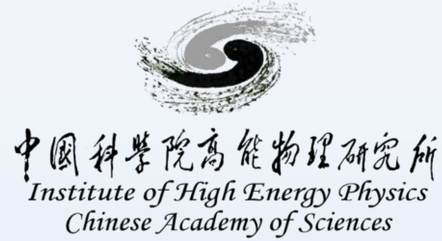
The Development of 4H-SiC Detector for Fast Minimum Ionization Particle Detection



Tao Yang[1], Qing Liu[2], Xiyuan Zhang[1], Congcong Wang[1], Hai Lu[2], Xin Shi[1]

[1]*Institute of High Energy Physics, CAS,* [2]*Nanjing University*

Benefits of 4H-SiC material

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

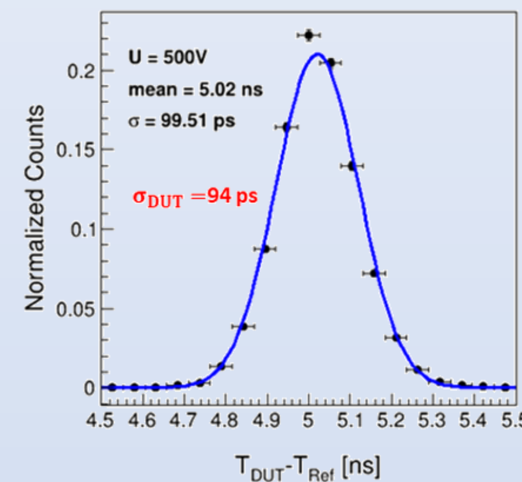
- ✓ High radiation hardness
- ✓ Low dark current
- ✓ Work on high temperature
- ✓ High saturated carrier velocity
- ✓ High energy resolution

4H-SiC Detector could be applied to fast MIPs detection in high radiation environment without cooling system

Good time resolution of 4H-SiC detector

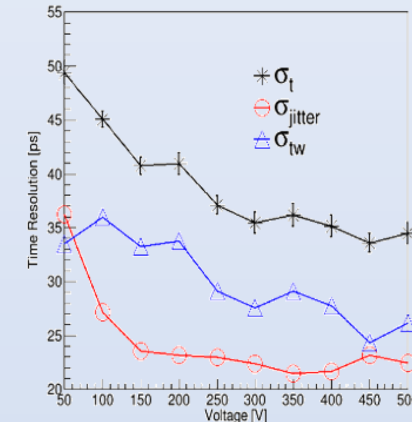
- **Present studies about different 4H-SiC detectors indicate the 4H-SiC detectors have good time resolution at room temperature. Such as $\sigma_T < 100$ ps for 4H-SiC PIN and $\sigma_T < 30$ ps for 3D 4H-SiC detector.**

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



doi: 10.3389/fphy.2022.718071

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

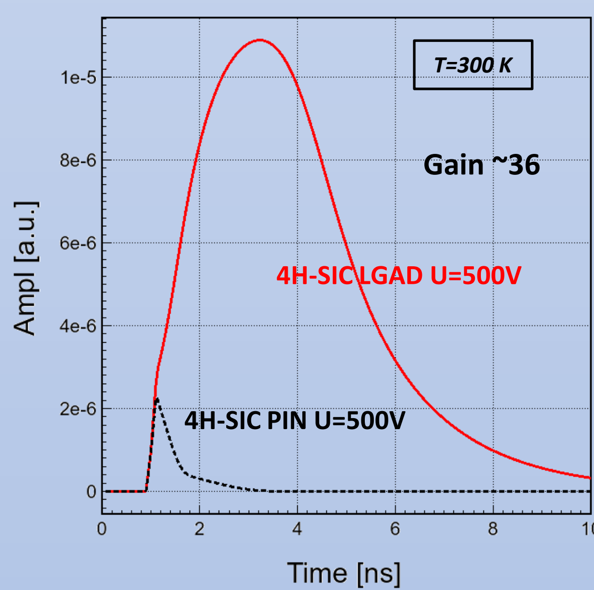


doi: 10.3390/mi13010046

The 4H-SiC Low Gain Avalanche Diode Concept

- **Background:** The Silicon Low Gain Avalanche Diode (LGAD) has been verified to have excellent time performance. Therefore, the 4H-SiC LGAD is introduced for application to detect the MIPs.
- **Motivation:** find the electric field range to achieve low gain avalanche in 4H-SiC material and obtain an excellent time resolution at room temperature.
- **Application:** room temperature, $> 10^{16}\ n_{eq}/cm^2$ NIEL radiation and fast MIPs detection $\sigma_T < 30$ ps.

Simulated MIP signal from 4H-SiC LGAD & PIN



Higher signal amplitude with higher S/N of 4H-SiC LGAD than PIN.

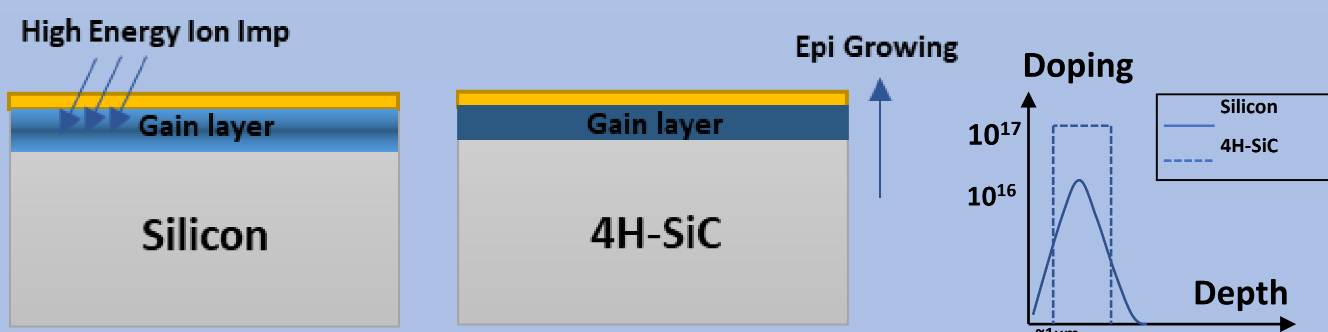
$$\sigma_t^2 = \sigma^2_{\text{Time Walk}} + \sigma^2_{\text{Landau Noise}} + \sigma^2_{\text{Distortion}} + \sigma^2_{\text{Jitter}} + \sigma^2_{\text{TDC}}$$

$$\sigma_{\text{Jitter}} = \frac{N}{dV/dt} = \frac{t_r}{S/N}$$

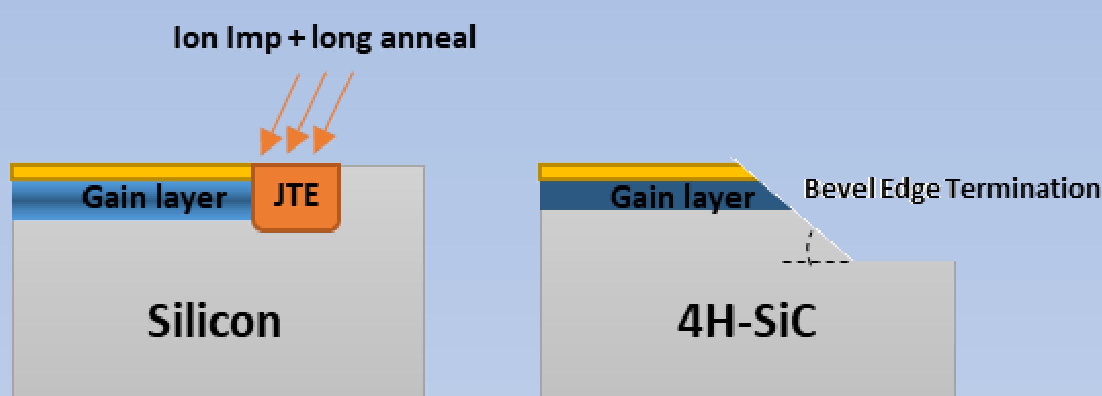
The contribution of σ_{Jitter} is supressed by the high S/N in LGAD. Therefore, LGAD has excellent time performance.

- **Process technology compare for Si & 4H-SiC LGAD:**

1. Process of gain layer: epitaxial growing gain layer and higher doping concentration are adopted in 4H-SiC LGAD.

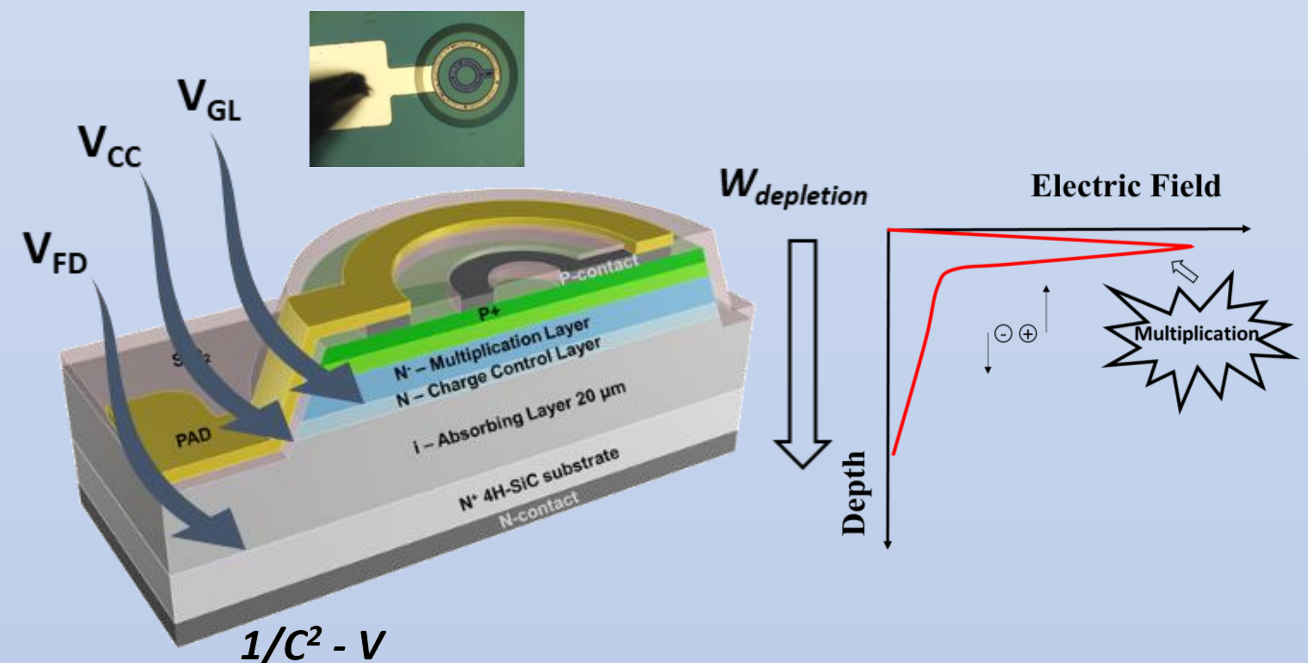


2. Termination: bevel Edge Termination is adopted in 4H-SiC LGAD to suppress premature breakdown caused by edge effects.

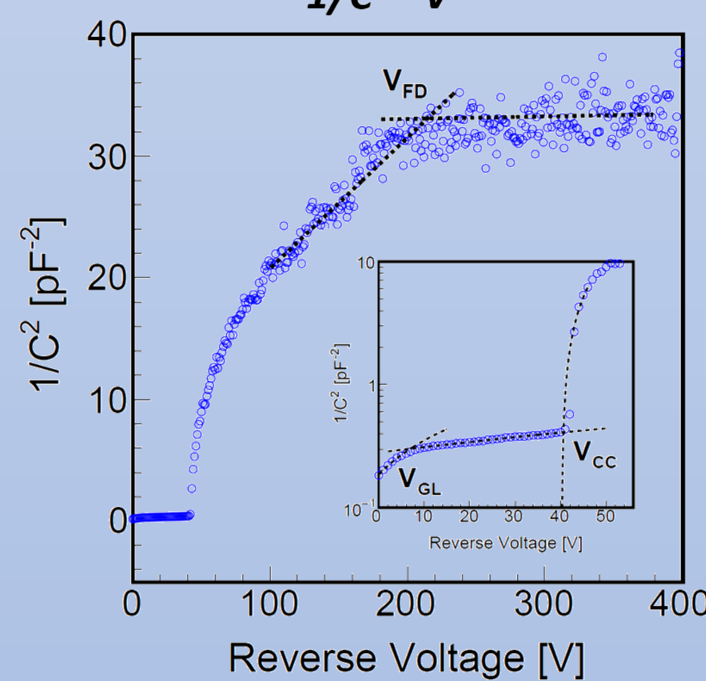


The NJU 4H-SiC Low Gain Avalanche Diode

- The NJU 4H-SiC LGAD is fabricated by Nanjing University which has 20 µm absorbing layer and 0.5 µm gain layer. The electric field is about 2e6 V/cm ~ 3e6 V/cm in gain layer.



1/C² - V



Key technologies of 4H-SiC LGAD :

- Epitaxial structure design.
- High quality and low doping 4H-SiC layer growing technology.
- Bevel Edge Termination.
- High quality passivation.
- N or P type ohmic contacts

Charge Collection Measurement

- To determine the gain factor, the collected charges of 4H-SiC LGAD and PIN from α particles are measured. High gain signals are observed and The highest gain is about 5 from dispersed gain signal distribution.

Collected charges spectrum