Thin LGADs as radiation-resilient sensors for 4D tracking

Matteo Durando, Anna Rita Altamura, Lucio Anderlini, Roberta Arcidiacono, Giacomo Borghi, Maurizio Boscardin, Nicolò Cartiglia, Matteo Centis Vignali, Tommaso Croci, Fabio Davolio, Marco Ferrero, Alessandro Fondacci, Simone Galletto, Leonardo Lanteri, Luca Menzio, Arianna Morozzi, Francesco Moscatelli, Daniele Passeri, Nadia Pastrone, Giovanni Paternoster, Federico Siviero, Valentina Sola, Robert White

eXFlu Project

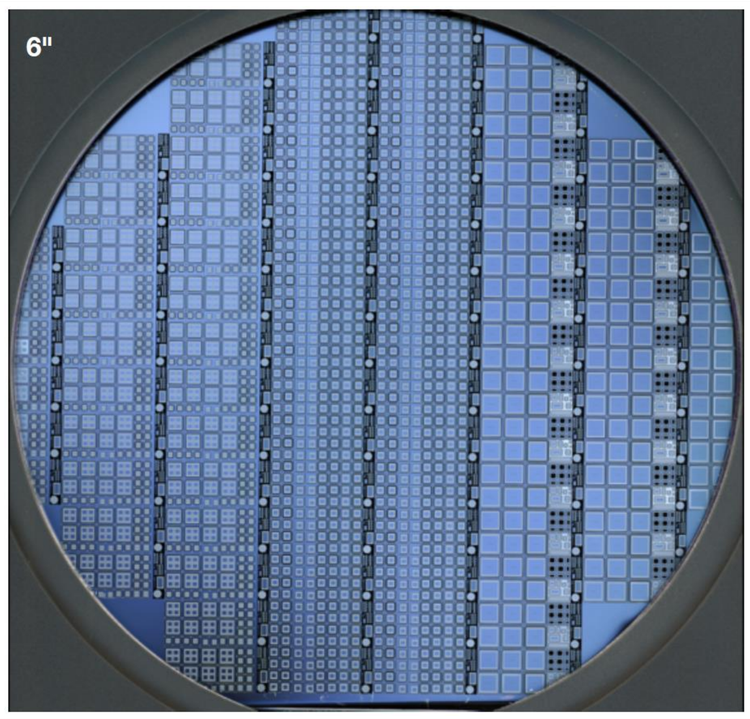
Developing **radiation-resilient silicon detectors** for **spatial** and **timing** reconstruction at **future collider experiments** (e.g. MuColl, FCC)

- ↑ Efficient operation up to **very high fluences** ($\phi \sim 10^{17}$ $n_{eq@1MeV}/cm^2$)
- ↓ Decrease in the signal amplitude and efficiency due to **lattice defects** induced by **radiation damage**
- ↑ Can be tackled **increasing** the **bias voltage** during the operation
- ↓ Increase in the **leakage current** flowing through the readout electronics with **higher noise level**, **power consumption** and **failure risk**

Possible solution:

- **Thin sensors** reduce the leakage current and the irradiation induced damages
- **Gain implant** increases the total signal amplitude

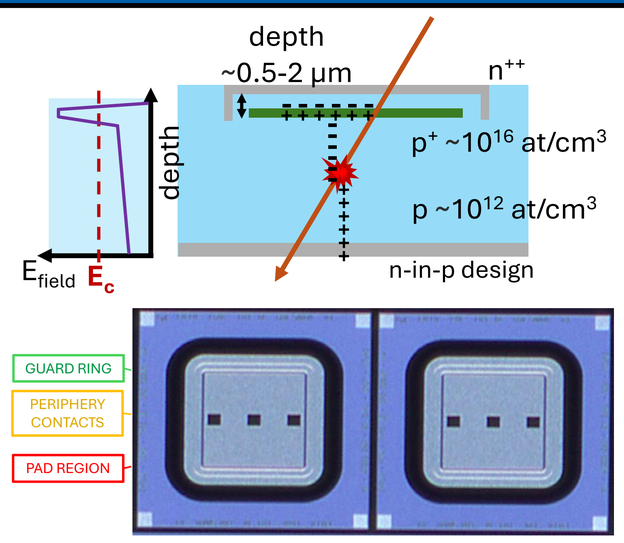
Thickness [µm]	p+ dose [a.u.]	C dose [a.u.]	Diffusion	Bulk
45	1.14	1.0	CBL	very high ρ
30	1.12	1.0	CBL	high ρ
20	0.96	1.0	CBL	low ρ
15	0.94	1.0	CBL	low ρ



LGAD structure and acceptor removal

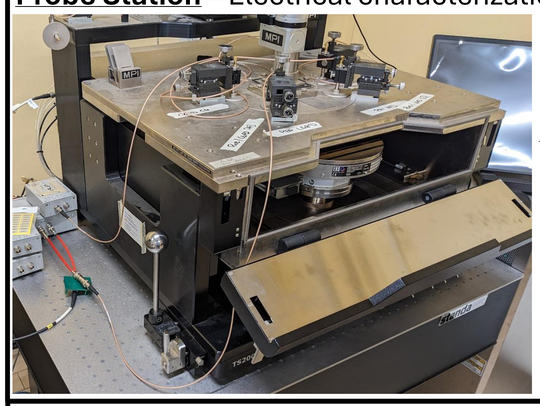
- **Low gain** (~20-30) and segmentation give **low leakage currents**, resulting in **low noise** and **faster response**
- High **electric field** (300kV/cm) **localized** near gain implant
  - Depletion before bulk
  - Gain mechanism by e-h pairs multiplication
- Gain is eroded due to radiation damage deactivating p^+ doping atoms → **acceptor removal**

$$p^+(\phi) = p_0^+ \cdot e^{-c_A \phi}$$



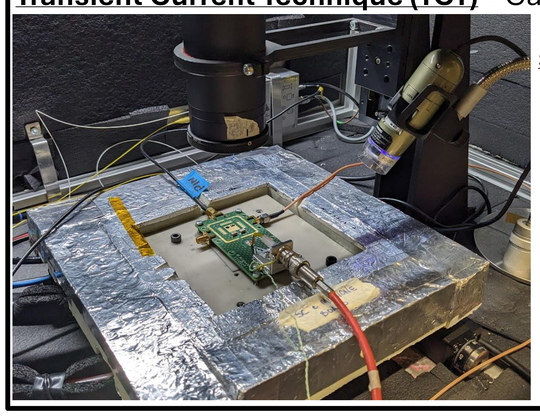
Measurement setups

Probe Station – Electrical characterization



Setup:
- Environmental isolated enclosure
- Thermal chuck [-60°C , +250°C]
- Metallic needles attached to micromanipulators
- Device analyser for automatic and precise measurements

Transient Current Technique (TCT) – Gain measurements



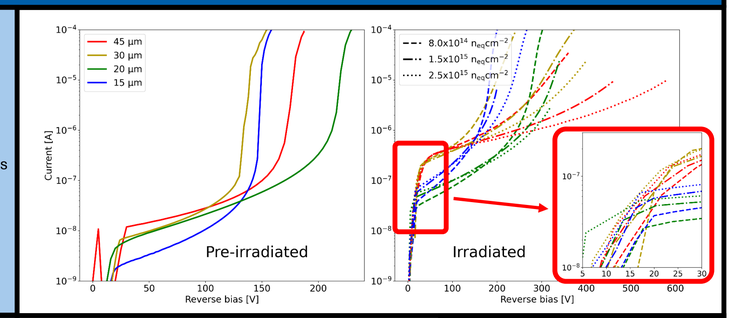
Setup:
- Electromagnetically and thermally isolated enclosure
- Thermal backplate (T = -10°C)
- Moving stage
- Near-IR laser
  - λ = 1064nm
  - Focal spot = 10µm
- Custom readout board
- Oscilloscope LeCroy WR 9254M
  - BW = 2.5GHz
  - Sampling rate = 40GS/s
  - 4 channels (LGAD + PiN + LaserTrigger + LaserDiode)

Electrical characterization

IV characteristics:

- **Bias scans** up to depletion (temperature from -20°C to 20°C)
- Measuring current flowing through the **pad**
- Gain layer depletion at **V_{gl}~30V**
  - ➢ **V_{gl} decreases** with irradiation due to gain layer deactivation

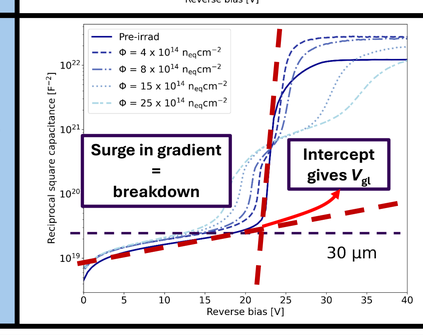
IV plots
- all thicknesses
- all fluences
- T = -20°C



CV characteristics:

- Measuring capacitance while depleting the gain layer and sensor bulk
- Extract **depletion voltage** for the gain layer (V_{gl})
- Extract doping information (bulk profile and rate of Gain Layer degradation)

CV plots
- 30µm
- all fluences
- T = 25°C
- f = 1-2kHz



See also: 43rd RD50 talk on EXFLU1 characterisation
Ref. ***Robert Stephen White***

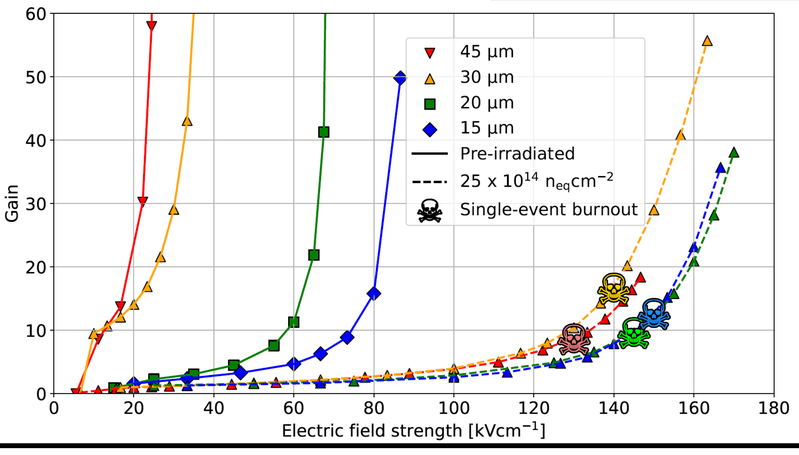
Gain measurements

- Laser calibrated for stimulation equivalent to ~4 MIPs
- Measuring signal for increasing bias

$$Gain = \frac{A_{LGAD}}{\langle A_{PIN} \rangle}$$

Single-event breakdown limit shown for these results

See also: 43rd RD50 talk on single event breakdown
Ref. ***Marco Ferrero***

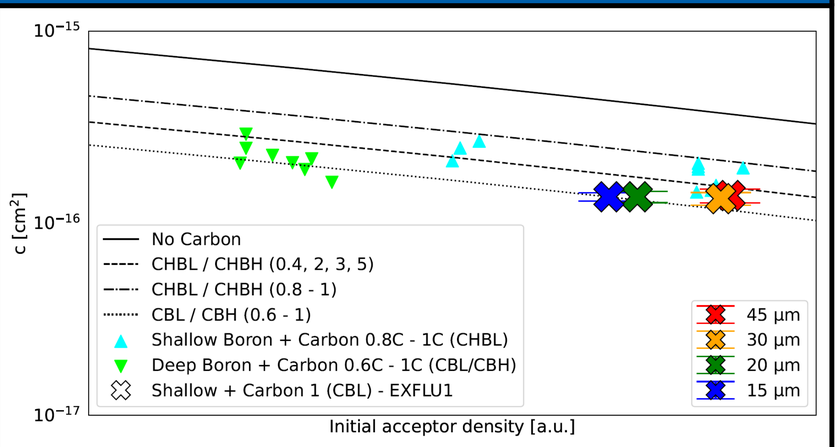


Acceptor removal rate

Acceptor removal rate can be estimated using the exponential law: $V_{gl}(\phi) \propto e^{-c_A \phi}$

Notes:
- c_A parameter depends on the production process and on the initial concentration of doping atoms
- Tests conducted on wafers with both carbon (C) and boron (B) implants
- Different parametrizations have been studied for carbon activation before or during boron annealing

eXFlu1 production has shown best performance so far



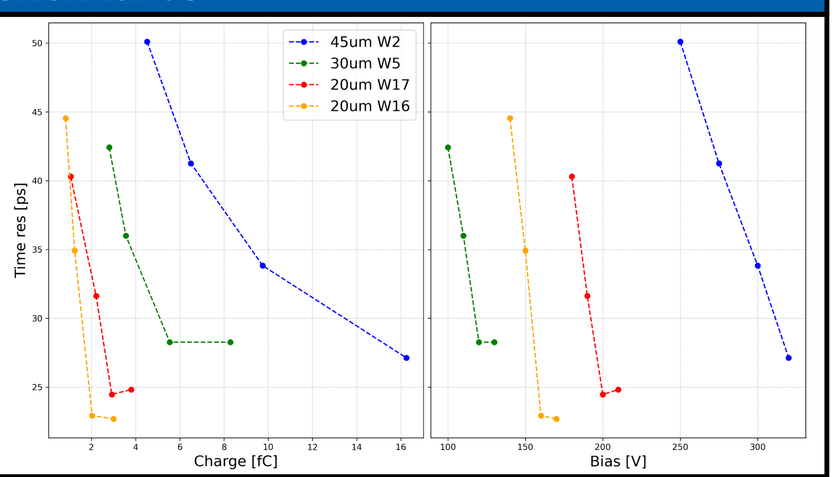
Timing performance

Timing analysis from β source pulses taking the coincidence with an MCP trigger.

σ_t = std dev of the ToA distribution (~gaussian)

Thin sensors properties:
- ↑ Low V_{bias} and leakage current
- ↑ Better timing resolution
  - ➢ $\sigma_{20\mu m}^{min} \sim 23ps < \sigma_{45\mu m}^{min} \sim 27ps$
- ↓ Low charge collection
  - ➢ Require better electronics for readout

See also:
4D tracking: present status and perspectives
Ref. ***Nicolò Cartiglia***



Future project

- ❑ Study doping compensation for high irradiated sensors
- ❑ Evaluate different implantation designs and processes

See also: DESY seminar about CompleX Project
Ref. ***Valentina Sola***

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreements Nos 101004761 (AIDAinnova) and 101057511 (EURO-LABS).
The work has been performed in collaboration with the INFN CSN5 "eXFlu" research project.
Co-funded by the European Union – Next Generation EU, Mission 4 Component 1 CUP D53D23002870001 (ComonSens).
We acknowledge the RD50 and DRD3 collaborations, CERN.