SiC AC-LGAD Timing Pixel Detector

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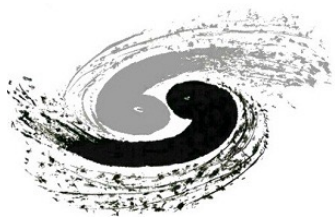
On behalf of Proposing Institutions

20 June 2024





Motivation and Goals

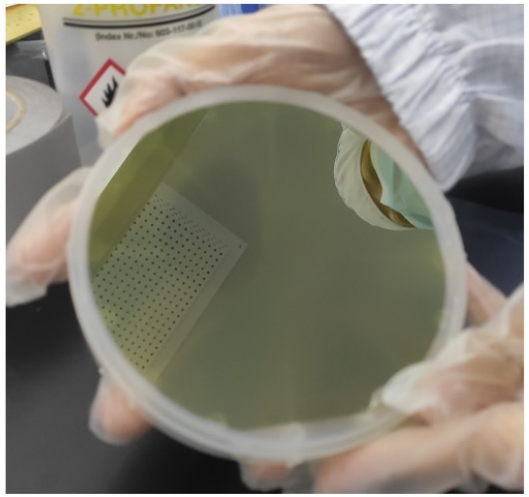
- Future vertex detector with high spatial and timing resolution under extreme fluences
- Strategic goals directly addressed in project as specified in DRDT 3.2
  - Target WP3
  - Task 2.2, 3.1
  - Milestone 3.5

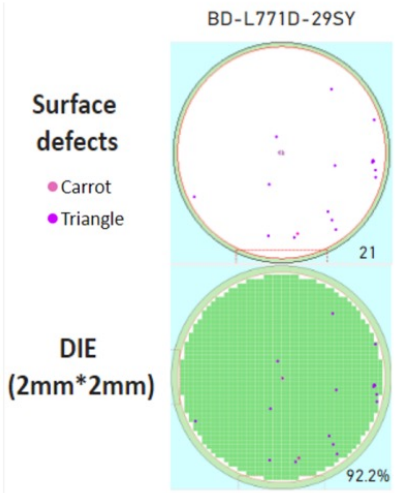
WP	Task	MS or D	Description	2024	2025	2026	2027-2029	> 2030
3	2.2, 3.1	MS3.5	SiC-LGAD (gain layer) proof of principle, simulation and first fabrication of devices with small areas (< 1 cm^2 in 2026) and in large areas (5 cm^2 after 2030).			x		x

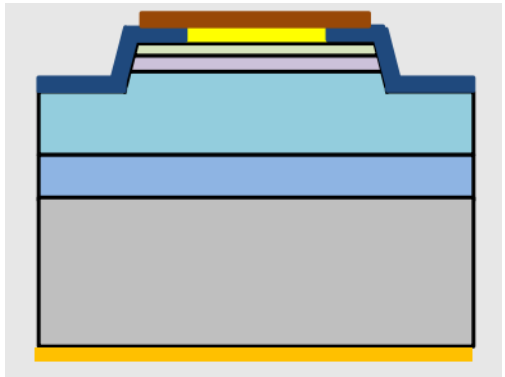
Research Backgroud

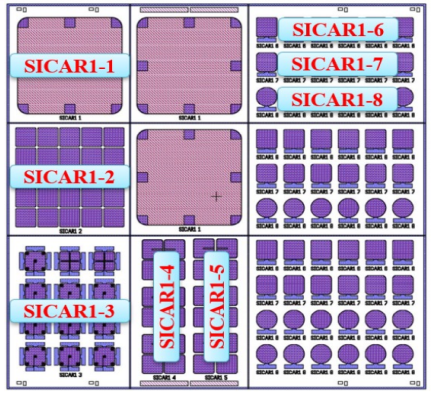
Development of 4H-SiC LGAD - SICAR

Epitaxy and processing technology



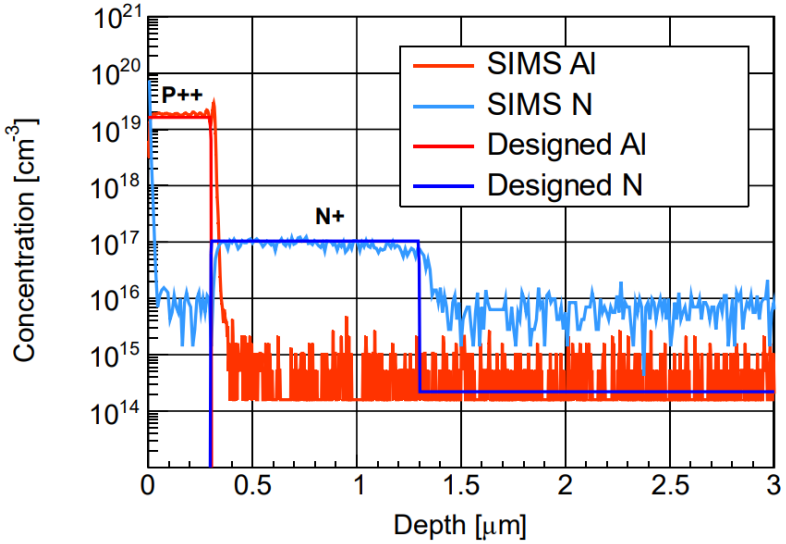


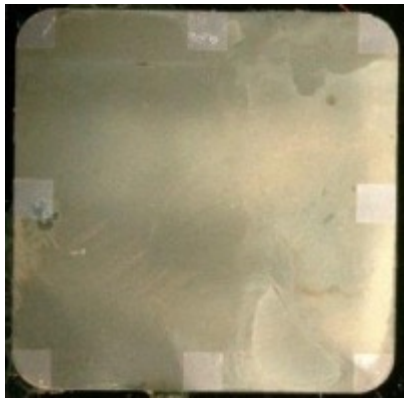


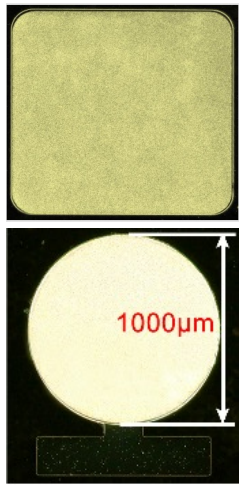


- N type & P type Ohmic contact
- Bevel etched termination

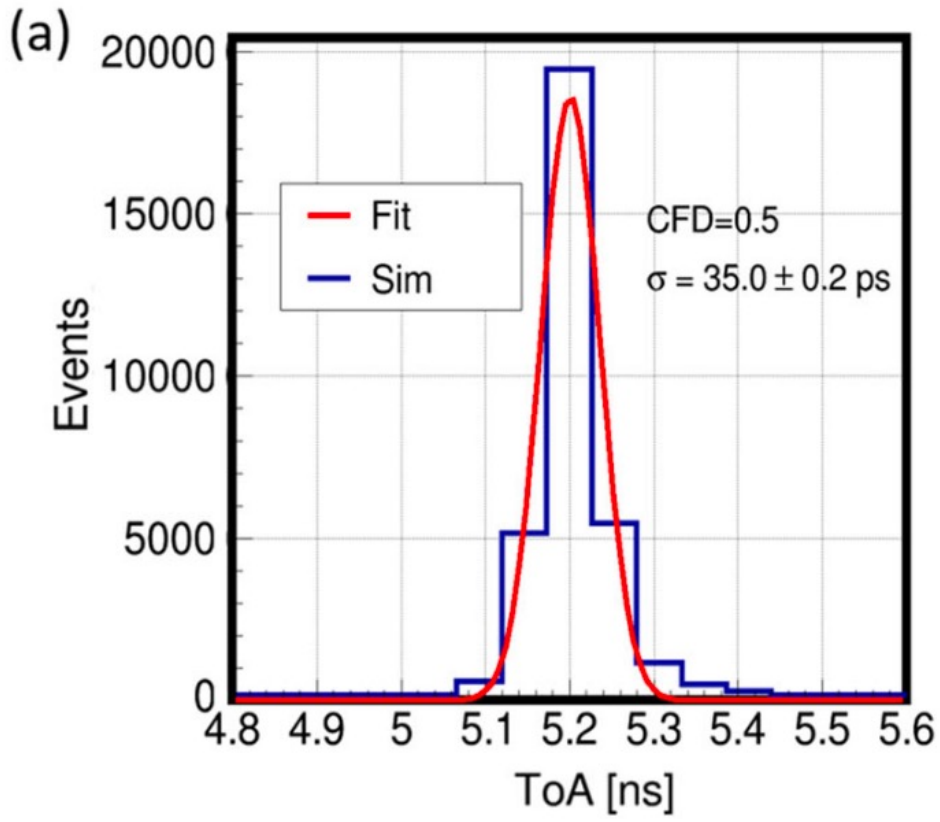
Doping concentration design and SIMS measurament

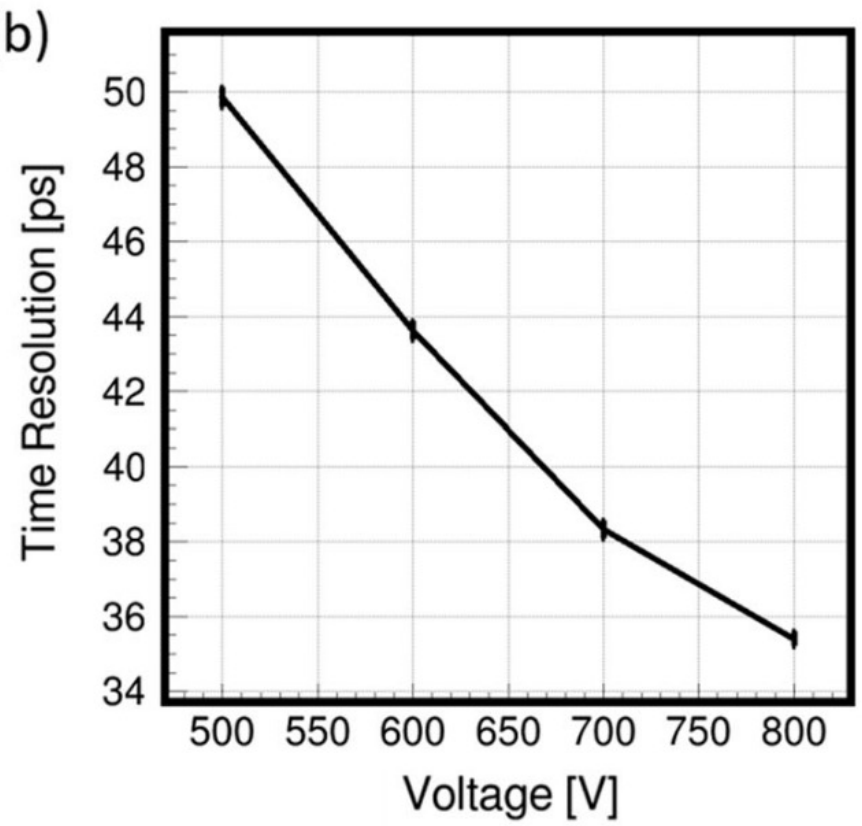






Timing resolusion simulation of SICAR1





https://doi.org/10.1007/s41605-023-00431-y

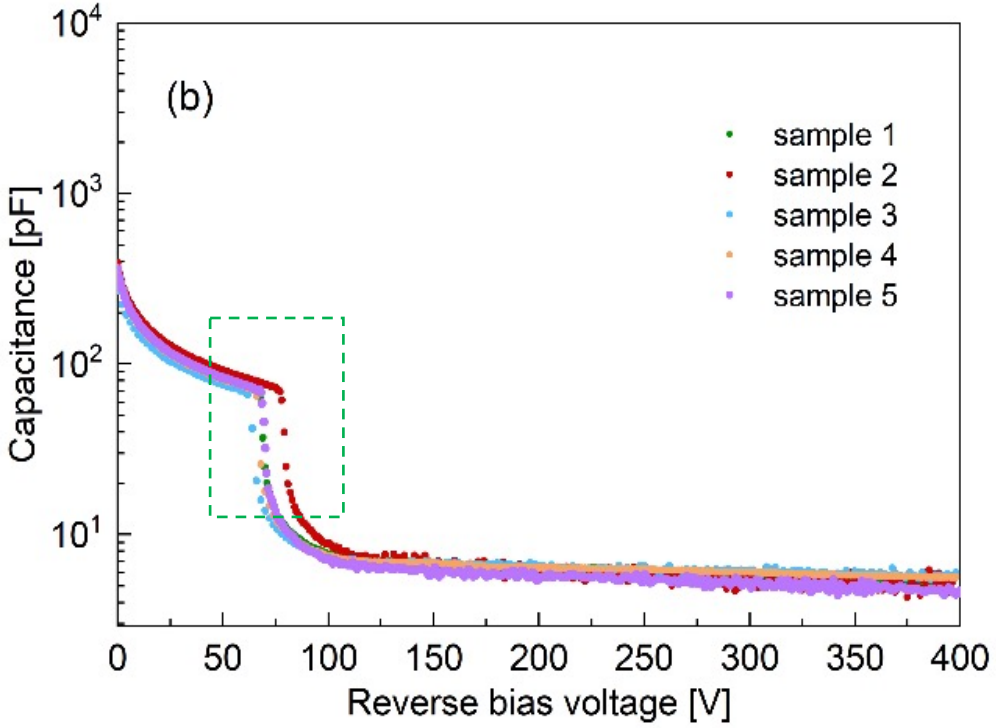
- Simulation of 4H-SiC LGAD has time resolution of 35ps
- Better than 4H-SiC PIN devices (94 ps)

RASER * https://pypi.org/project/raser/

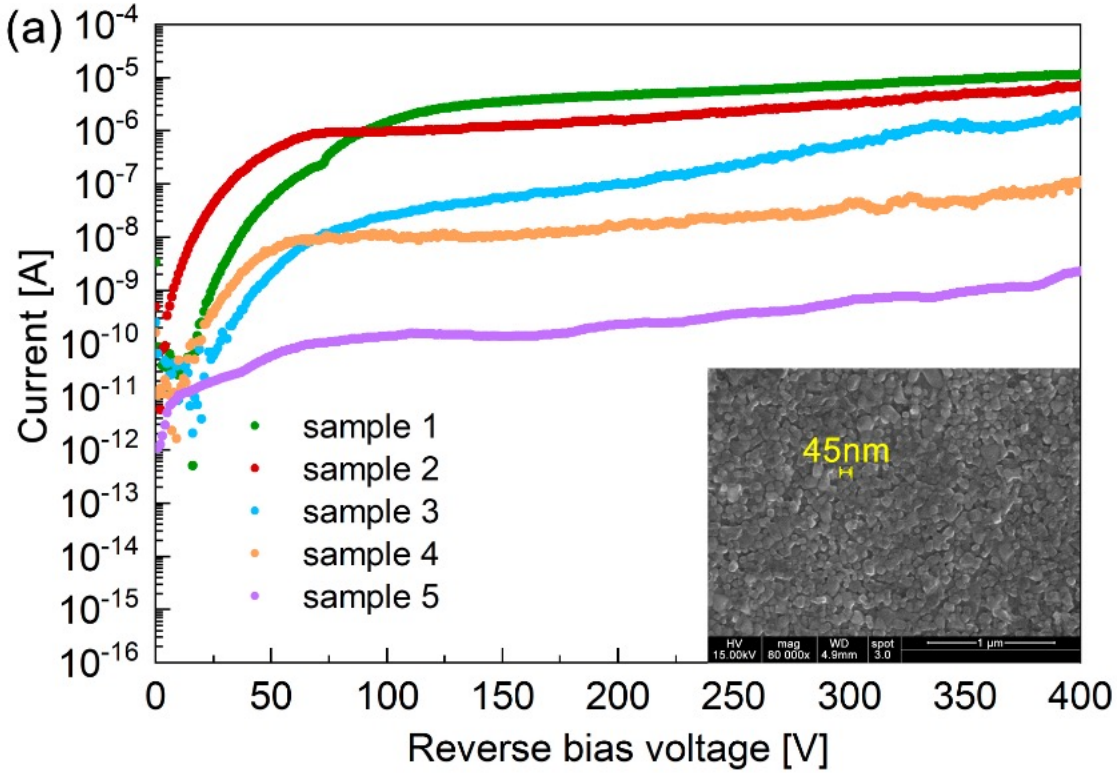
SICAR1- IV & CV properties

Design requirement of LGAD： $V_{GL} < V_{FD} < V_{BD}$

Operating voltage： $V_{FD} \sim V_{BD}$

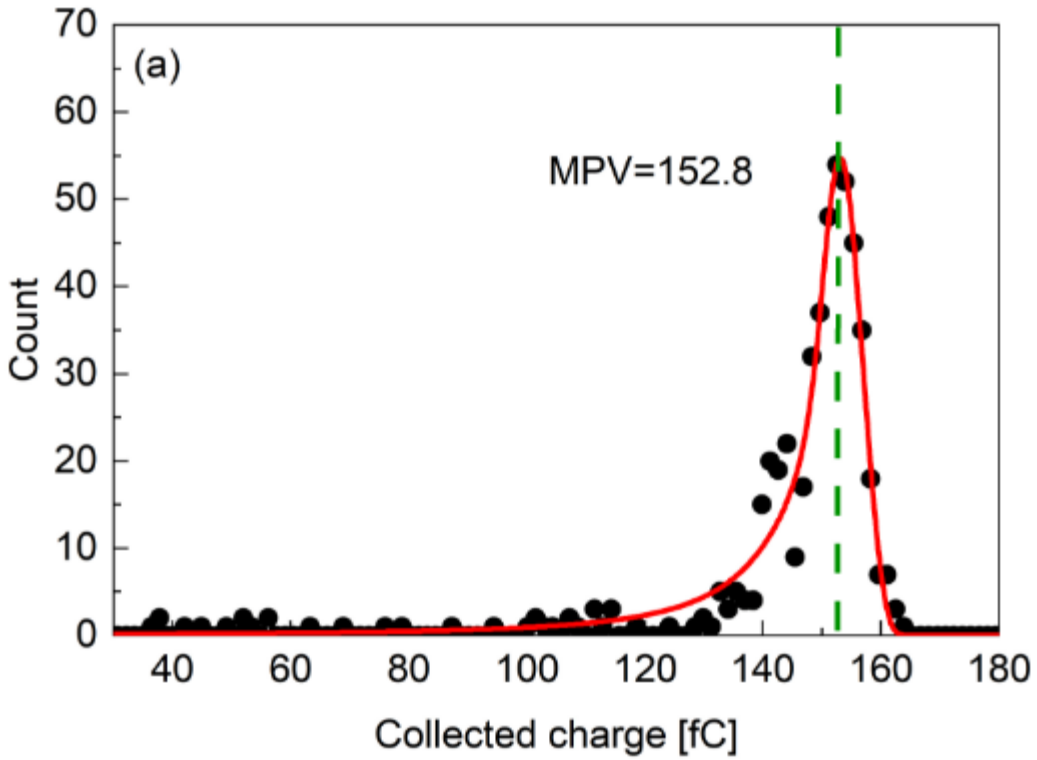


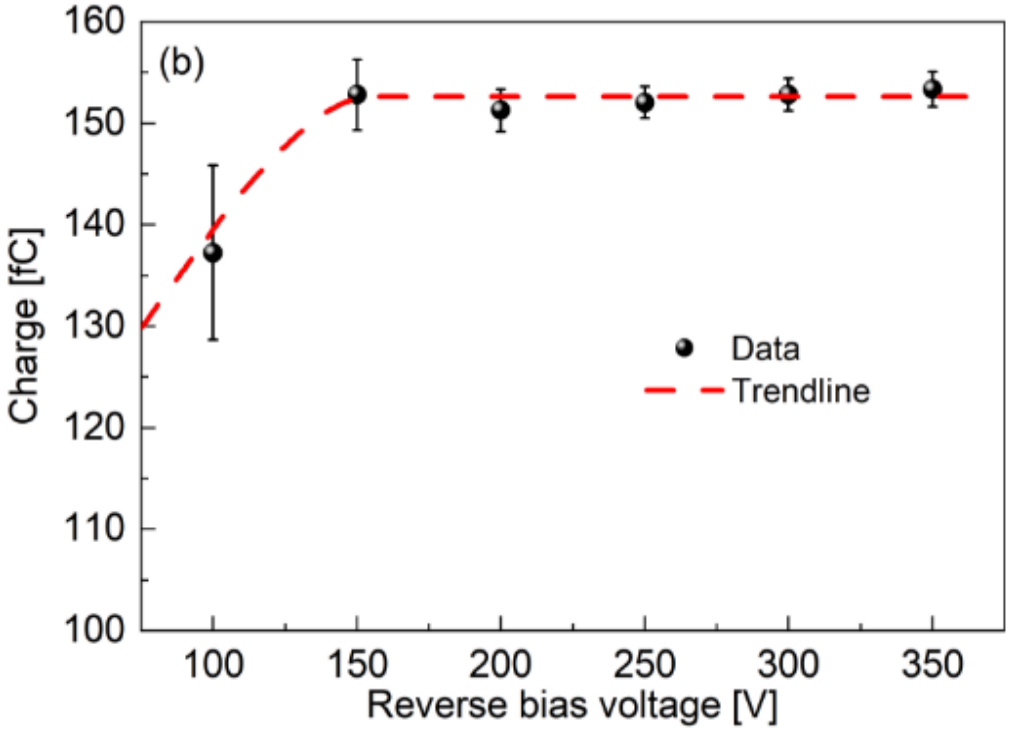
- V_{GL}~ 75V
- V_{FD} ~ 350V



- Leakage current can reach ~nA
- Breakdown voltage > 400V

SICAR1- charge collection with α particle





- Charge collection reached 150 fC @150V
- Saturation reached around 150 V

https://arxiv.org/abs/2405.18112

Proposal of SiC AC-LGAD Timing Detector

Challenges of SiC for high spatial resoluiton

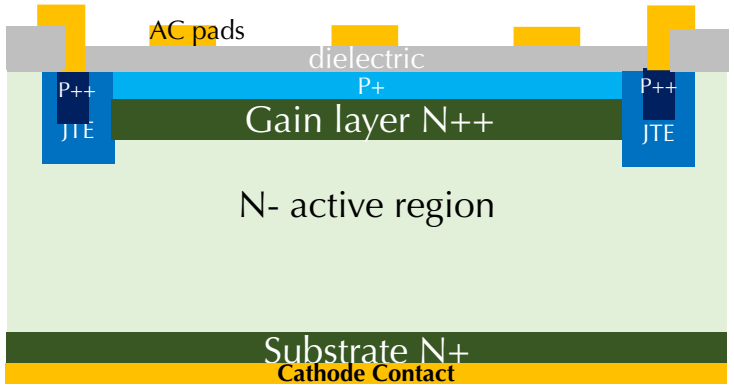
- Goal: Improve the spatial resolution while maitaining good timing resolusion

- Challenges
  - Terminal etching is more difficult for SiC material
  - The reduction in pixel size exacerbates the difficulty of etching
  - The position resolution limit of the DC-coupling detector is more than 10um

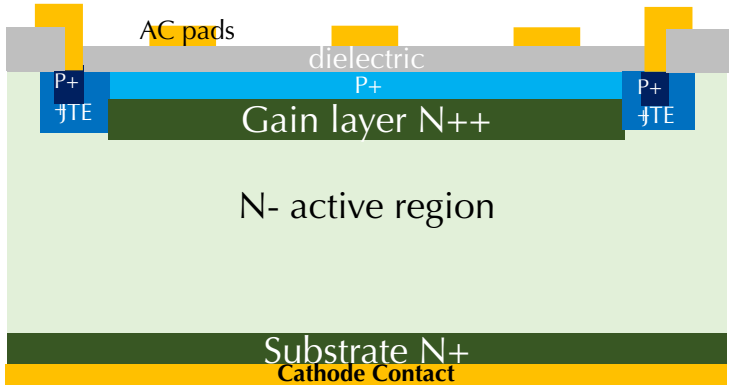
Advantages of AC-coupled LGAD

- Can achieve same level of spatial resolution with larger pixel size
- Only need lower doping concentration without ohmic contact
- Only required etching of a protective ring structure around the whole pixel array
- Fill factor ~ 100%
- Can reach better spatial resoluion
- Potential higher radiation hardness with SiC

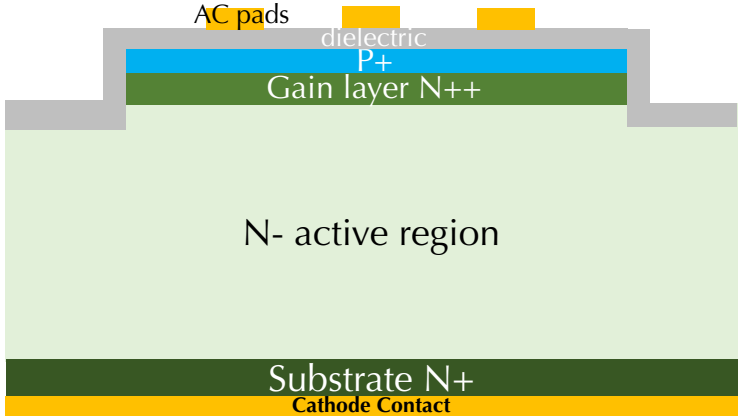
Structure of AC-LGAD SiC



JTE injection depth is difficult to reach more than 700nm

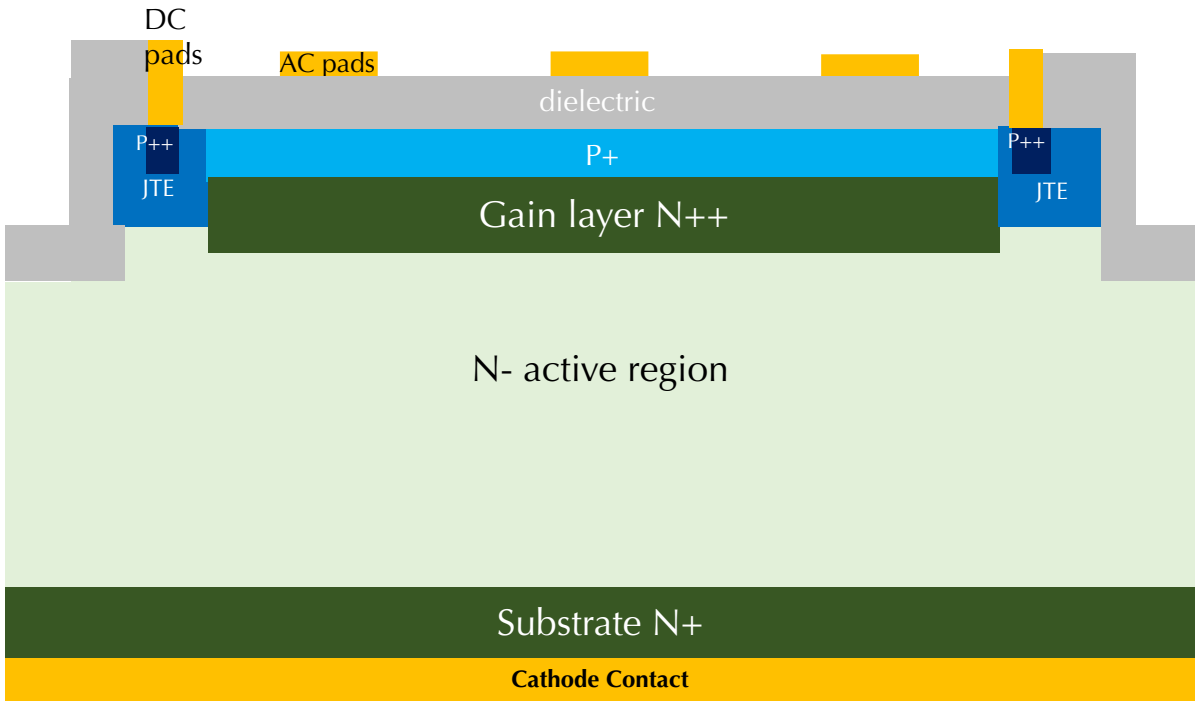


JTE junction: The depth is not enough



Etching termination: No DC-electrodes

Proposed structure of 4H-SiC AC-LGAD



Termination：Etching combined with JTE

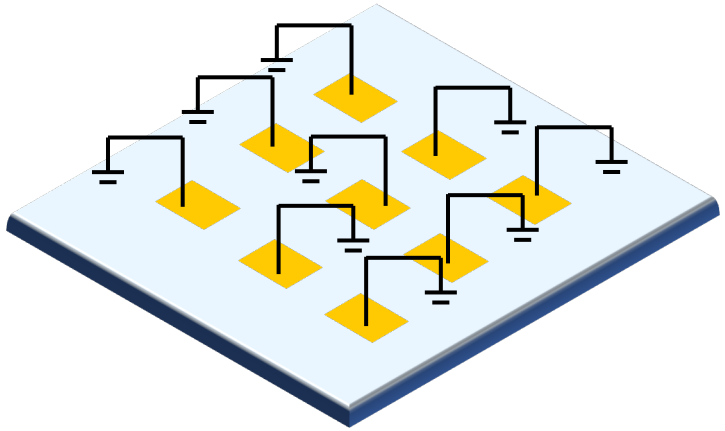
- Reduce leakage current
- Avoid premature breakdown
- Improve carrier collection efficiency

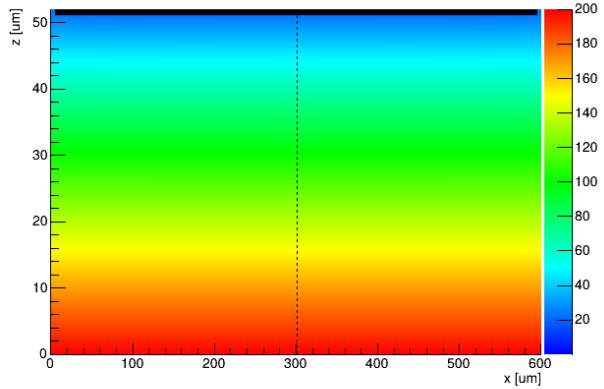
Etching termination outside the JTE termination

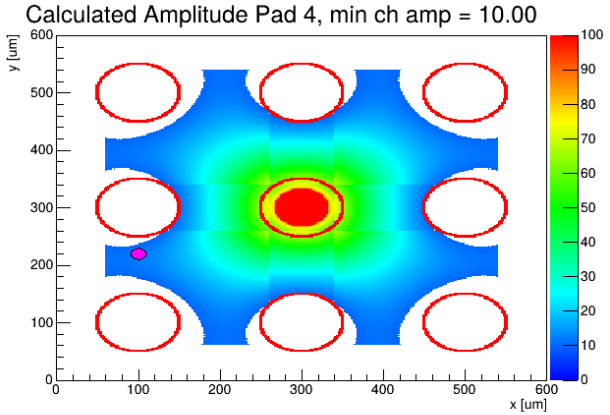
Sen Zhao

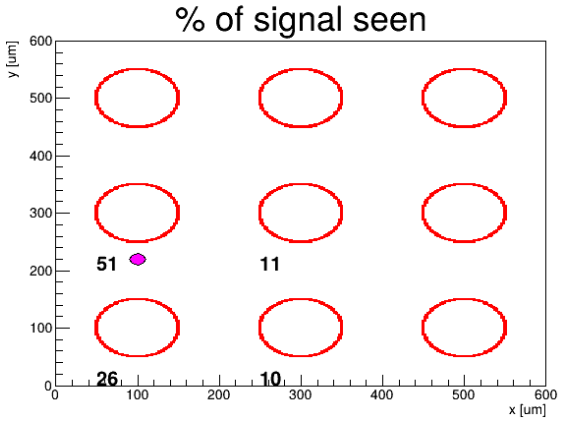
Signal response simulation of 4H-SiC AC-LGAD

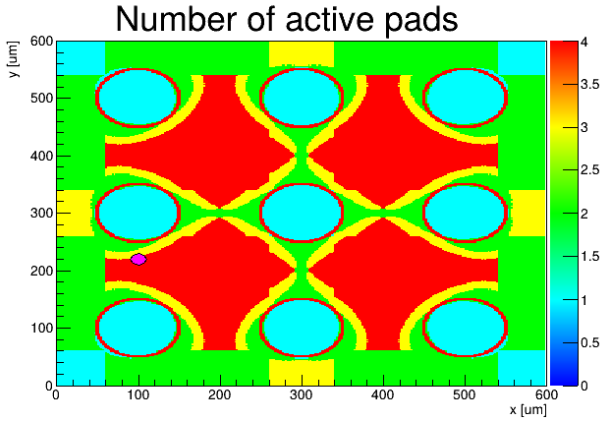
- Simulate the signal response of 4H-SiC under LASER using WF2
  - (4-600nm)/Alpha(5MeV)
- Parameter:
  - full depletion: 150V
  - operating voltage: 200V











- Preliminary result indicates positive AC-LGAD behavior for 4H-SiC

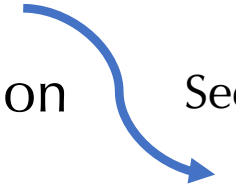
Preliminary Milestones

- Device design and fabrication
  - Gain layer and JTE optimizaion
  - Resistive layer and Capcitive layer optimizaion
  - Simulation study
- Device characterization
  - IV, CV, TCT, alpha, MIPs
- Spacial and Temperoal resolusion
- Proton/Neutron irradiation
- Beam Test with ASICs

More detailed milestones and deliverables with be discussed within WG6 in the next few months

Participants and preliminary activities

- Already interested institutions with topics of interest
  - IHEP: Device design and fabrication
  - Jilin University / Shandong IAT: Software development
  - Dalian University of Technology: Device characterization
  - Ludong University: Device characterization
  - IMECAS: Device characterization
  - JSI: Neutron irradiation
  - Oxford: Device characterization
  - CERN: NIEL studies
  - Nikhef: Beam telescope studies
- Not covered activities
  - AC-coupled readout board for SiC-LGAD
  - Proton irradiation
  - Defect characterization



See talk in the afternoon:

Development of Simulation Software - RASER

Collaborative work

- WG2, 3, 5: characterization of irradiated and non-irradiated devices
- WG4: modelling of radiation damage
- WG8: dissemination and outreach

- Potential synergies with similar projects
  - RD50: SiC-LGAD, SiC-LGAD-TPIX
  - TCAD Radiation Damage Model for 4H-SiC
  - Defect characterization on 4H-SiC sensors
- Converge on a WP3 subproject with 4D-tracking

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