Low Gain Avalanche Diodes Technology: state of the art and new developments

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On behalf of "UFSD Collaboration" (Università degli Studi di Torino – INFN Torino – Università del Piemonte Orientale - Fondazione Bruno Kessler - Università di Trento - TIFPA-INFN. With the contribution of RD50 collaboration, CERN.

Abstract

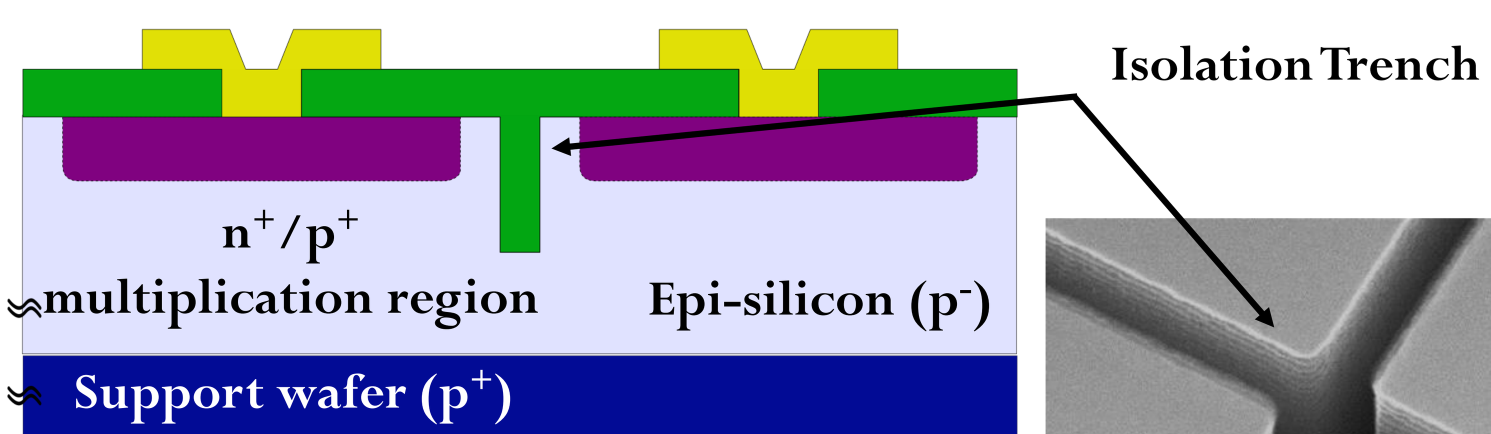
Low Gain Avalanche Diodes (LGAD) are considered one of the most promising solutions for timing application in HEP experiments and 4-dimensional tracking, due to some important advantages: larger internal signal, better time resolution and higher radiation hardness with respect to standard p-i-n based sensors.

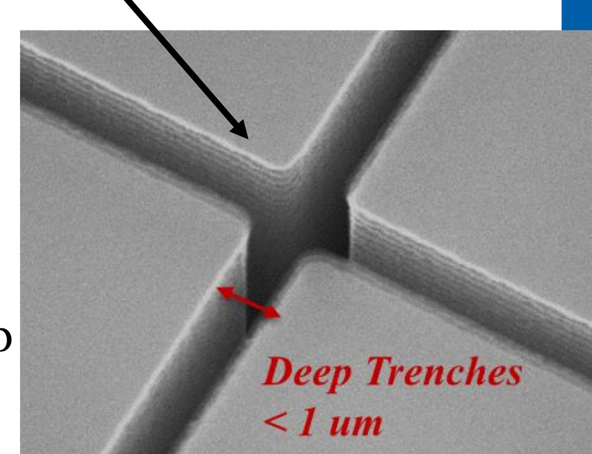
Novel design schemes and microfabrication technologies are under investigation, mainly focused on improving two key aspects of the technology: i) **increasing the radiation hardness at fluence higher than 3e15 neq/cm^2** and ii) **improving the spatial resolution** moving through fine-pixellated and high-fill-factor sensor designs. To improve the spatial resolution, novel segmentations schemes have been developed: i) Trench-Isolated LGAD (**TI-LGAD**) exploits narrow trenches, physically etched in the silicon to reduce the dead-border area of the pixel, while **AC- and DC-coupled Resistive Silicon Detectors** (RSD and DC-RSD, respectively) exploit signal sharing among multiple pads. Both the technologies allow to reach excellent spatial resolution without spoiling time resolution.

To improve the radiation hardness at high fluences, Carbon **co-implantation** shown to be effective in preserving the excellent time resolution of LGADs up to fluence 2e15 neq/cm^2. Novel techniques like **compensated doping** profiles are under investigations and could be effective in leading the radiation hardens of these devices up to unprecedent levels.

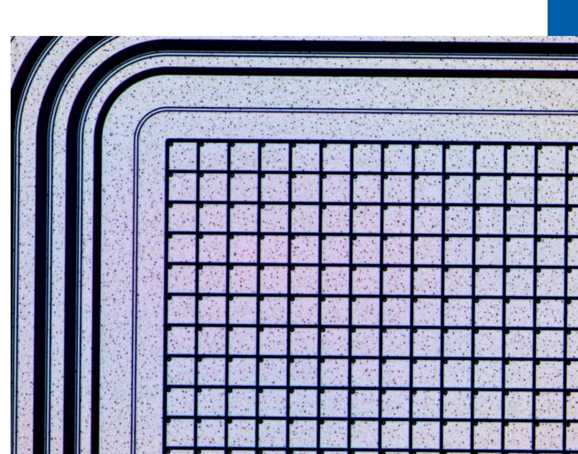
Trench-Isolated LGAD

[1] G. Paternoster

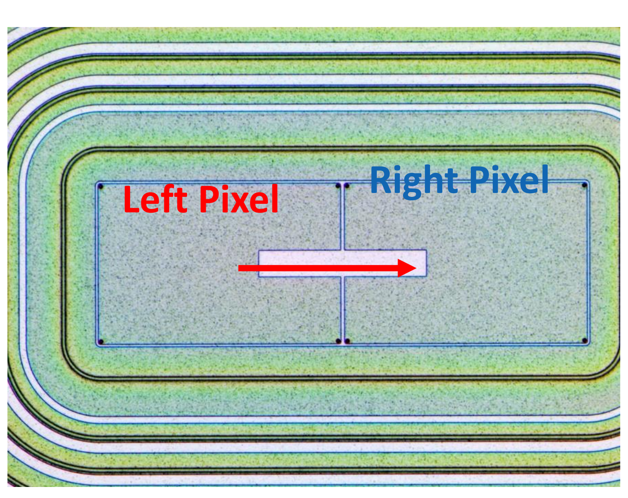


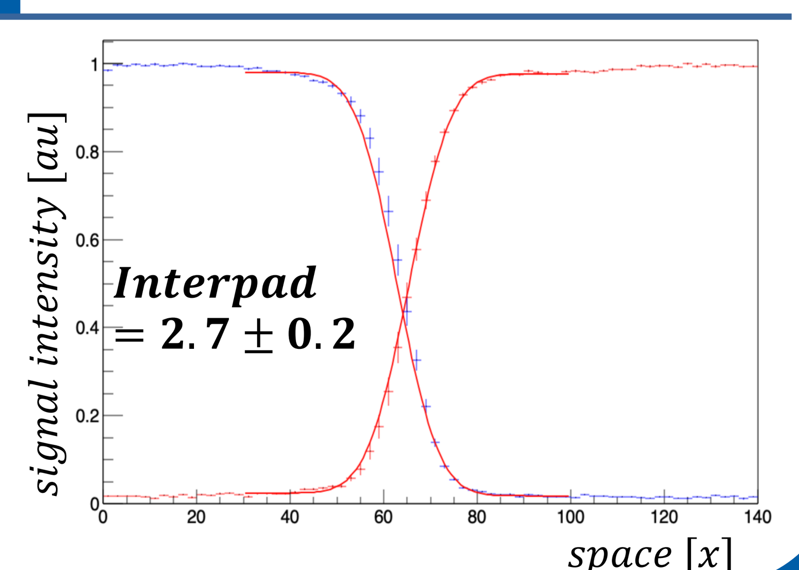


* Junction Termination Edge (JTE) and p-stop are replaced by a single trench.
* Reduced inter-pixel region with no gain (< 5 µm)
* Arrays with 50 -55 µm anf FF > 85% (compatible with Medipix/Timepix)
* Same time resolution of standard LGAD
* Same radiation resistance of standard LGAD



Inter-pixel width measured with laser scan

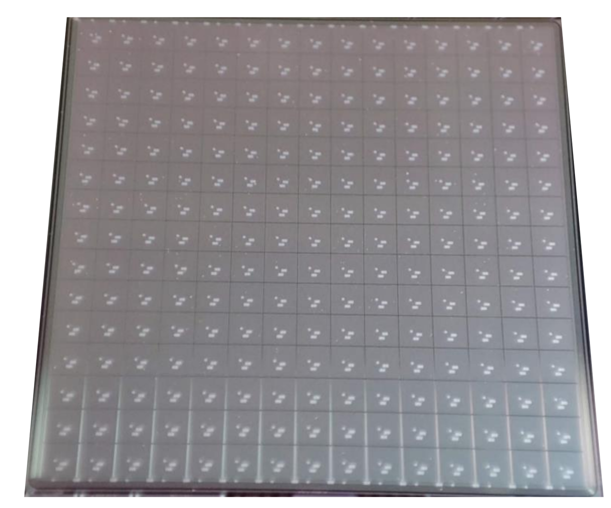




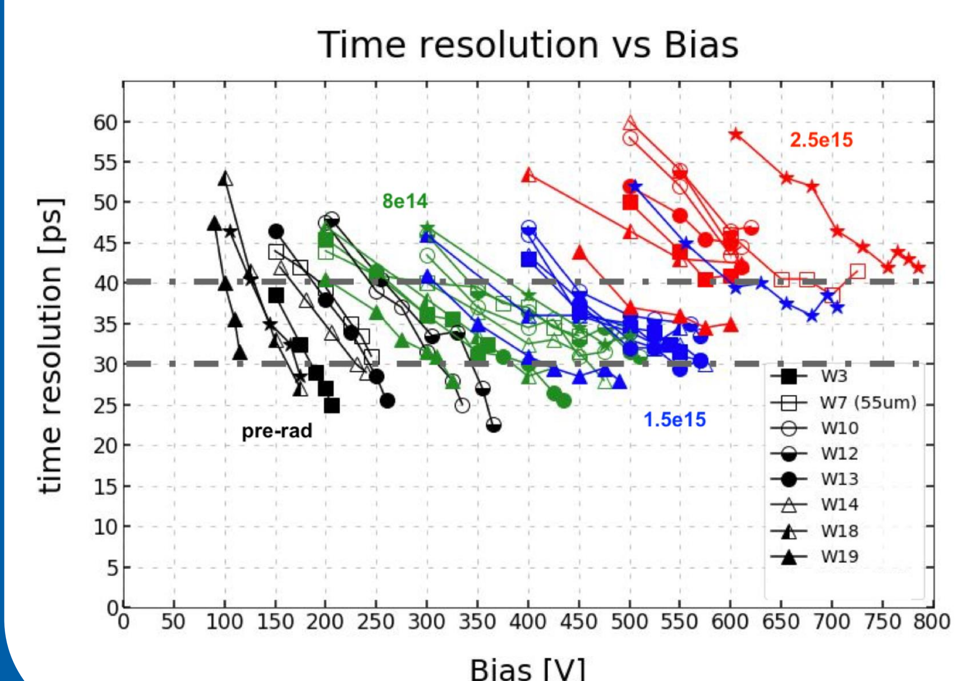
Radiation Hardening

[2] M. Ferrero

* LGADs suffer from gain loss at high fluence (>10^{14} neq/cm^2) due to "acceptor removal" effect
* Carbon co-implantation allows to mitigate the gain-loss and preserve time resolution



15x15 array for ATLAS HGTD



Carbon co-implantation

* Excellent time resolution (< 30ps, for MIP) up to 1.5e15 neq/cm^2
* Reduced bias voltage

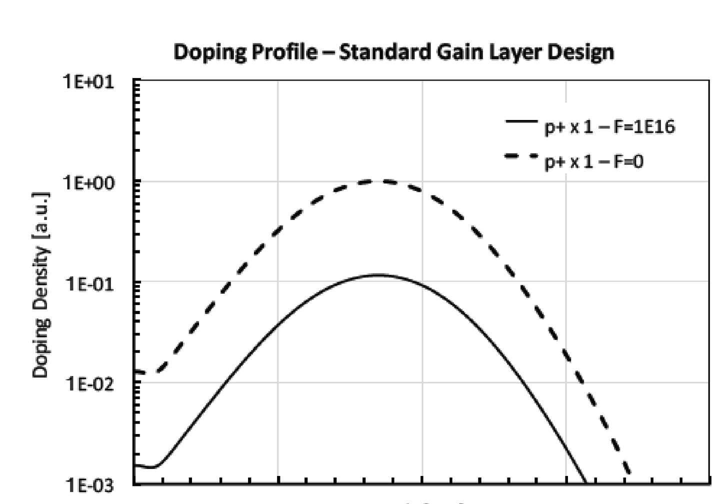
Radiation Hardening at extreme fluences

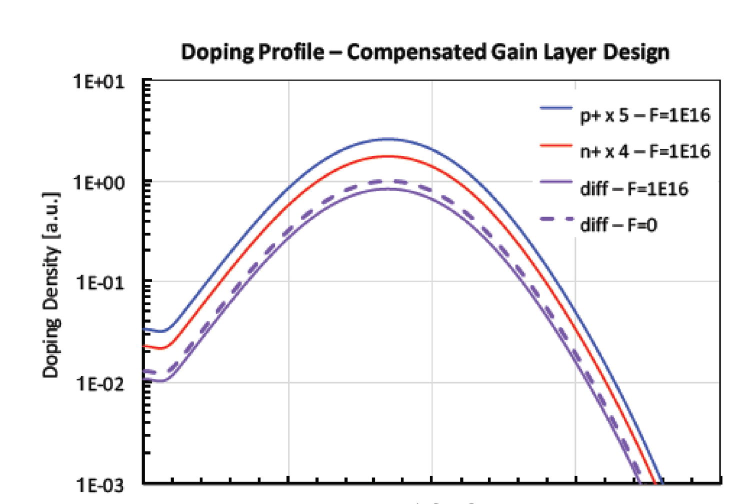
[7] V. Sola

GOAL: operate LGADs at fluence > 10^{16} neq/cm^2

(not possible with the current technology due to: induced defects and traps, change in the bulk doping, gain-loss (acceptor removal)

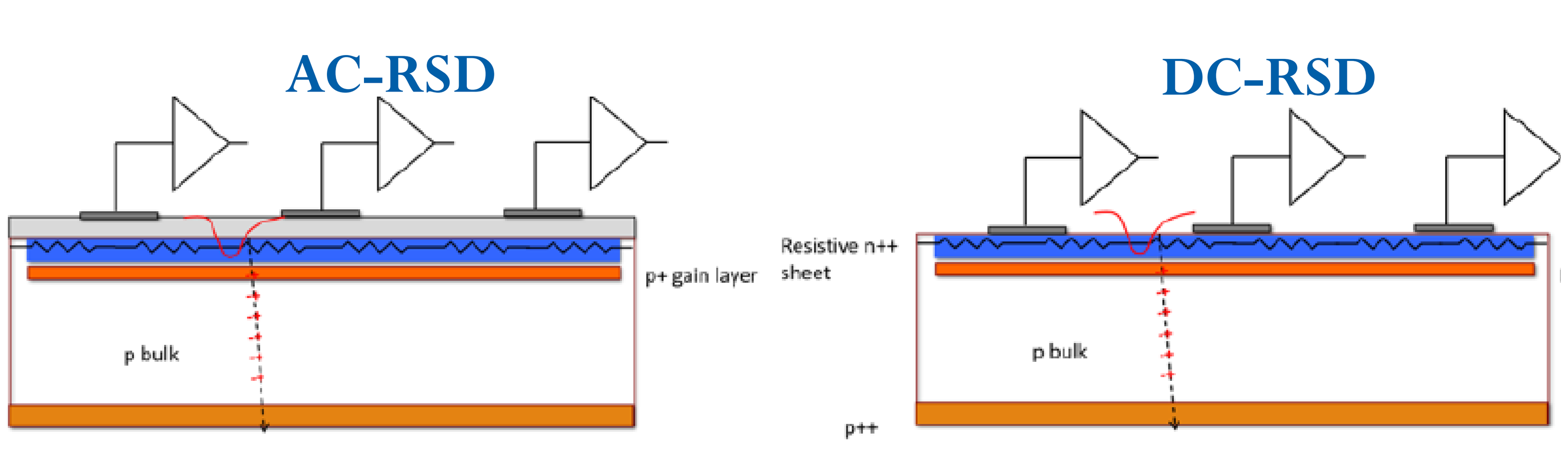
DOPING COMPENSATION: Use the interplay between acceptor and donor removal to keep a constant gain-layer doping density



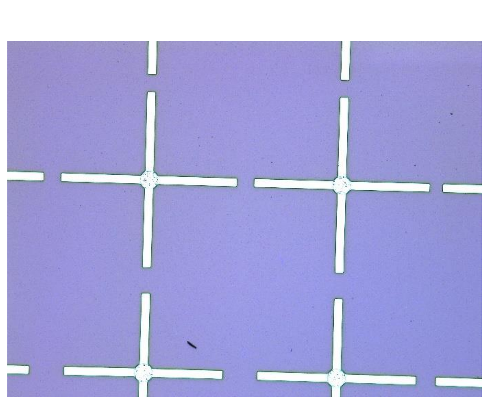


AC- and DC- Resistive Silicon Detectors

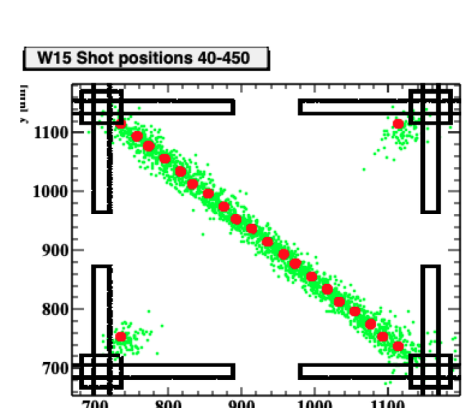
[3] N. Cartiglia, [4] M. tornago [5] M. Mandurrino



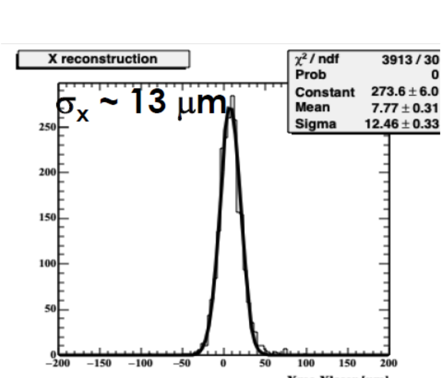
* RSD readout scheme exploits signal sharing among pads to reach high spatial resolution keeping a coarse pad segmentation
* 100% fill-factor
* Preserve time resolution of LGADs
* Spatial resolution (sigma) ~ 13 µm with a 450 µm pitch



AC-RSD with "cross-shaped" pads



Laser position red, reconstructed position green



Spatial resolution at all positions (sigma)

References

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[4] N. Cartiglia, presented at Trento Workshop (TREDI) 2022
[5] M. Tornago, NIMA 2021 DOI: 10.1016/j.nima.2021.165319
[6] M. Mandurrino, arxiv.org/abs/2111.14235
[7] V. Sola, presented at Trento Workshop (TREDI) 2022