First generation 4H-SiC LGAD production

and its performance evaluation

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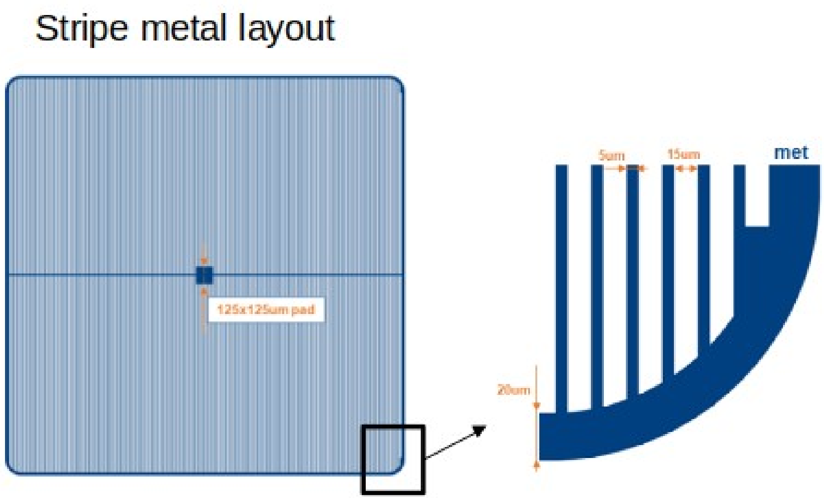
Introduction

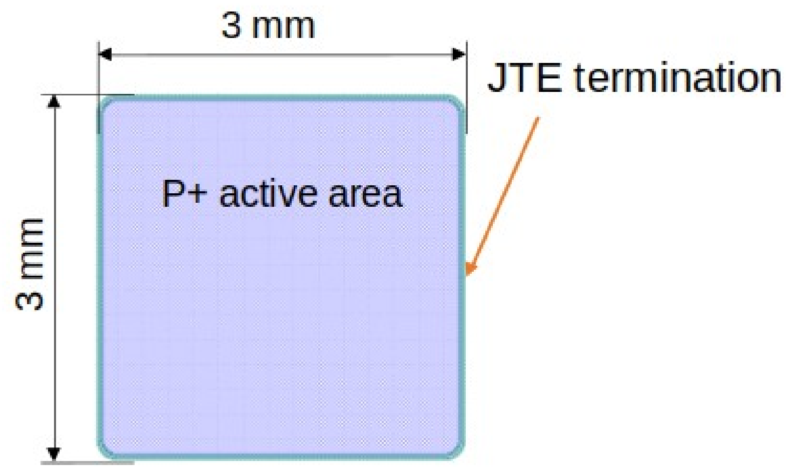
- SiC is an emerging material for semiconductor detectors that became affordable due to advancements in the manufacturing process
- The 3.26 eV wide bandgap results in a lower charge production in the bulk material so the LGAD structure arises as a natural choice
- The radiation tolerance of SiC is assumed to be high; therefore, it could be an optimal detector for high-energy physics

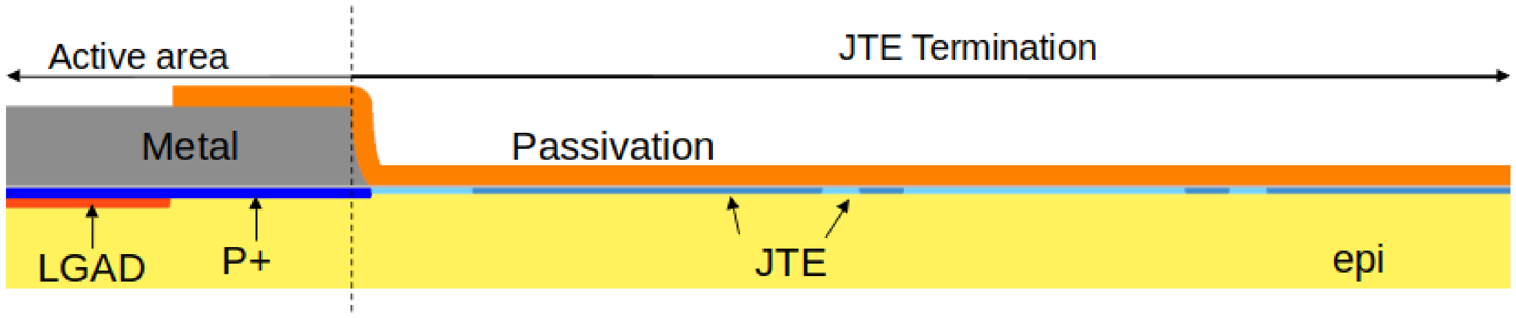
Common project with onsemi (link) and collaboration with the Institute of Physics of the Czech Academy of Sciences (link)

SiC LGAD design

- We have designed 3×3 mm^2 sensors for testing the functionality of the design
- Some sensors have metal “grill” structure at the top to allow laser testing
- JTE termination was initially designed for breakdown voltage above 1 kV
- The SiC sensors are produced in the onsemi company and the manufacturing process is optimized for their foundries







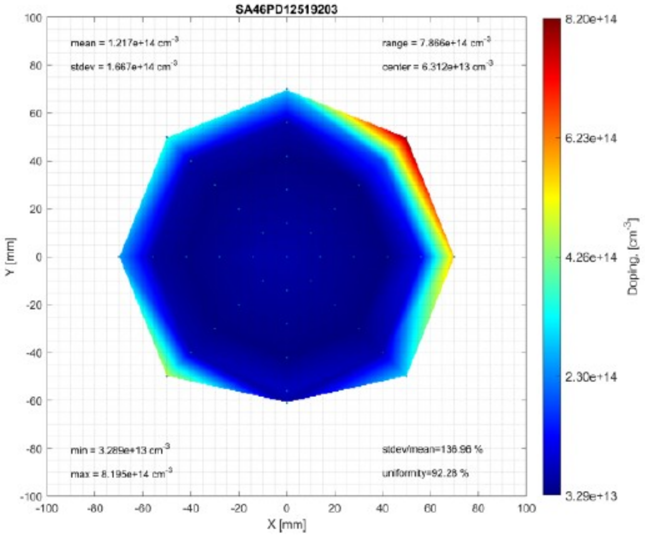
Epitaxial parameters

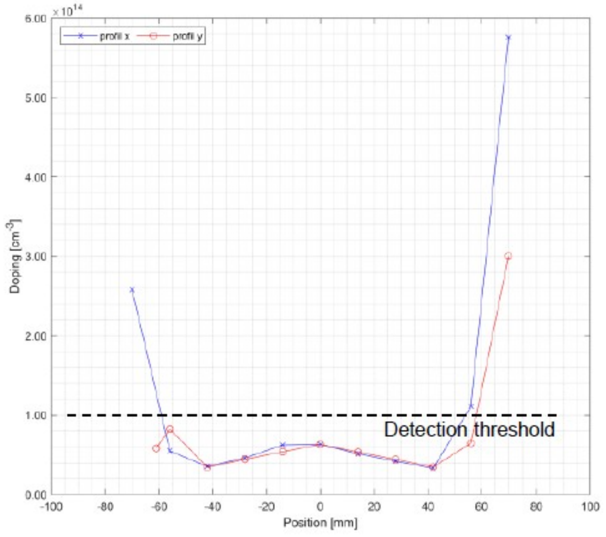
- The substrate wafer is 6'' n-type 4H-SiC with doping conc. ≈ $10^{19} cm^{-3}$
- N-type epitaxial layer is in the range of 30-100 µm and down to ≈ 5×10^{13} cm^{-3}
- Thick epi and low doping - below 10^{14} cm^{-3} are very challenging to achieve

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

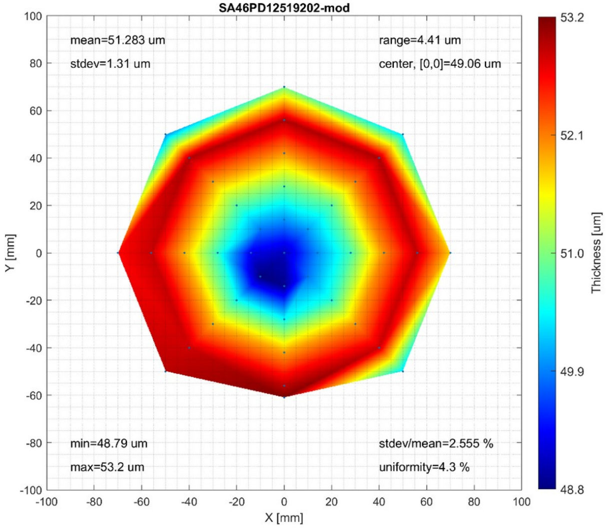
* *Proprietary information*

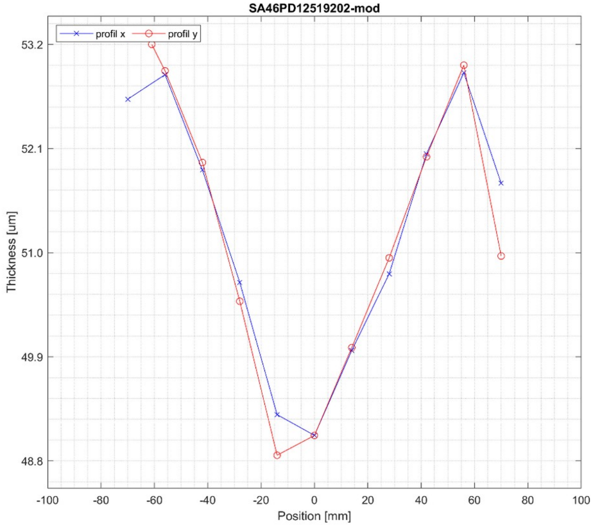
Epi resistivity map (Mercury CV) – limit of method is 1E14 cm-3





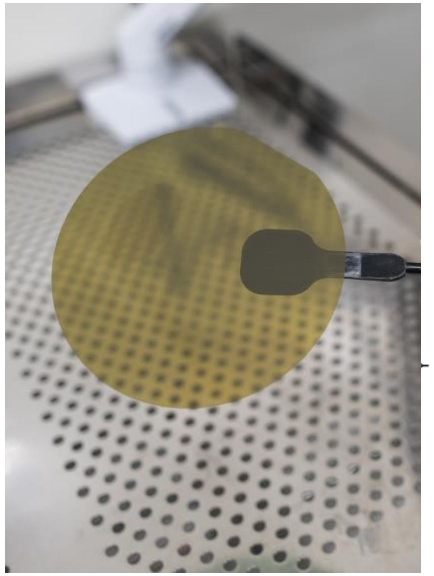
Epi thickness map (FTIR)



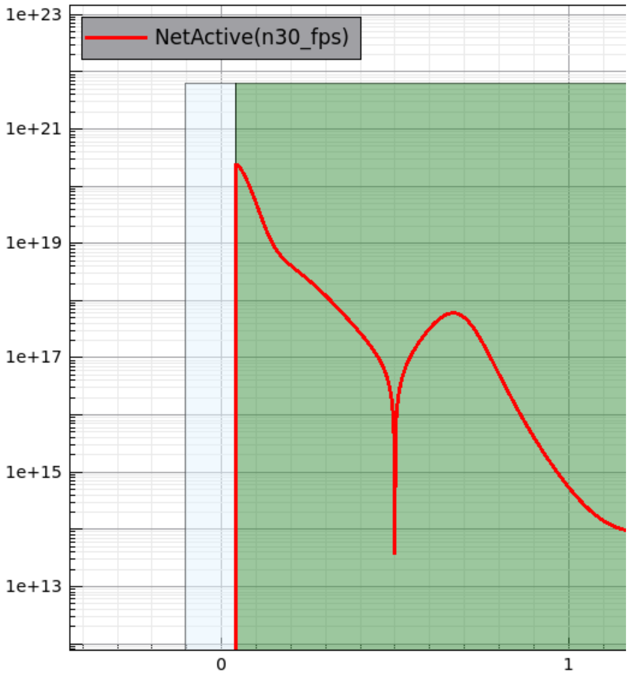


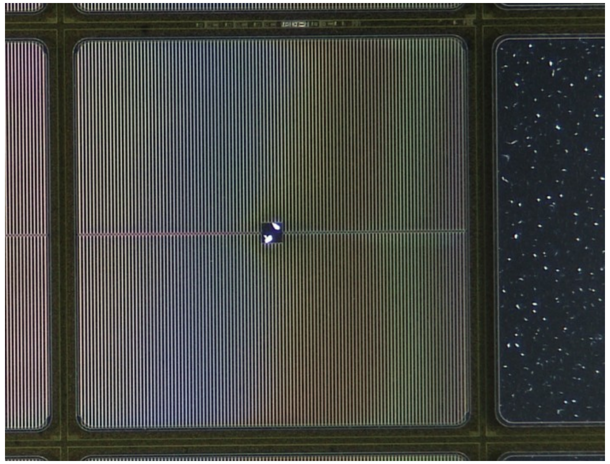
LGAD diode process flow

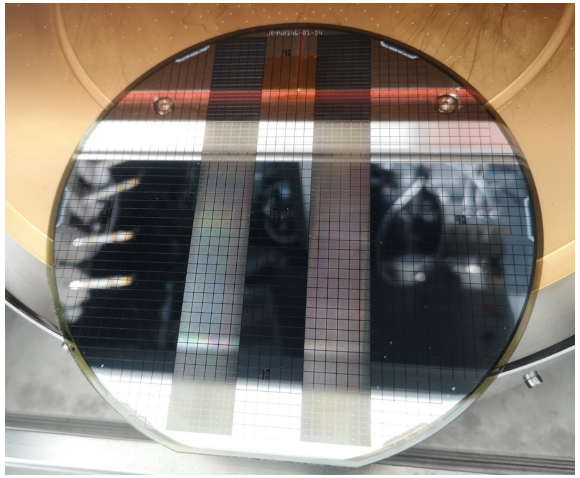
- Each wafer had split on diodes with and without LGAD layer for evaluation of gain over simple PN diode
- P+ and LGAD layers were evaluated using DOE splits of implant energy/dose
- P+: chain implant with energies 30-200 keV, doses 1-8 $\times 10^{14}$ cm^{-2}
- LGAD: single implant 950-1250 keV, 1.5-1.8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



Example of simulated profiles of active structure in LGAD diode

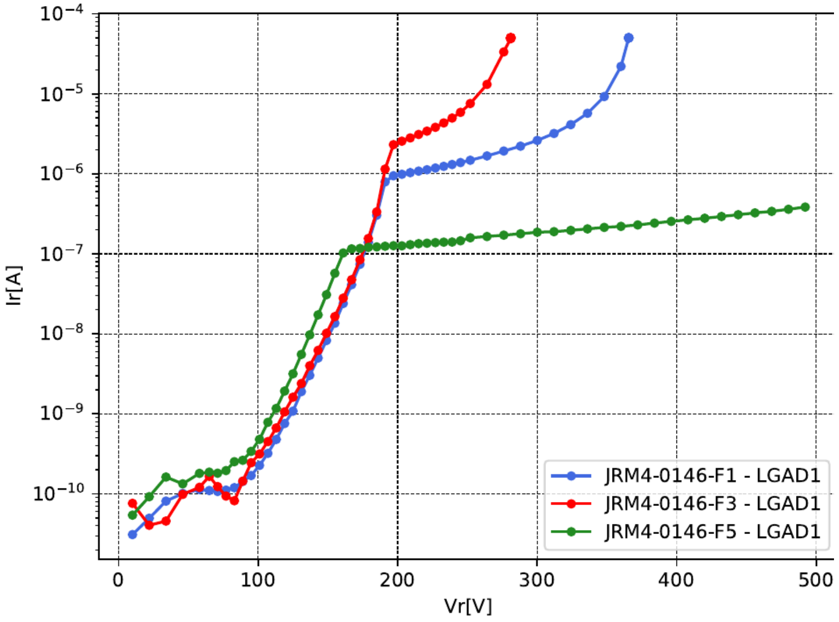


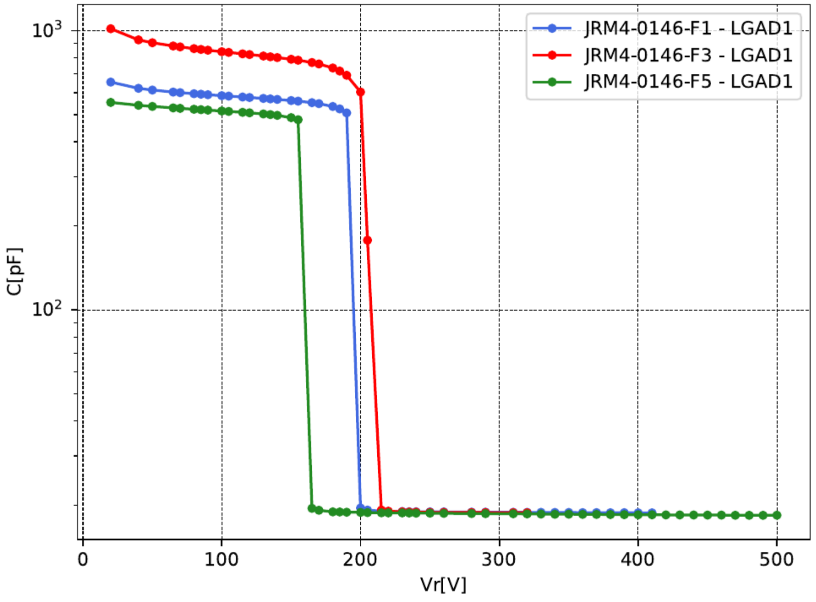


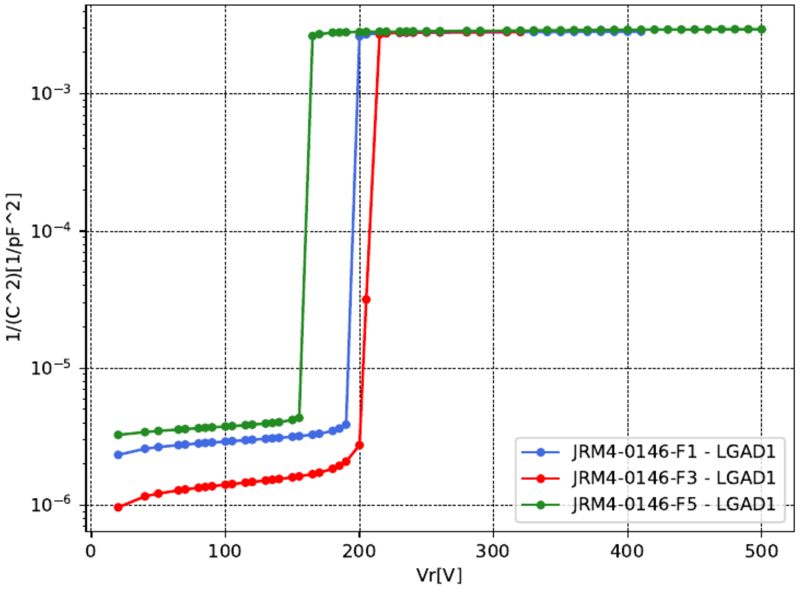


Electrical testing

- 3 splits with PN, LGAD1 and LGAD2 structures each
- The IV and CV characteristics were measured to validate the design and compare to the TCAD simulations
- LGAD depletion voltage in range of 150-200 V



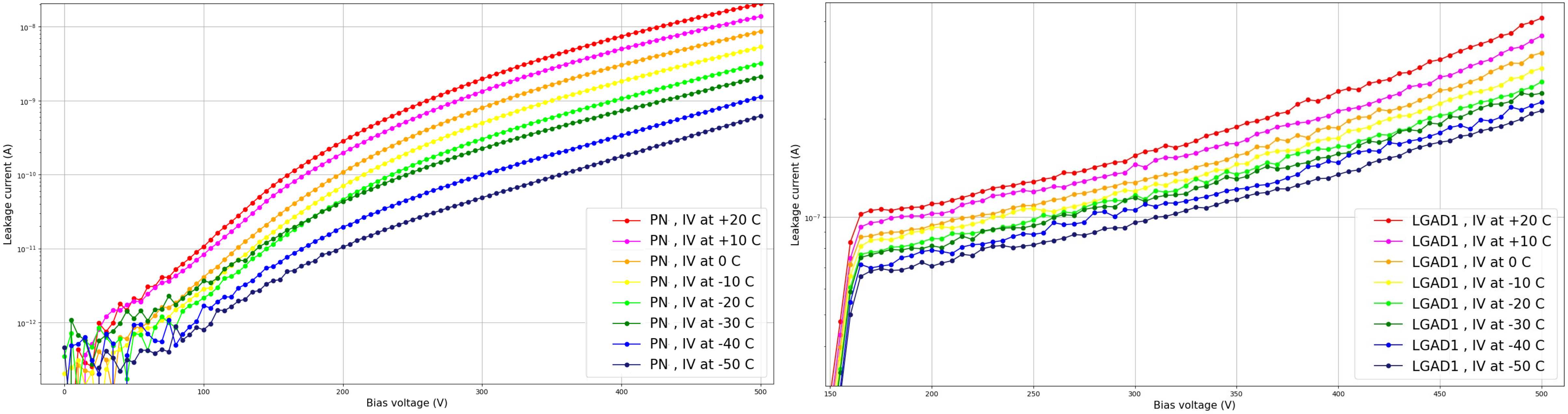




Comparison of LGAD1 structure for different splits

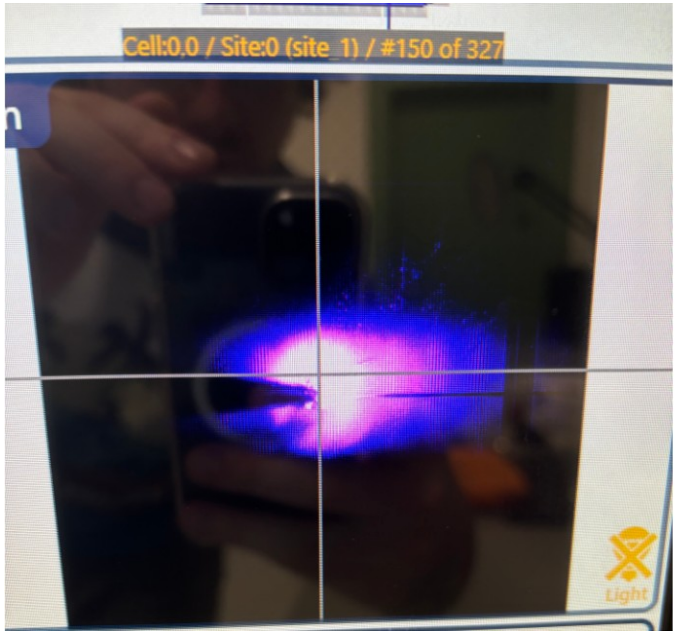
Thermal stability

- The thermal stability of PN and LGAD structures was measured
- The leakage current dependency on the temperature of SiC is lower than for Si

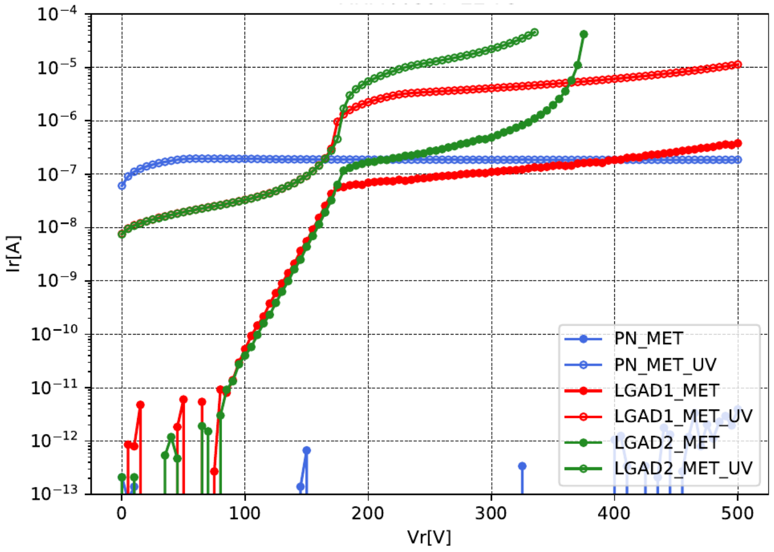


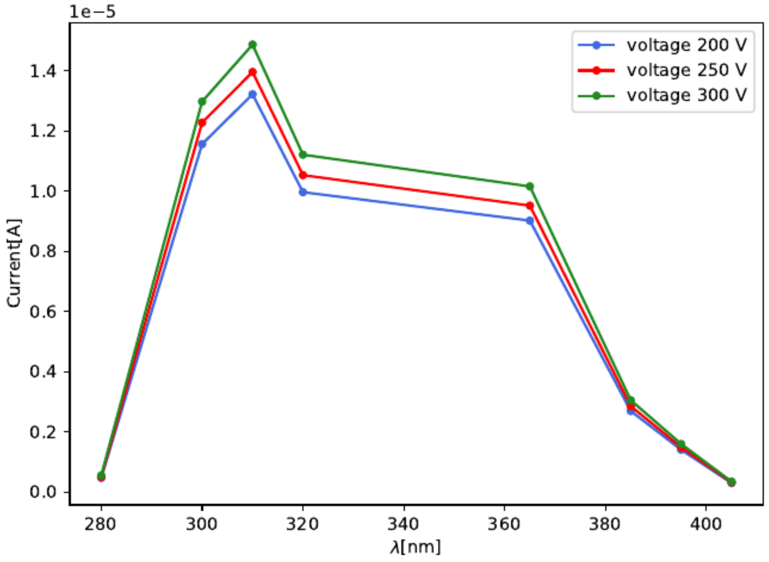
Temperature dependency of leakage current

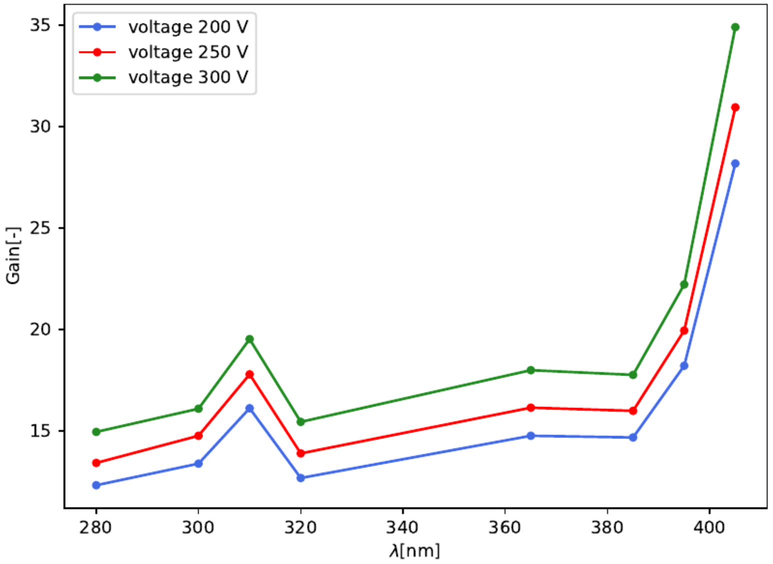
Gain estimation



- The sensor response was tested using a UV-LED source coupled to the fiber (TCT tests in progress)
- Wavelength dependency in the range 277-405 nm
- Gain evaluated from the ratio to PN diode





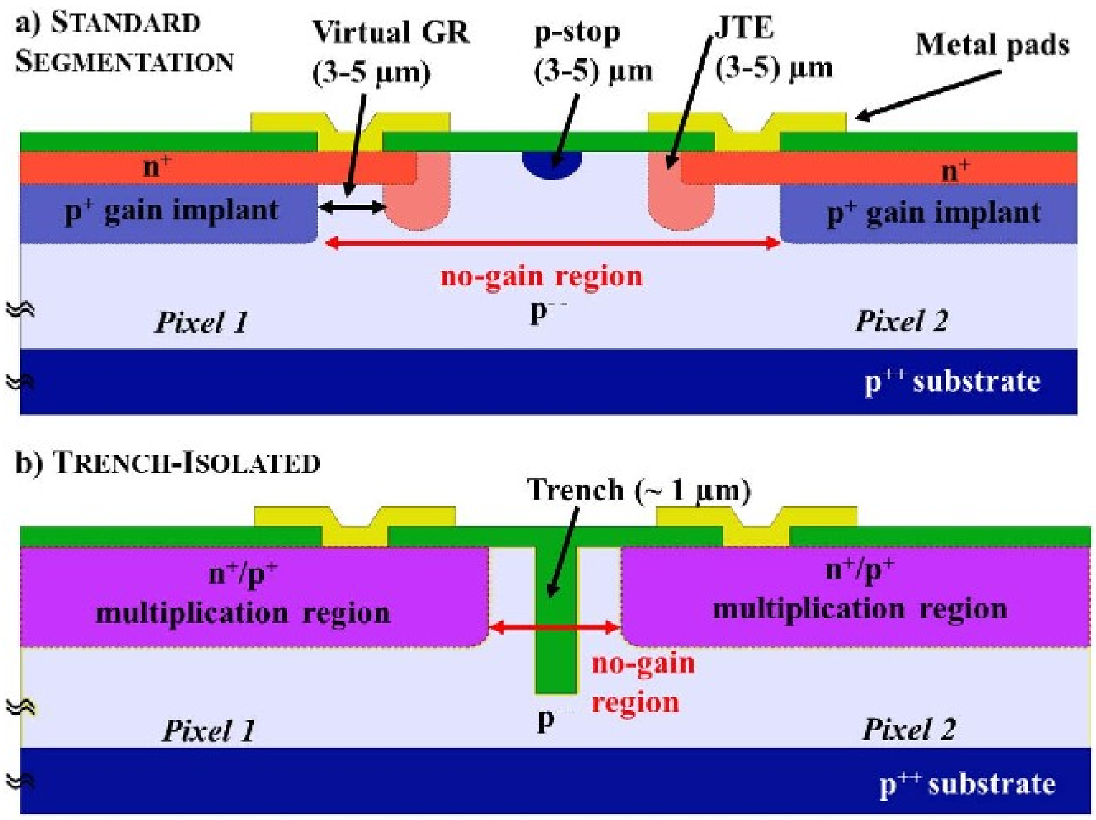


Radiation hardness tests

- Diced samples were tested using Co-60 facilities at UJP Prague as well as the 24 GeV protons at IRRAD CERN
- The irradiation was completed, but we are still waiting for the samples to be analyz

Segmentation strategy

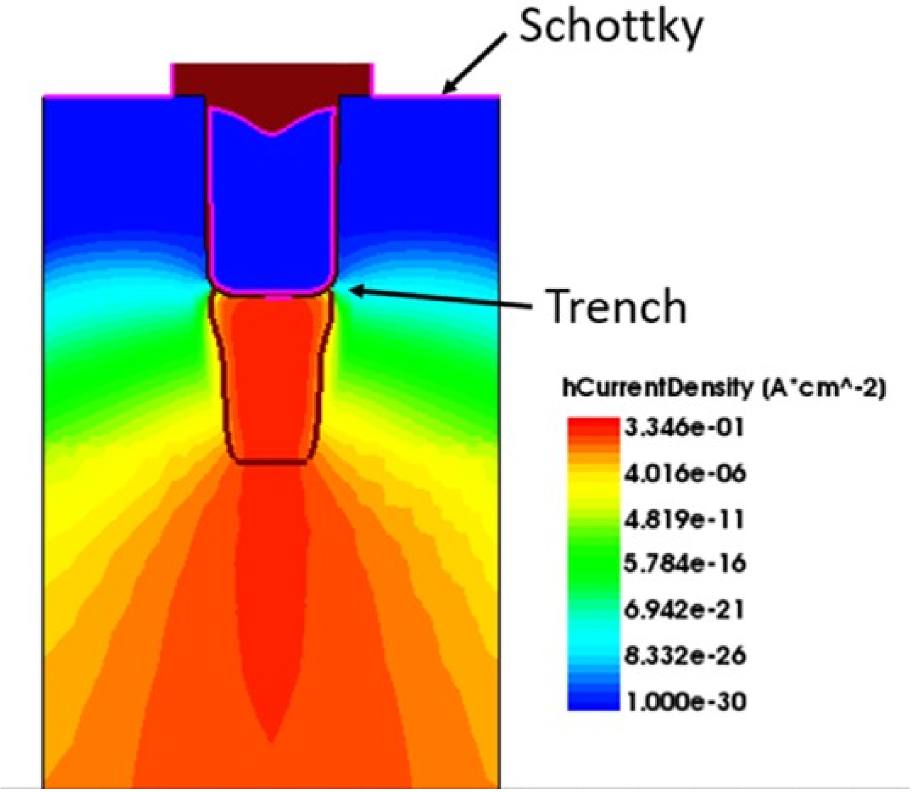
- Due to the high-intensity field, the individual channels of the strip/pixel detector must be separated
- The standard choice would be the JTE; however, the inactive area is relatively large
- The trench isolation could be a solution
- We are investigating both variants

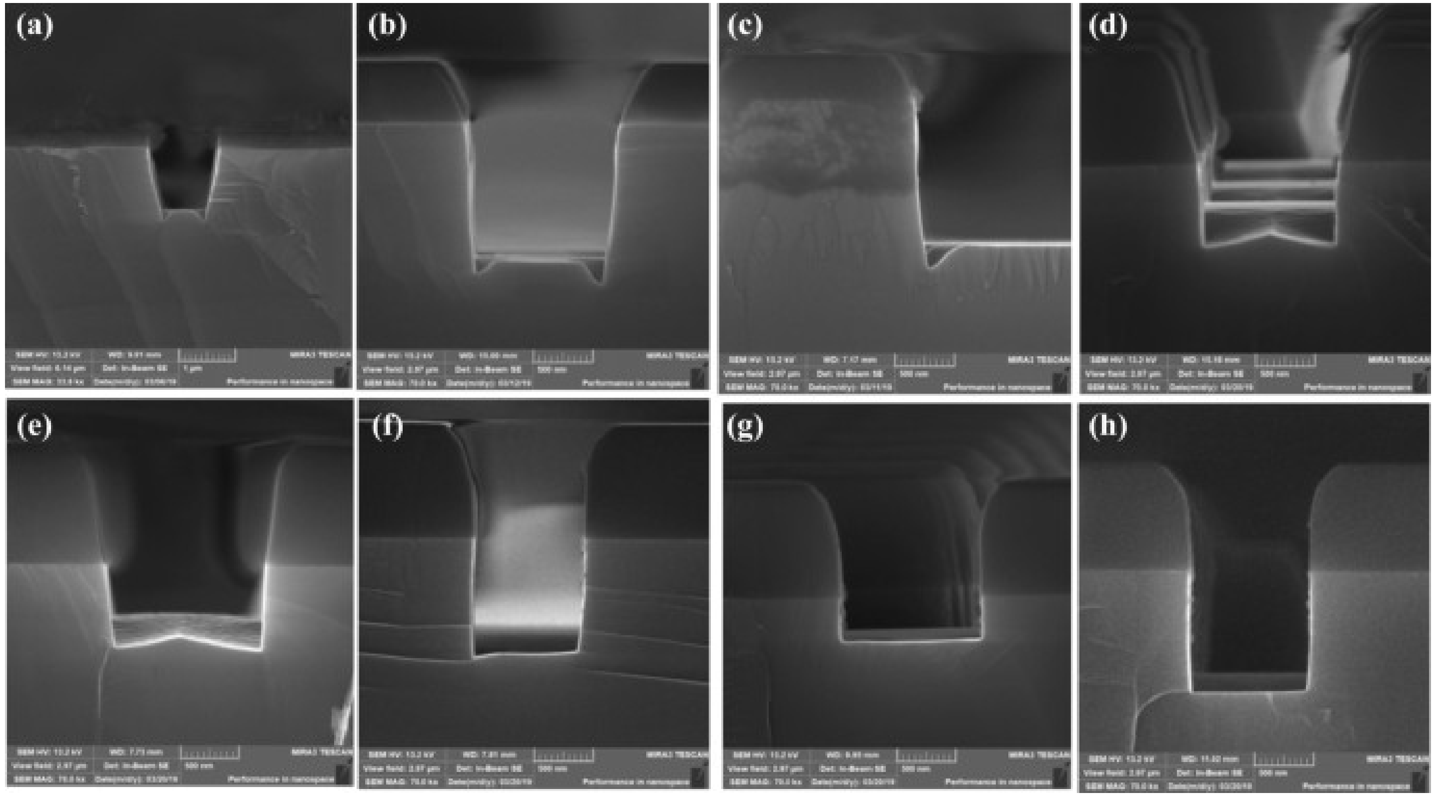


G. Paternoster et al., "Trench-Isolated Low Gain Avalanche Diodes (TI-LGADs)," in IEEE Electron Device Letters, vol. 41, no. 6, pp. 884-887, June 2020, doi: 10.1109/LED.2020.2991351.

SiC - trench isolation challenges

- Deep trenches are challenging to be produced
- First attempts to produce >2µm deep trenches were made





Zhuang et.al. (2019). Microscale pattern etch of 4H–SiC by inductively coupled plasma. Journal of Materials Science Materials in Electronics. 30. 18788–18793. 10.1007/s10854-019-02232-w.

Outlook

- The current goal is to develop a segmented detector where at the first iteration we will produce 16 channel strip detector with a 220 µm pitch
- The future goal is to develop a pixel detector compatible with TimePix2/TimePix3 readout chips
- The homogeneity of the manufacturing process and segmentation of LGAD sensor might be a challenge for large-area sensors

Thank you for your attention!

https://capads.fjfi.cvut.cz