Charge Collection Study of SiC-LGAD – SICAR1

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On behalf of RASER team

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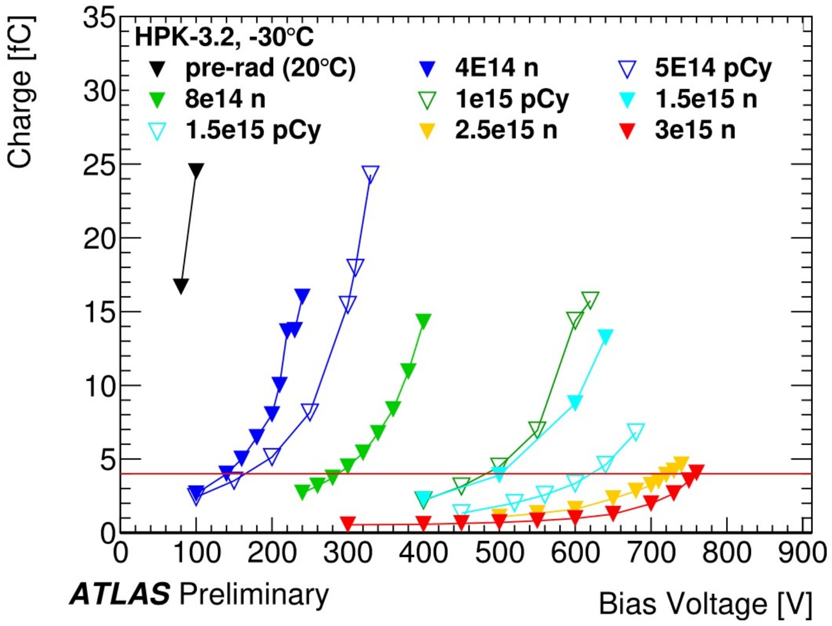
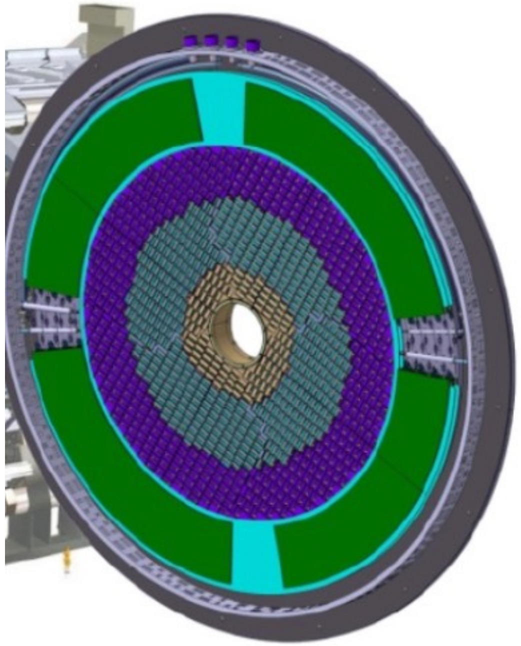
Last (43rd) RD50 Workshop

Silicon Detector Liminations

- Silicon detector works but with some limitations:
  - Not radiaiton hard -> need to change the inner layers
  - High leakage current after irradation -> Need to operature with cold temberature

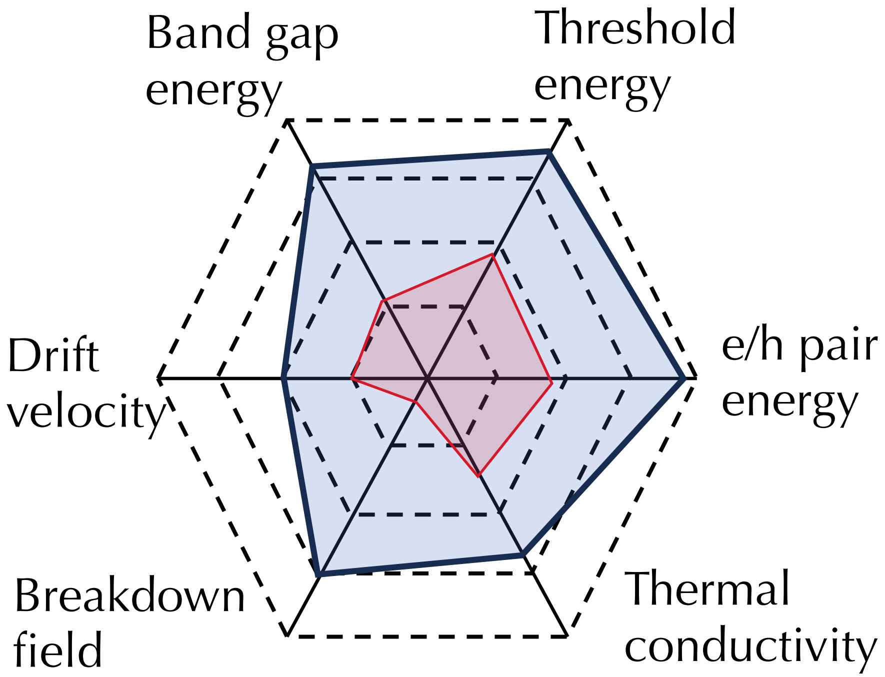


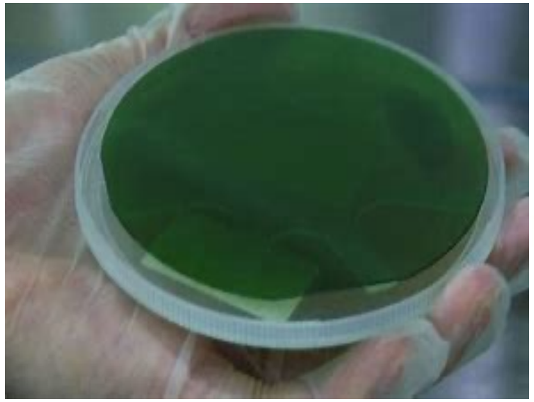


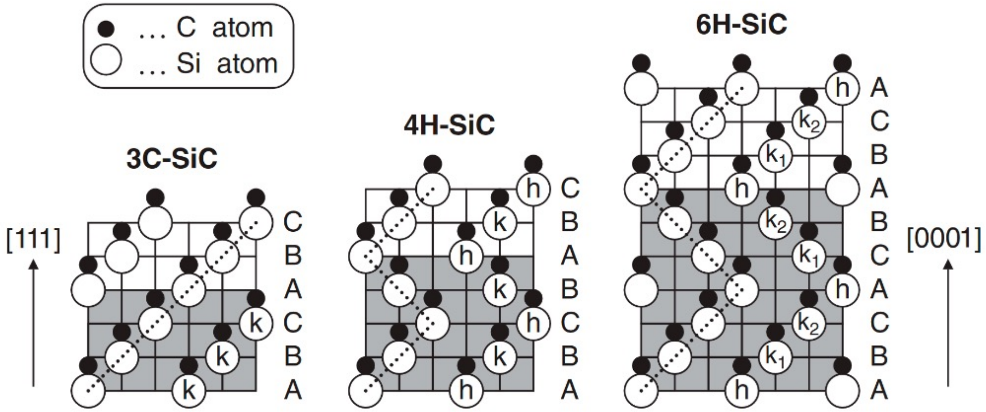
evaporative cooling system of ATLAS inner detector

SiC as potential particle detector

Physical Parameter	Si	4H-SiC
Band gap energy [eV]	1.12	3.26
Thermal conductivity [W/K·cm]	1.5	4.9
Breakdown field [MV/cm]	0.3	3.0
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
Mean ionization energy for e/h pair (eV)	3.6	7.8
Atomic shift threshold energy(eV)	13	22







- ✓ Radiation resistant
- ✓ Low leakage current
- ✓ High working temperature
- ✓ High time resolution

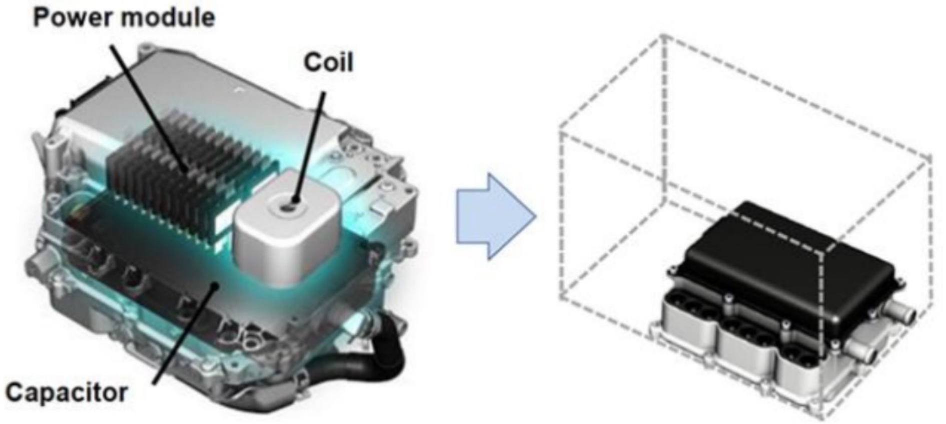
SiC Market in China

- China's 14th Five-Year Plan (2021-2025):
  "specifically aims for breakthroughs in
  wide-band gap semiconductors (e.g., silicon carbide) … "

- 4413 companies in China since 2022 (source)

- Widely used in the field of power electronics
  - New energy vehicles, photovoltaics, charging piles, UPS …

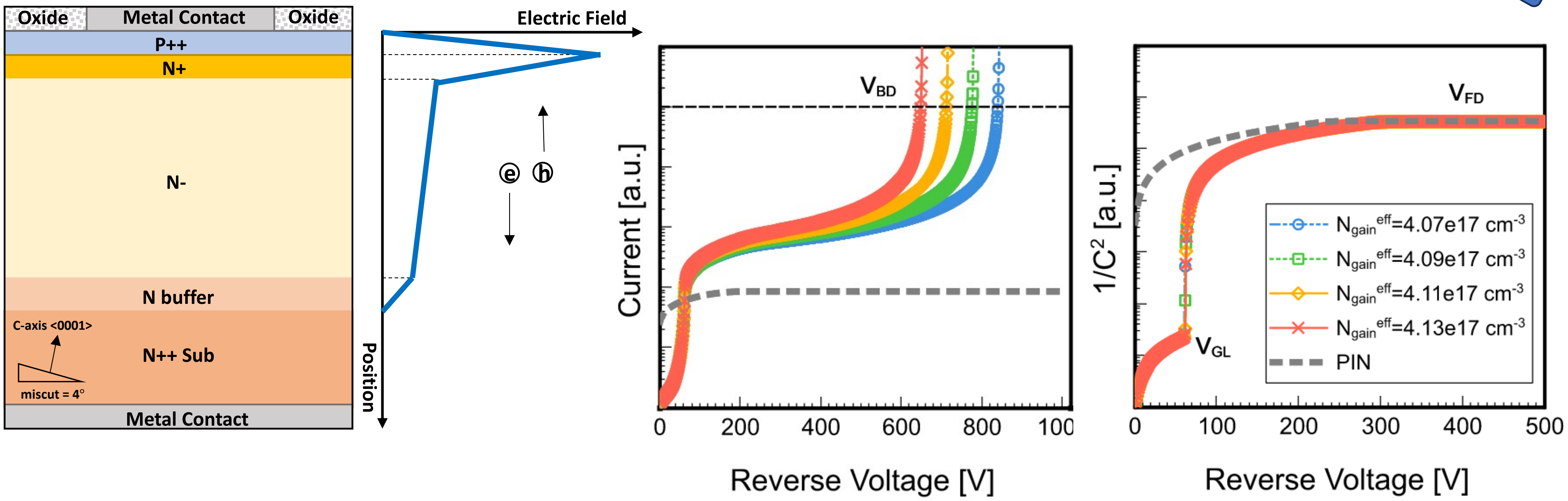
- High-temperature, high-frequency, high-power, high-voltage devices
  - Power control unit (PCU)
  - inverter
  - DC-DC converters
  - Car charger



Goal: 80% less volume

Design and Simulation of 4H-SiC LGAD

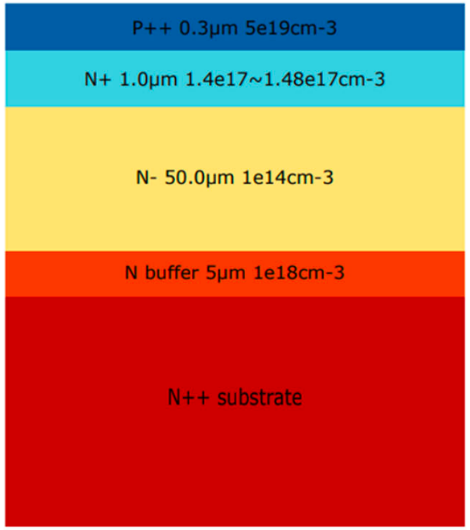
TCAD

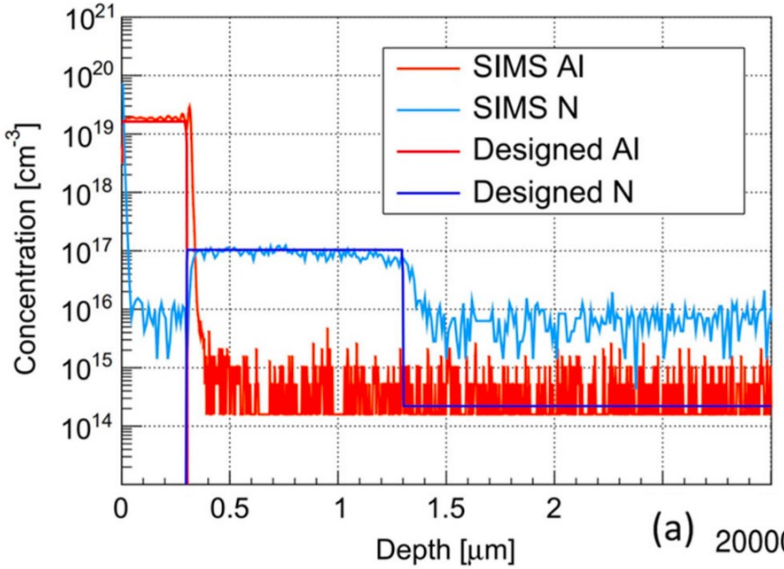


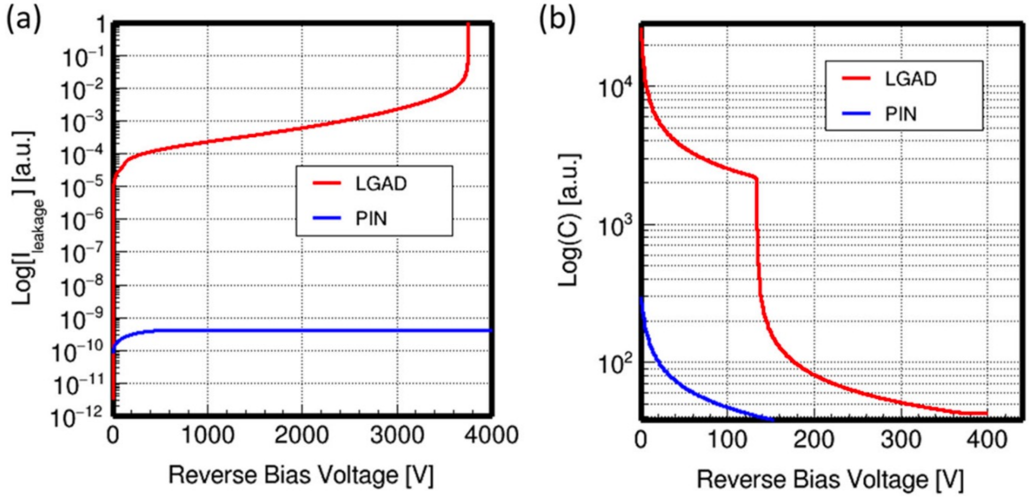
- "Triangle" Electric Field determined by gain layer doping concentration or depth
- Could reach full depletion less than 500V, with gain larger than 10

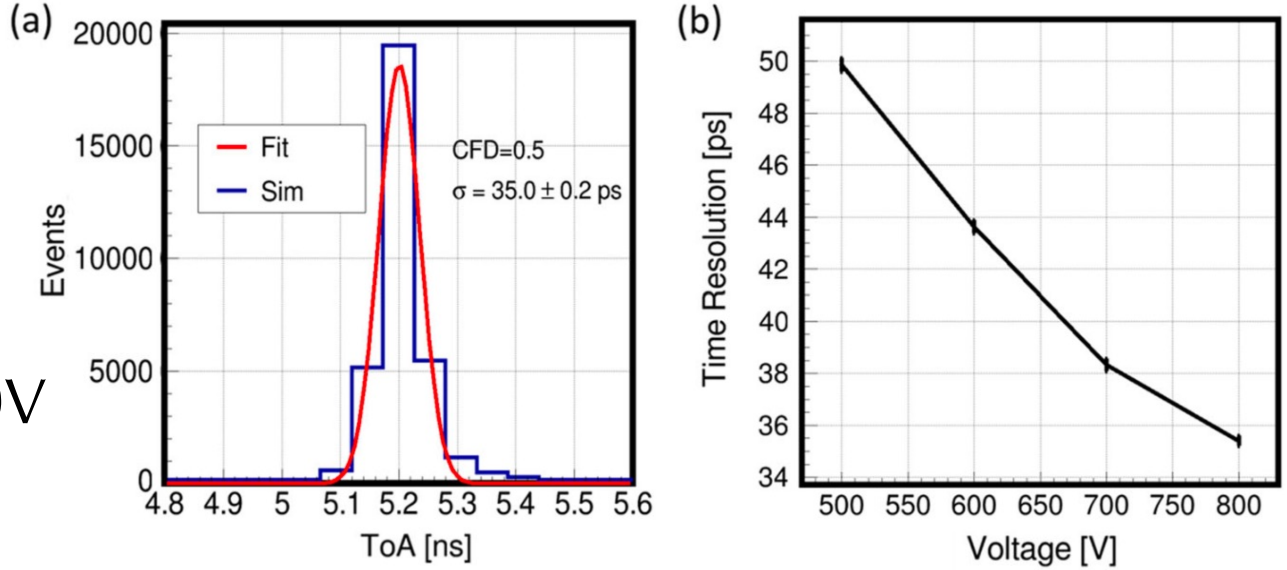
https://doi.org/10.1016/j.nima.2023.168677

Design and SIMS of SICAR1







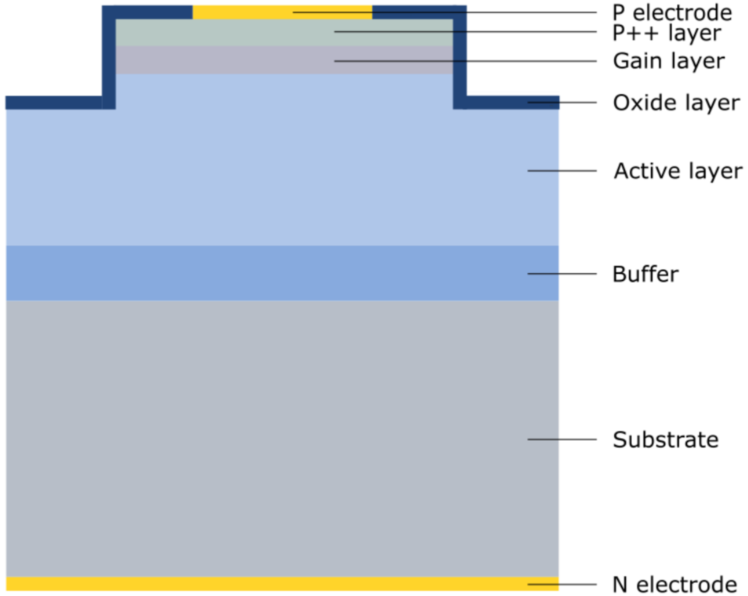


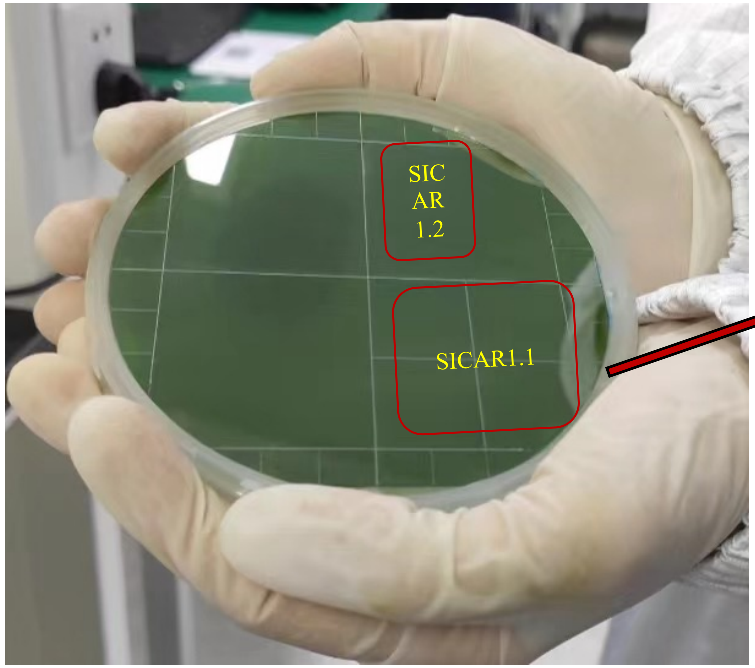
- Simulation with RASER* indicates full depletion of 400V
- With a timing resolution of 35ps @800V

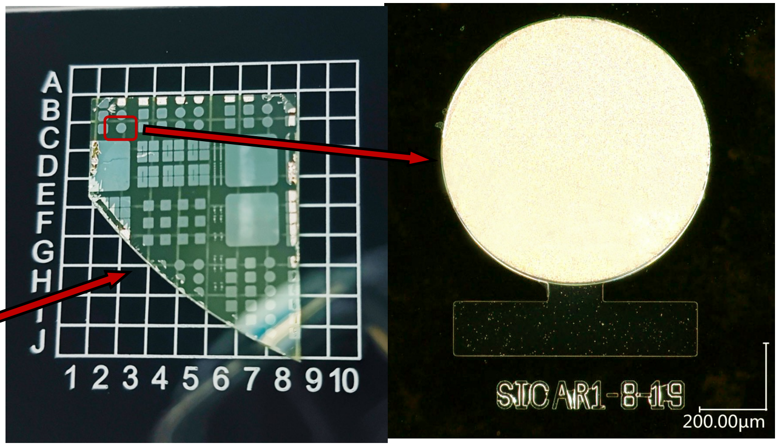
* https://pypi.org/project/raser/

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

4H-SiC LGAD（SICAR1）

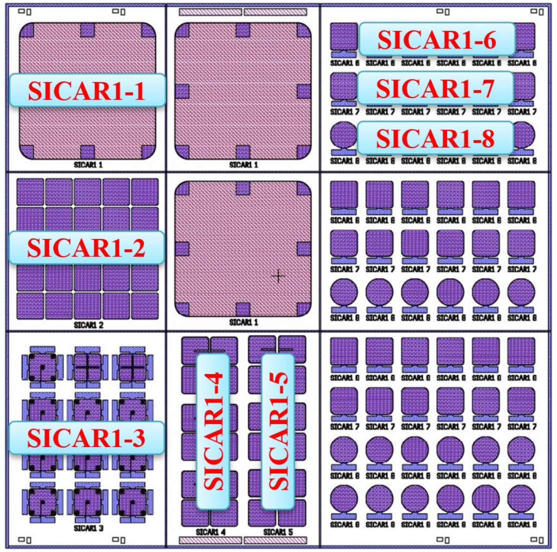






SICAR1

42nd RD50 Talk



- The effects of size, shape and boundary fillet on leakage current, charge collection and time resolution
- The effects of detection range and spacing of detector array

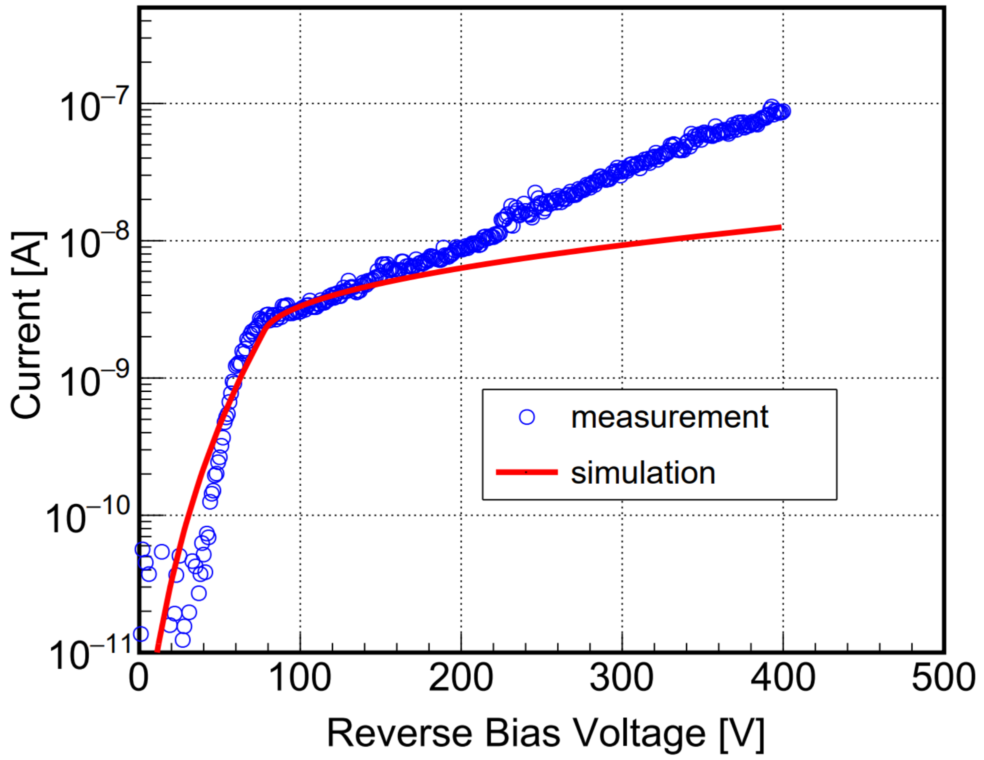
The first version of SICAR, the first flowsheet, SICAR1.1.8 has been successfully manufactured

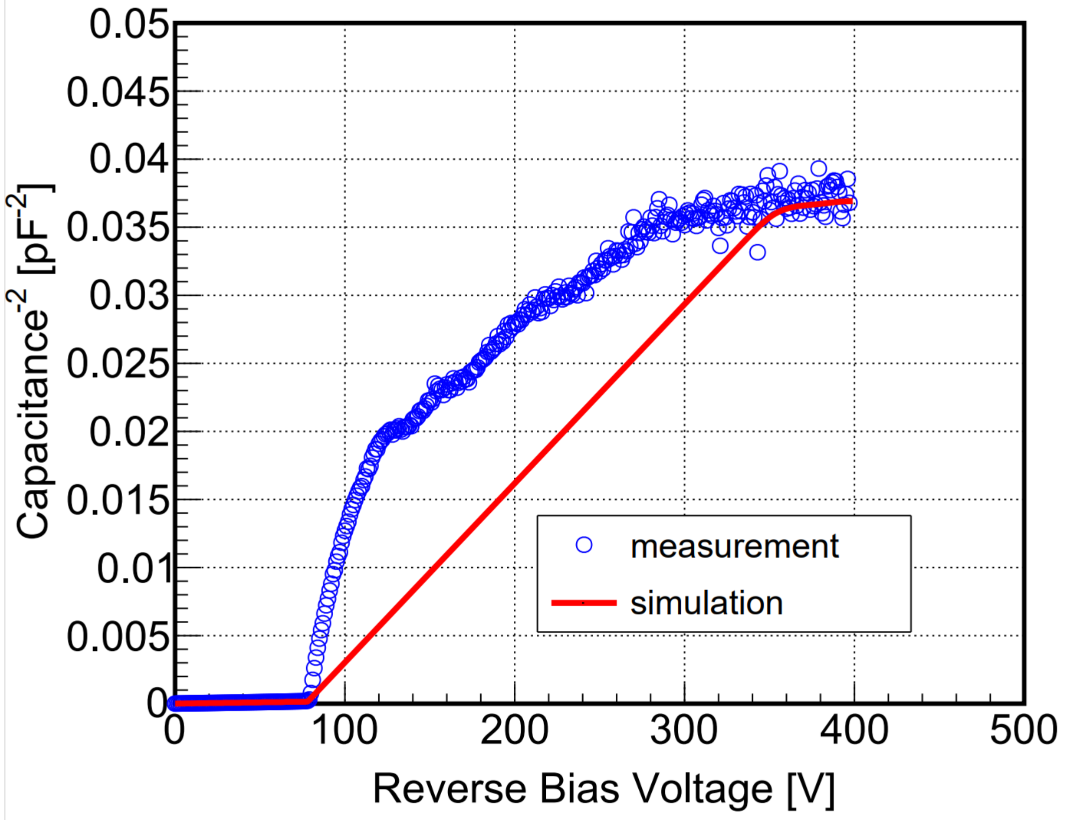
I-V and C-V characteristics

RASER

- I-V: $V_{BD} > 400\ V$, $I_{leakage} \sim 87 nA@400\ V$
- C-V: $V_{GL} \sim 80\ V, V_{FD} \sim 350\ V$

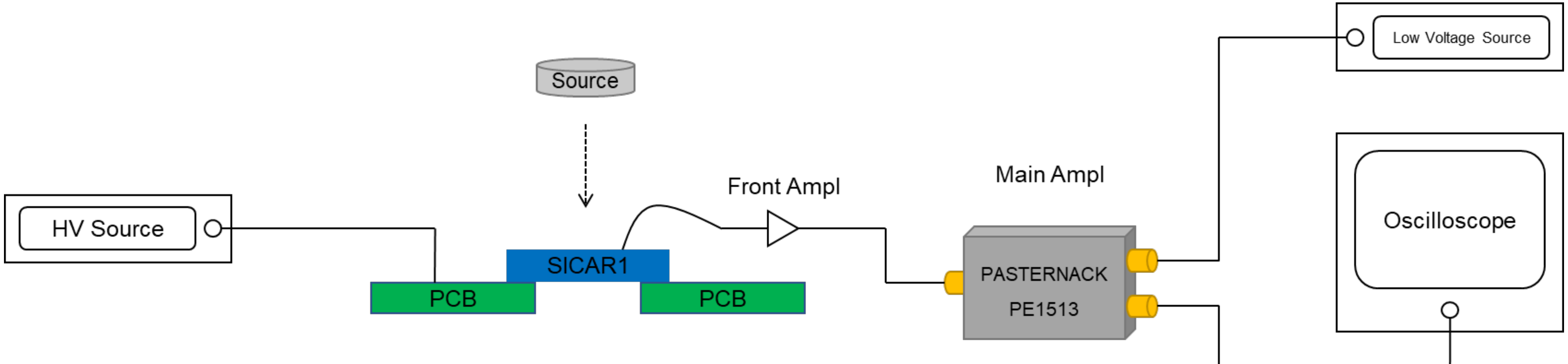
Due to the Bias Adapter, the DC bias voltage is measured in a range of ±400 V at room temperature





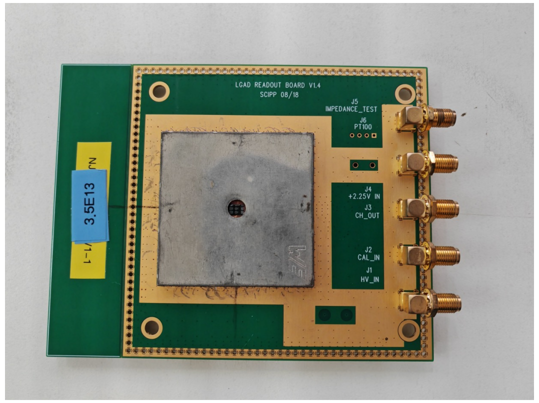
- The operate voltage of SICAR1.1.8 is set as 350V~400V

The measurement of charge collection efficiency



Schematic diagram of the charge collection efficiency measurement system

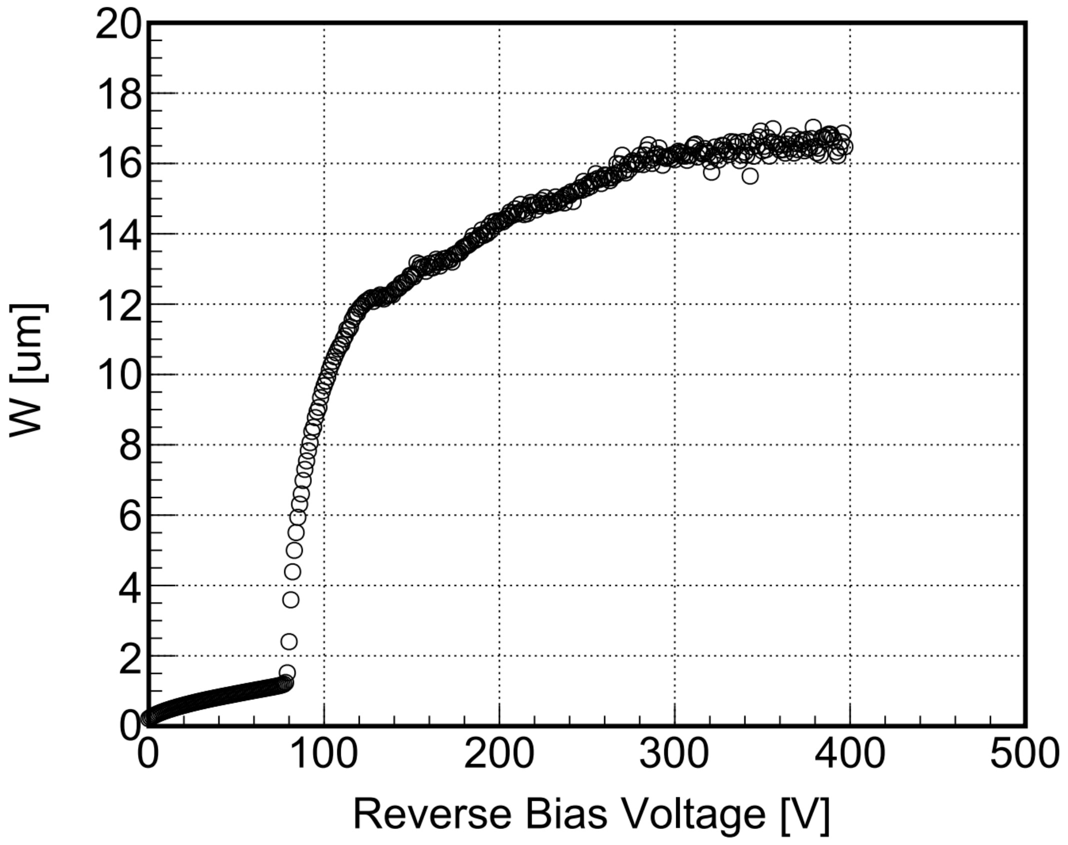
- ◆ Radiation source: Am-241(α source)
- ◆ Readout board: UCSC
- ◆ Main amplifier: 20 dB
- ◆ Sampling rate: 10 Gsa/s

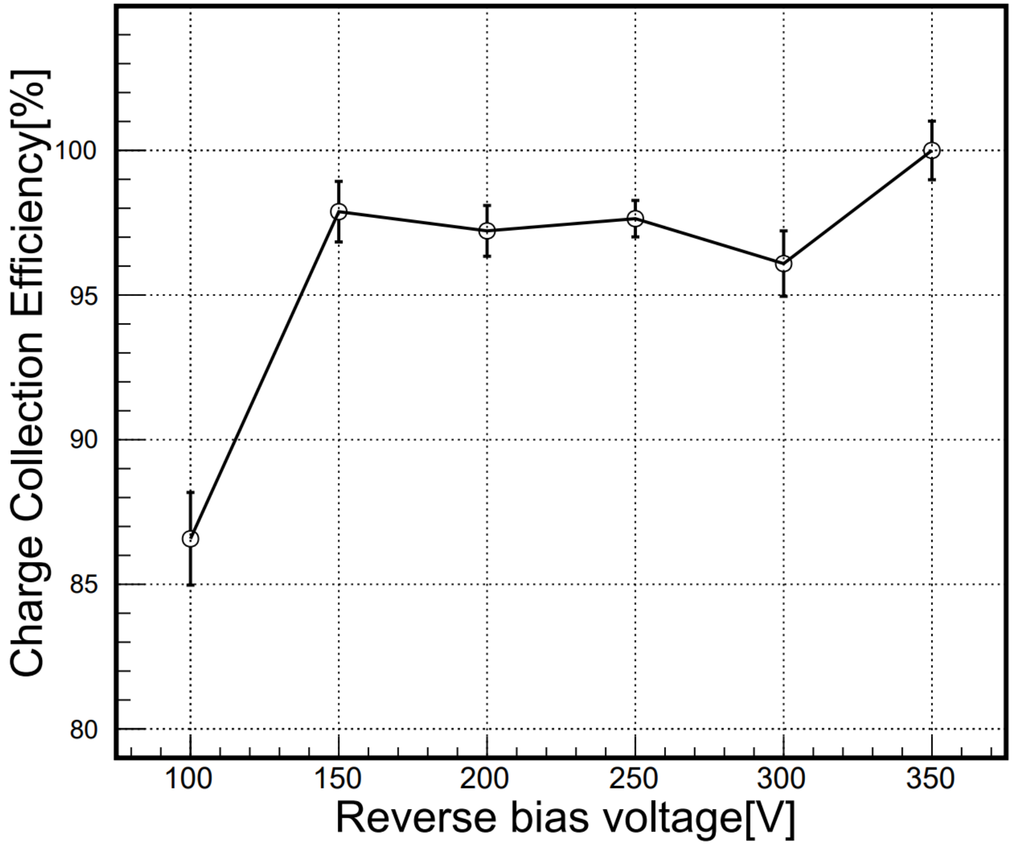


measure at room temperature

Preliminary results of charge collection efficiency

- Setting the collected charge at 350V to 100 %
- The charge collection efficiency is up to 98%@ 150V





Summary and plan

- ✓ Designed 4H-SiC LGAD with a gain layer thickness of 1um and a doping concentration of 1.4e17 cm^{-3}
- ✓ The gain layer depletion voltage 80 V, full depletion (?) voltage 350 V, leakage current is about 87nA@400 V
- ✓ Charge collection efficiency is up to 98%@ 150V

Plan:

- ☐ Perform beta test with timing, investigate the effects of array devices
- ☐ Optimize the process and layout for SICAR1.2, with strip and pixel layout
- ☐ Manufacture SiC PIN devices to compare with SiC LGAD

Goodbye to RD50

- It's was great to join RD50 since 2018

Thanks for all your kind support!

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Published Papers (13 papers)

https://www.mdpi.com/journal/sensors/special_issues/RSDMPA

- Looking forward to more great ideas at DRD3!