Prototype of SiC-LGAD Detector

Xin Shi

On behalf of Participating Institutions

5 December 2024

Work Package Description

- Pixelated SiC LGAD device with timing and position capabilities has potential to address the 4D tracking in extreme conditions of future collider experiment
- Fabricate DC and AC LGAD SiC device with pixelated structures
- Characterize spatial and temporal resolution before and after irradiation up to 1e17 n_{eq}/cm^2
- Investigate SiC-LGAD properties after high fluence irradiation with correlation of the detector performance

DRD3-PROJECT-2024-002: https://cds.cern.ch/record/2907318

Participating Institutions

Country	Collaborating Institution	Institution Code	Contact
China	IHEP Beijing	IHEP	Xin Shi
Austria	OEAW-HEPHY	HEPHY	Thomas Bergauer
China	Jilin University	JLU	Weimin Song
China	Shandong Institute of Advanced Technology	IAT	Suyu Xiao
China	Dalian University of Technology	DLUT	Hongwei Liang
China	Ludong University	LDU	Zheng Li
China	IMECAS	IME	Manwen Liu
Slovenia	Jožef Stefan Institute	JSI	Gregor Kramberger
UK	University of Oxford	Oxford	Daniela Bortoletto
Switzerland	CERN	CERN	Michael Moll / Susanne Kuehn
Netherlands	Nikhef	Nikhef	Kazu Akiba
Israel	Weizmann Institute of Science	WIS	Noam Tal Hod

Country	Collaborating Institution	Institution Code	Contact
Romania	NIMP Bucharest	NIMP	Ioana Pintilie
Czech	Czech Technical University FNSPE	FNSPE	Peter Svihra
Czech	Institute of Physics of the Czech Academy of Sciences	FZU	Marcela Mikestikova
Spain	IMB-CNM	CNM	Giulio Pellegrini
Spain	IFCA	IFCA	Ivan Vila Alvarez
Spain	CNA Serville	CNA	Maria del Carmen Jimenez Ramos
UK	The University of Manchester	Manchester	Alexander Oh
Italy	INFN Torino	Torino	Valentina Sola
Italy	INFN Perugia	Perugia	Francesco Moscatelli
Italy	FBK	FBK	Giovanni Paternoster
Greece	NTU Athens	NTUA	Ioannis Kopsalis
Italy	INFN Firenze	Firenze	Mara Bruzzi
Israel	Tel Aviv University	TAU	Arie Ruzin

25 insitutions from 12 countries

Deliverables and Key questions

Number	Title	Description	Start date	End date	Institutions
Di.1	Fabrication of PIN Device	Fabrication of SiC-PIN device Fabrication of the SiC-AC-PIN device	11/2024	5/2025	IHEP, CNM, FNSPE
Di.2	Fabrication of LGAD Device	Fabrication of SiC-DC-LGAD device Fabrication of SiC-AC-LGAD Avalanche gain to 10-50	6/2025	12/2025	IHEP, CNM, FNSPE, Nikhef

- How to effectively improve charge collection efficiency and time resolution?
  - Thickness and doping concentration of epitaxial active region and gain layer
  - Advantages and disadvantages of epitaxial growth and ion implantation of the gain layer
  - Effect of etched terminal and JTE terminal on device performance
  - Effective formation of P-type Ohmic contact
- Influence of the size and pitch of strip and pixel devices on device performance (AC/DC)

Deliverables and Key questions

Number	Title	Description	Start date	End date	Institutions
Di.3	Electronics Readout	Development of the readout board and ASICs	6/2025	12/2025	Manchester, NTUA

- Readout Electronics tuned for SiC device
  - Improve signal-to-noise ratio
  - Impedance match
- Single-channel DC/AC readout board
- Multi-channel DC/AC readout board
- Radiation hardness
- ASICs and FPGA dev with other projects …

Deliverables & Key questions

Number	Title	Description	Start date	End date	Institutions
Di.4	Characterization	Characterization of IV, CV, Charge collection, time resolution test and spatial resolution test	1/2026	12/2026	IHEP, HEPHY, DLUT, IAT, JLU, LDU, IME, CNM, CERN, Oxford, WIS, Nikhef, IFCA, CNA, Torino, Perugia, FBK, NTU, Firenze, TAU, FNSPE, FZU
Di.5	Irradiation	Irradiate SiC-LGAD devices above 1×10^{17} n_{eq}/cm^2	1/2027	6/2027	JSI, HEPHY, FZU, NTUA, CNA

Irradiation type

- Neutron irradiation
- Proton irradiation
- Heavy ion irradiation
- Gamma ray

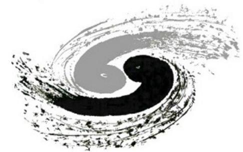
Deliverables and Key questions

Number	Title	Description	Start date	End date	Institutions
Di.6	Study of Irradiation Defects	Analysis of device defects caused by different types of irradiation	1/2027	6/2027	IHEP, HEPHY, CERN, NTU, NIMP, Firenze, TAU, FZU

- Defects characterization
- Effects of different types on 4H-SiC LGAD
- Understanding of temperature dependence, annealing on irradiation defects
- Can gain be used to compensate for the decrease in CCE caused by irradiation
- NIEL/TID

- Effective SiC simulation software and models
  - Improve the SiC physical property model
  - Improve SiC irradiation defect model

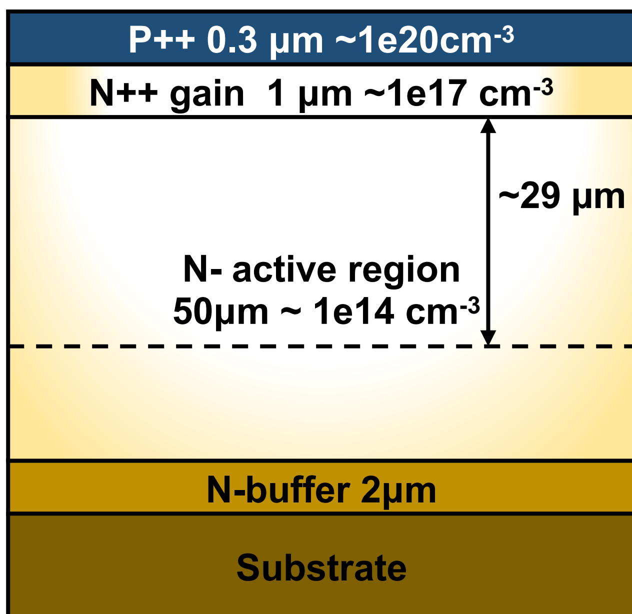
4H-SiC LGAD (SICAR) progress at IHEP



SICAR1

- Gain layer doping concentration ~1e17cm^{-3} , ~1 μm thick
- Active region doping concentration ~1e14 cm^{-3} thickness ~50 μm
- The full depletion depth reaches ~ 29 μm
- Ohmic contact Ni/Ti/Al (50/15/80nm, Annealing Temperature 1050°C)

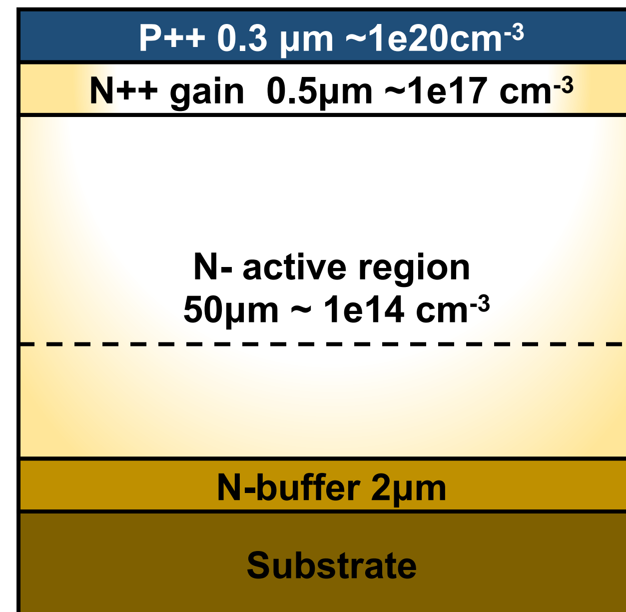
SICAR1 epitaxial structure



SICAR2 (In progress)

- Optimization of the concentration and thickness of the gain layer to enhance the Gain factor
- Gain layer with doping concentration 4e17cm^{-3} ~ 5e17cm^{-3}
- thickness of 0.5 μm to enhance the gain~20

SICAR2 epitaxial structure



Refers to Sen Zhao's talk

Device progress at FNSPE

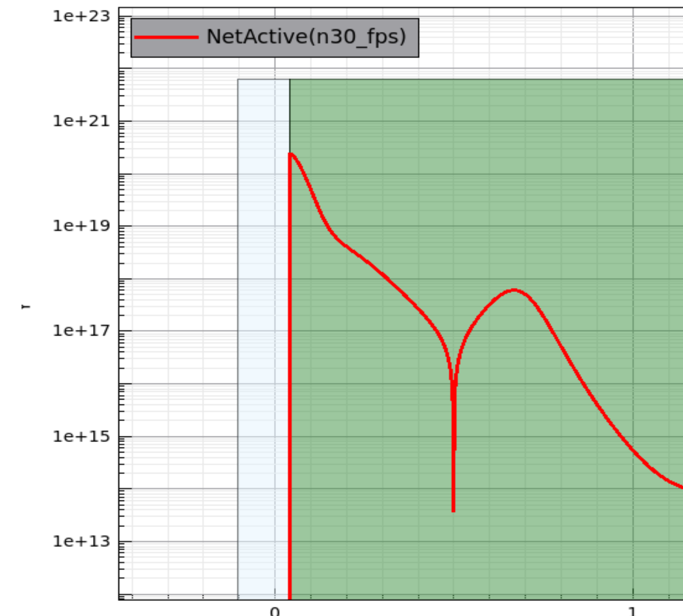
- The substrate wafer is 6″ n-type
  - 4H-SiC with doping conc. ≈ $10^{19}cm^{-3}$
  - N-type epitaxial layer is in the range of 30-100 µm and down to ≈ $5×10^{13}$ cm^{-3}
  - Thick epi and low doping - below 10^{14} cm^{-3} are very challenging to achieve

Epi tool parameter	Description
Chamber type	Horizontal
Silicon precursor	Trichlorsilane
Carbon precursor	Ethen
Dopant	Nitrogen compound*
Heating	Induction
Process temperature	~1630 °C
Process pressure	sub-atmospheric

* *Proprietary information*

- Wafer splits on diodes with and without LGAD layer for evaluation of gain over simple PN diode
  - P+ and LGAD layers were evaluated using DOE splits of implant energy/dose
  - P+: chain implant with energies 30-200 keV, doses 1-8 $×10^{14}$ cm^{-2}
  - LGAD: single implant 950-1250 keV, 1.5-1.8 $×10^{13}$ cm^{-2}

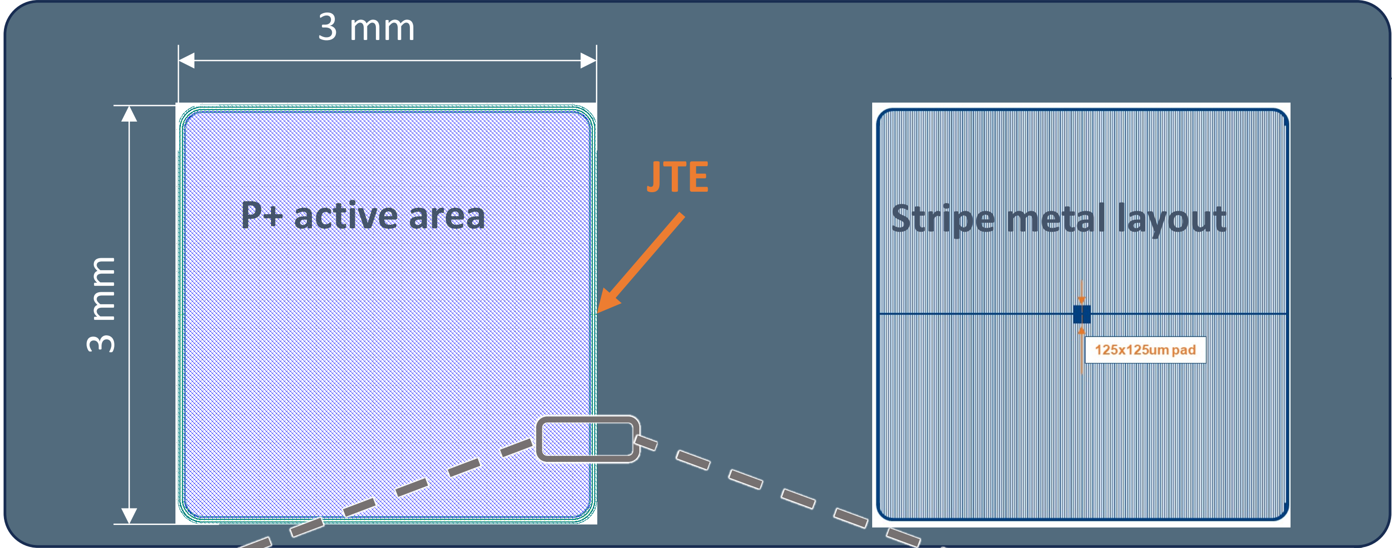
Example of simulated profiles of active structure in LGAD diode

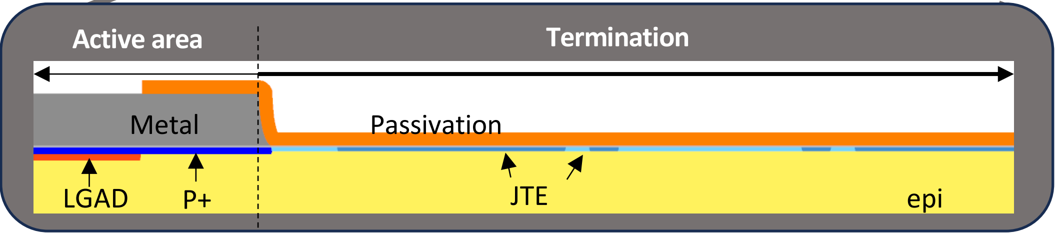


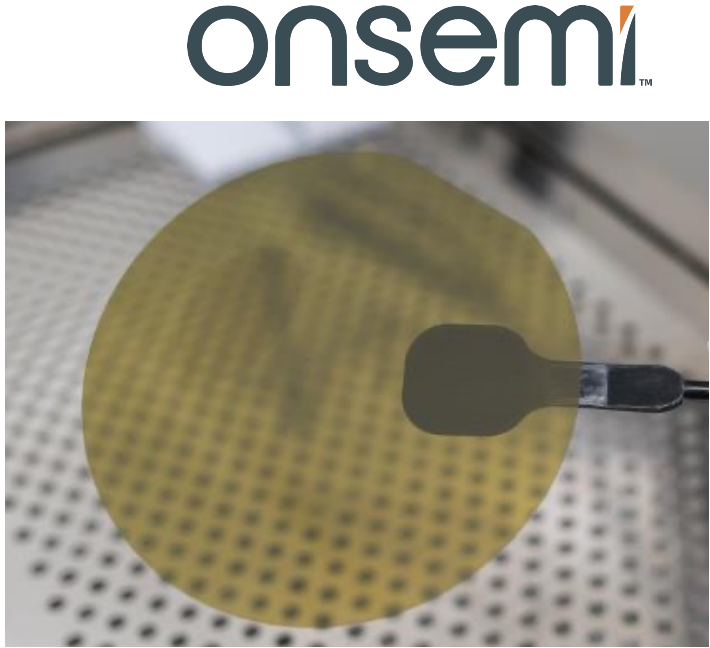
Existing LGADs on SiC

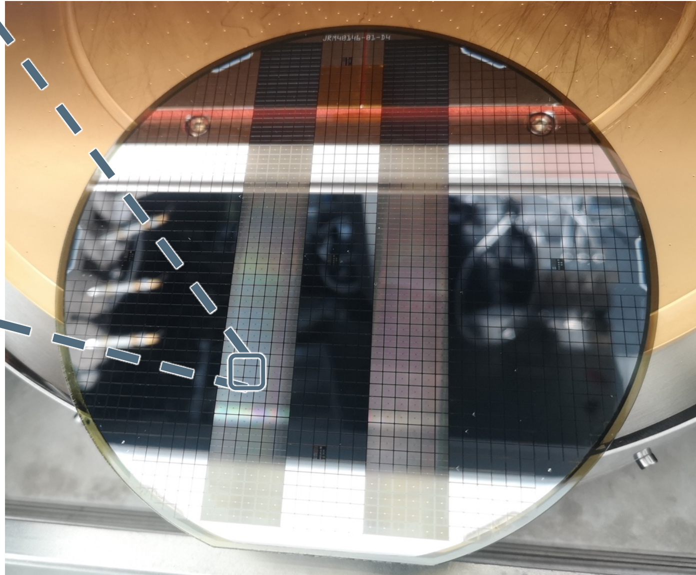
onsemi

- Diode 3 x 3 mm^2 used for R&D
- Already on 3rd iteration of wafers









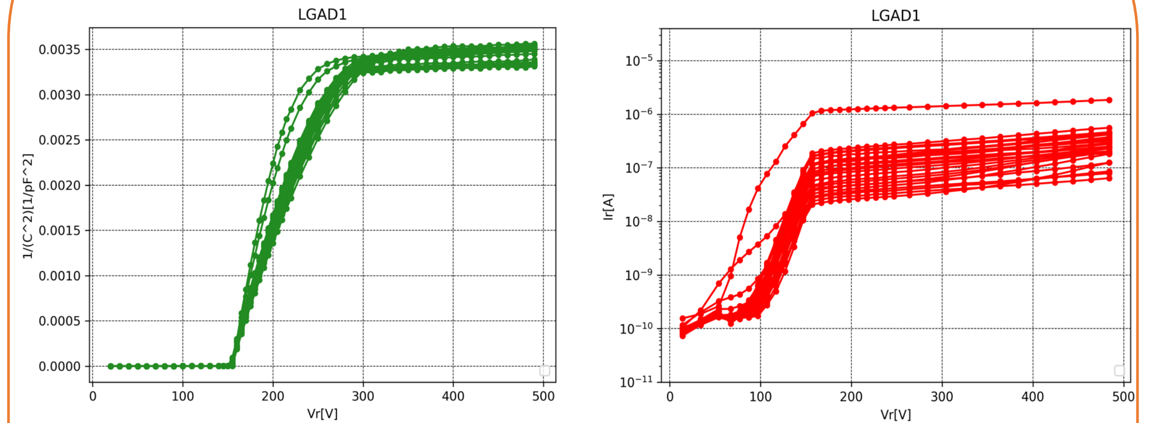
FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

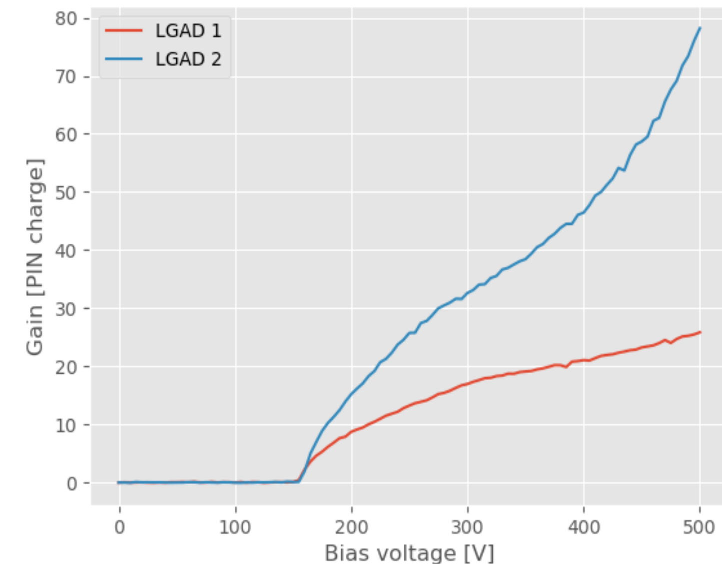
CAPADS FNSPE CTU

Characterisation at FZU and FNSPE

- Stable results of produced diodes
 (IV and CV curves across 20 devices per type)
- Waiting to measure devices after irradiation
- Planning beta source setup for timing

Wafer 19





FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

CAPADS FNSPE CTU

FZU Institute of Physics of the Czech Academy of Sciences

Summary and Plan

- SiC-LGAD Detector as potential candidate for future 4D tracking
- Orgnize regular WP meetings (every other three weeks)
- Will arrange the first sample distribution

Welcome to join us!

drd3-wg6-sic-lgad@cern.ch

Path towards Publication – a proposal

- Two lines with the WP in DRD3
  - Research Goal – defined by the scientifc proposal, common for DRD3 members
  - Funding Agencies (PIs) – publication as corresponding authors + ackonoledgement the Grant number (requested by some countries)
  - Students – need to graduate as first author appeared in the publication (requested by some countries)
- To create collaborateive environment while keeping individual motivated
  1. Express your interest of publication with in the WP meeting (in WG6 case, the SiC session rotated every three weeks)
  2. Present at least one talk during the DRD3 meeting by the first author
  3. Draft the paper and submit to CDS within the WP/WG6 e-group to collect comment and suggestion at least one week
  4. Get approval by WG6 conveinors and propage to DRD3 publication committee
  5. Approved by DRD3 and submit to journal