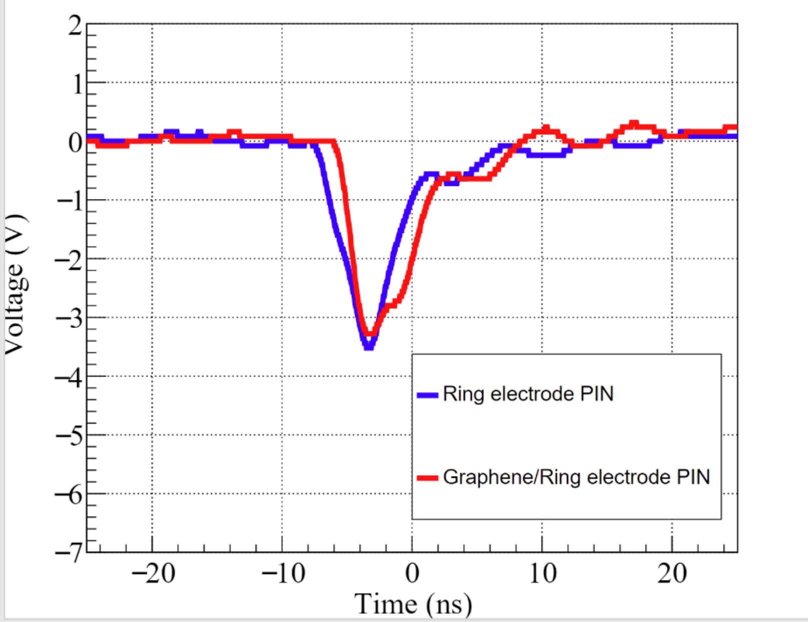


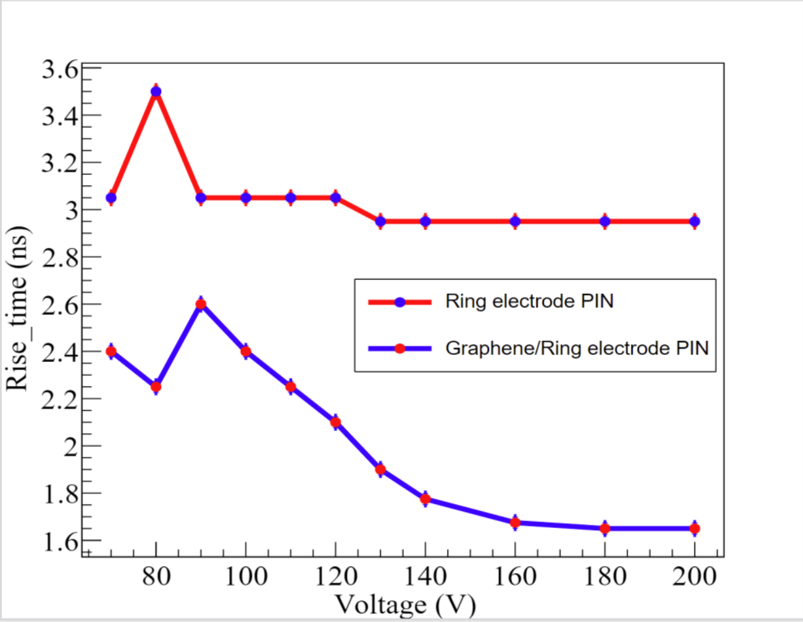
Fig.1 Experimental setup for α particle measurement





Waveforms and charge collection performance





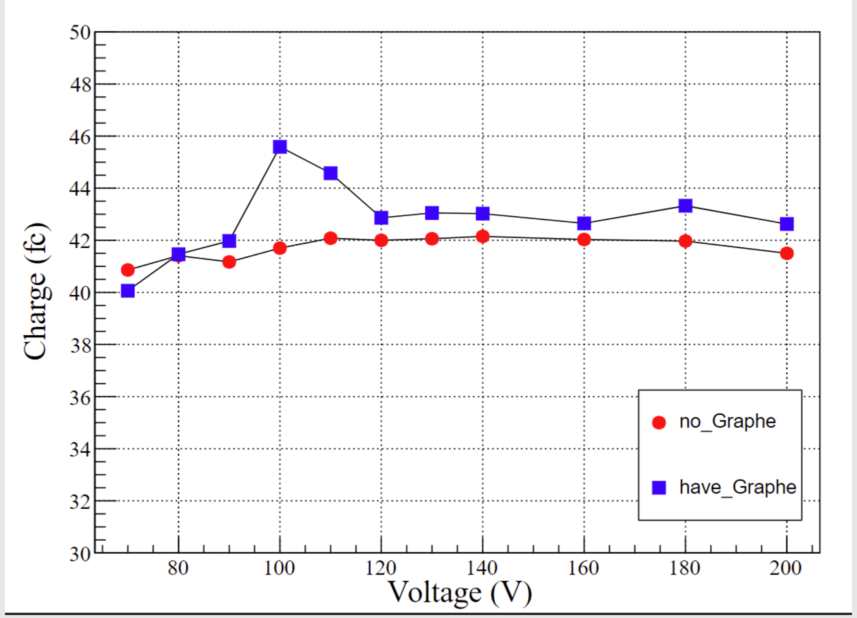


Fig. 1 Waveforms of two detector

Fig. 2 The relationship between voltage and rising time

Fig.3 Charge collection performance

Experimental conclusion

Rise time of the graphene/ring electrode PIN detector signal is smaller than that of the ring electrode detector. This means that graphene makes charge collection rate faster. The rise time decreases with the increase of voltage.

Summary and Plan

Summary

- Graphene PIN was successfully produced.
- Rising time is reduced and the charge collection rate is faster.
- The depletion depth is about 43 microns close to the thickness of the intrinsic layer.
- Effective doping concentrations of the intrinsic layer meets the design requirements.

Plan

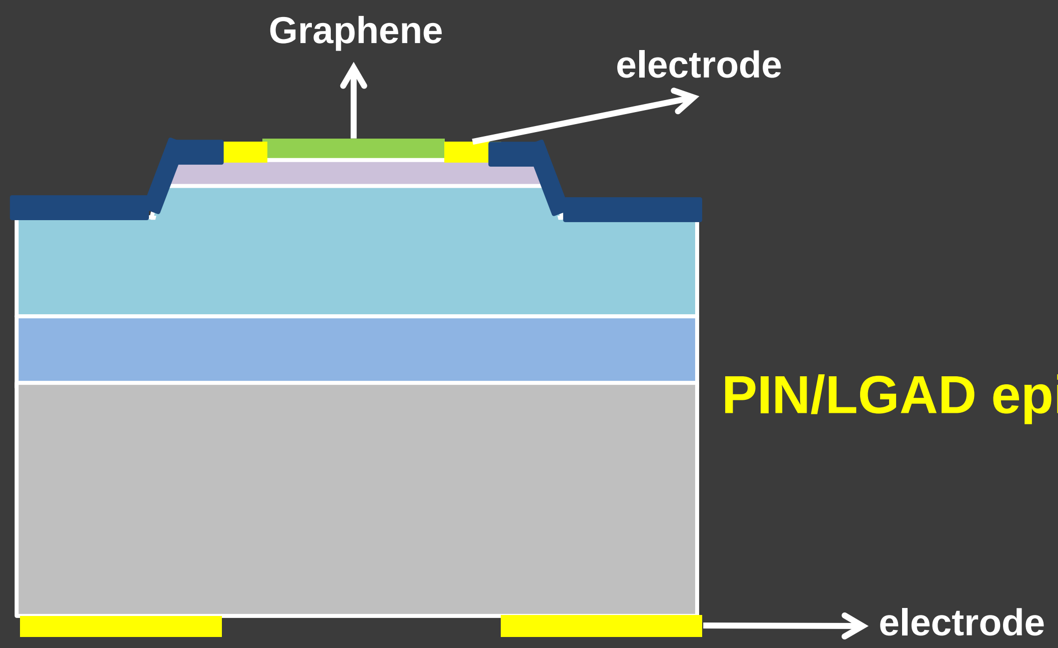
- Test and analyze time resolution.
- Study the irradiation performance.

Graphene-optimized Silicon Carbide Detector (GSCD) Plan

WG6 subproject with RG 6.4

Motivation and Goals

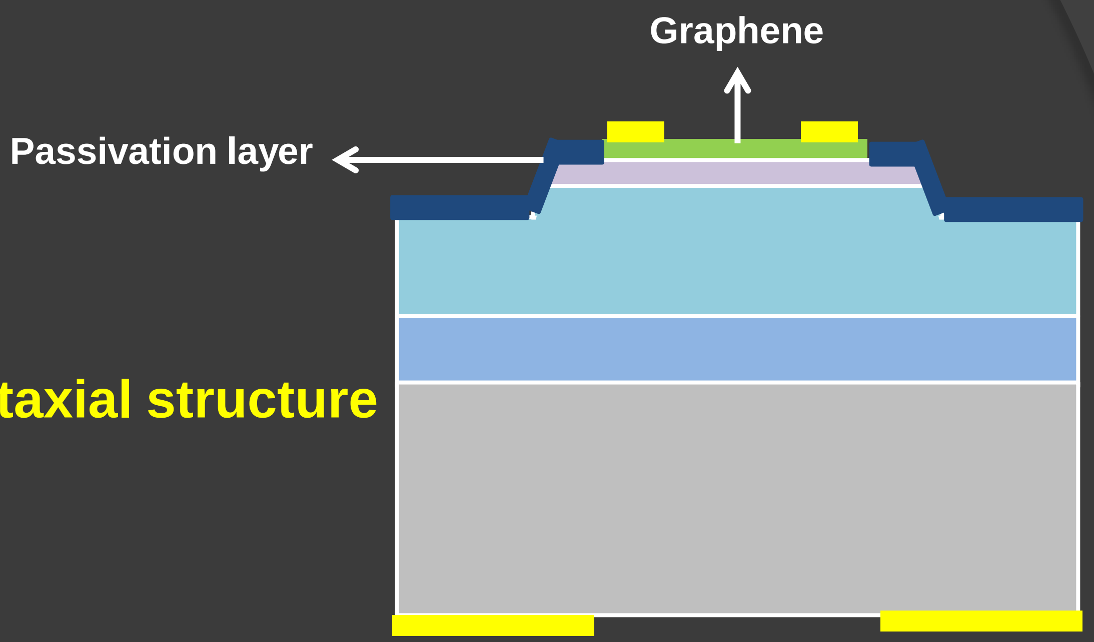
Prototype —GSCD1



Graphene is used as an electrode

PIN/LGAD epitaxial structure

Prototype —GSCD2



Used as an electrode

Reduces the contact barrier

- Reduce the contact barrier and improve the P-ohmic contact performance
- Improve charge collection rate and time resolution

Scientific problems to be solved

- **How to effectively improve charge collection rate and time resolution?**
  1. Using graphene to reduce the contact barrier and improve the P-ohmic contact performance
  2. Graphene is used as an electrode
- **How to reduce graphene defects?**
  1. Transfer graphene to direct growth graphene on SiC
- **Readout electrical board and readout ASICs?**
  1. Improve signal-to-noise ratio
  2. impedance mismatch
- **Effect of irradiation on the performance**
  1. Effects of different irradiation types on 4H-SiC devices
  2. Understanding of temperature dependence

Deliverables & time scales & contributing institutions

No.	Title	Description	Start date	End date	Institutions
Di.1	Fabrication of Graphene/SiC PIN	Fabrication of Graphene/SiC PIN	1/2025	8/2025	IHEP
Di.2	Fabrication of Graphene/SiC LGAD	Fabrication of Graphene/SiC LGAD	8/2025	12/2025	IHEP
Di.3	Electronics Readout	Development of the readout single board and ASICs	6/2025	12/2025	IHEP, IAT
Di.4	Characterization	IV, CV, Charge collection, time resolution test	1/2026	12/2026	IHEP, JLU, IAT
Di.5	Irradiation	Irradiation Graphene/SiC devices	1/2027	6/2027	IHEP
Di.6	Study of Irradiation Defects	Analysis of device defects caused by different types of irradiation	1/2027	6/2027	IHEP, IAT

JLU: Jilin University

IAT: Shandong Institute of Advanced Technology

Collaborative work

- WG2, 3, 5: characterization of irradiated and non-irradiated devices
- WG4: modelling of radiation damage
- WG8: dissemination and outreach
- Converge on a WG6 subproject with RG 6.4 Two-dimensional material detector

Welcome to join us!

Contact Person
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