Karlsruhe Institute of Technology

Recent results of the RD50 collaboration

Marta Baselga on behalf of the RD50 collaboration

ETP - KIT

RD50 collaboration

RD50 Collaboration: Radiation hard semiconductor devices for high luminosity colliders

- 60 institutes around the world
- 354 members
- 33 workshops (2001-2018) to discuss the results of the collaboration

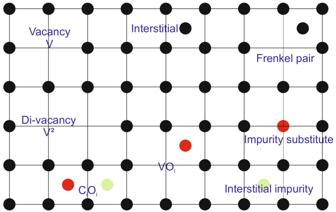
RD50 Organization structure - 4 research lines

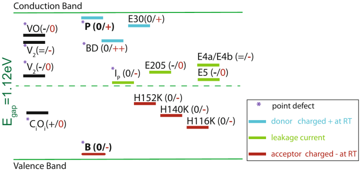
1. Defect and material characterization
2. Detector characterization
3. New structures
4. Full detector systems

1. Defect and material characterization

Reminder

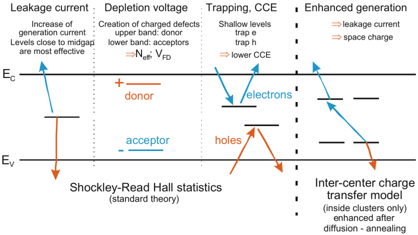
Microscopic defects





Macroscopic effects

- Increase leakage current
- Changes in doping profile
- Decrease charge collection

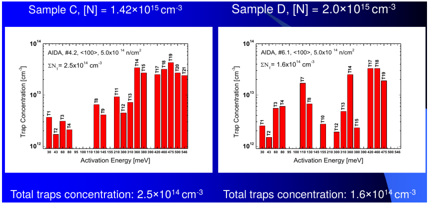


[Evolution of Silicon Sensor Technology in Particle Physics, Hartmann, Springer 2017]

1. Defect and material characterization

NitroStrip project: Example for ongoing project on defect engineering

- Nitrogen enriched wafers show promising behavior after irradiation
- Fluence $5 \times 10^{14}\ n_{eq}/cm^2$:

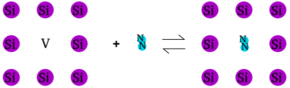


→ The total traps concentration is lower for higher [N] concentration

[Kaminski, RD50 Workshop, November 2014]

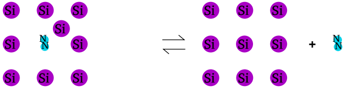
Vacancy suppression:

$$N_2 + V \rightleftharpoons N_2 V$$



Suppression of interstitials:

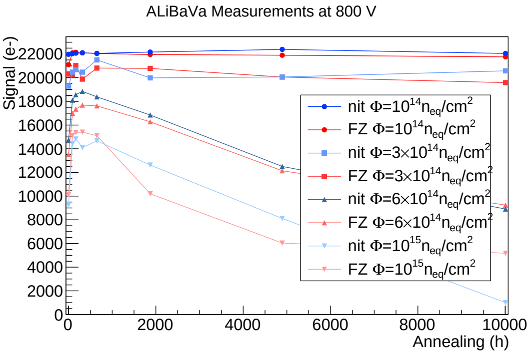
$$N_2 V + I \rightleftharpoons N_2$$



[W. von Ammon et al. J. Cryst. Growth 226, 19 (2001)]

1. Defect and material characterization

NitroStrip project: ALiBaVa measurements @800 V irradiated with 23 MeV protons



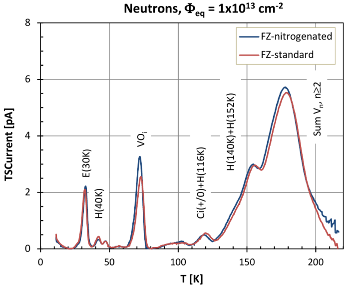
- Strips and diodes fabricated on p-in-n FZ and nitrogenated FZ wafers
- No big difference between FZ and nitrogenated wafers after irradiation

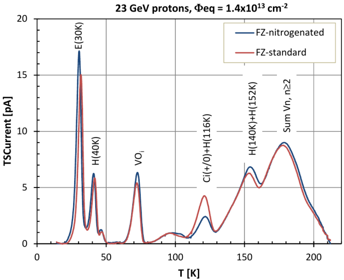
[Baselga, 32nd RD50 Workshop, Hamburg 2018]

1. Defect and material characterization

NitroStrip: TSC measurements

TSC measurements (annealing 80 min @ 60 °C)





[Fretwurst 33rd RD50 Workshop, CERN 2018]

Overview for NitroStrip project

- Nitrogen concentration is supposed to be 1.5×10^{15} /cm^3
- It seems that the concentration is not high enough for an improvement

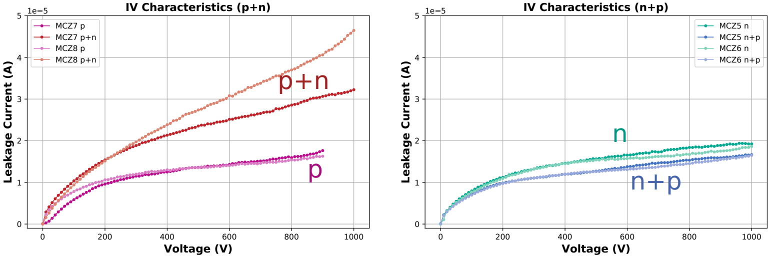
1. Defect and material characterization

Mixed irradiation

How critical is the order of mixed irradiations?

- Samples were irradiated with 23 MeV protons at KIT and neutrons in Ljubljana (p-in-n material).

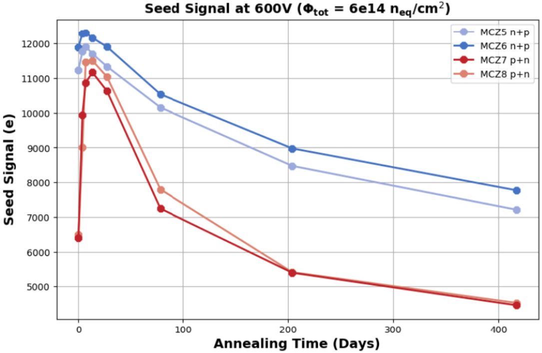
$\Phi = 3 \times 10^{14}\, n_{eq}/cm^2$		$\Phi = 3 \times 10^{14}\, n_{eq}/cm^2$	Total:
protons	→	neutrons	$\Phi = 6 \times 10^{14}\, n_{eq}/cm^2$
neutrons	→	protons	$\Phi = 6 \times 10^{14}\, n_{eq}/cm^2$



[Gosewisch 33rd RD50 Workshop, CERN 2018]

1. Defect and material characterization
Mixed irradiation

ALiBaVa measurements



- The annealing charge also change with the irradiation order
- Unexpected results, further analyses needed

[Gosewisch 33rd RD50 Workshop, CERN 2018]

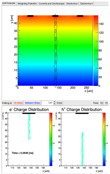
2. Detector characterization

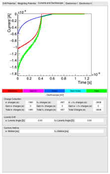
Simulations TCAD - Overview

- They are used to be able to foresee in maximum detail the sensors performance under irradiation

RD50 developed softwares

- KDetSim
- TRACS
- Weightfield2

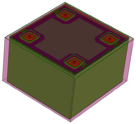


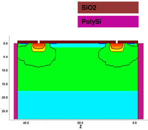


Commercial TCAD softwares

- Synopsys sentaurus
- Silvaco

Adjust radiation into the software for surface and bulk defects





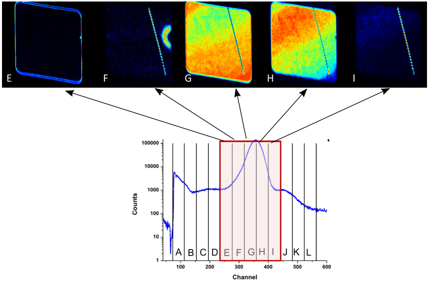
[Villani 33rd RD50 Workshop, CERN 2018]

2. Detector characterization

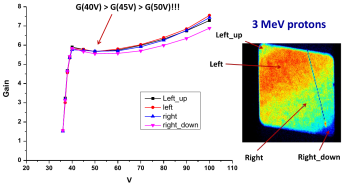
Measurement techniques

- CV, IV
- e-TCT (edge Transient Current Technique)
- TPA-TCT (Two photon absorption-TCT)
- IBIC (Ion Beam Induced Current)

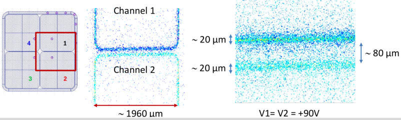
IBIC spectrum for LGAD



Gain vs Voltage for different positions within the sensor



Signals from channel 1 & 2

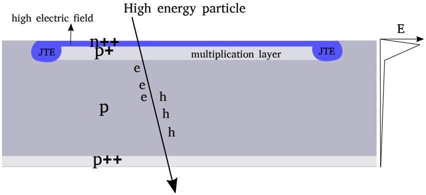


[Jiménez-Ramos 33rd RD50 Workshop, CERN 2018]

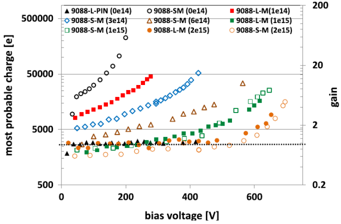
3. New structures

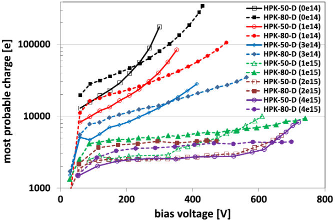
LGADs - 50 µm thick sensors

- Thin sensors ideal for timings (4D, UFSD) are planned to be introduced in ETL (CMS) and HGTD (ATLAS).
- Strong acceptor removal
- Gallium or carbon implants?



After irradiation, the multiplication decreases

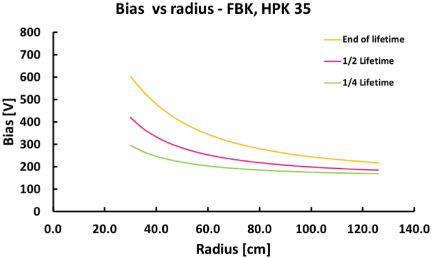


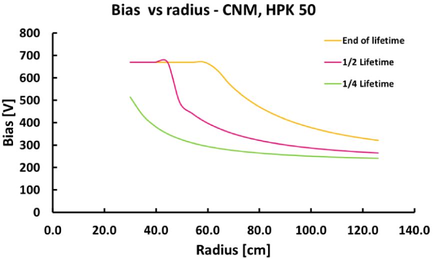


[NIMA 891 (2018) 68-77]

3. New structures
LGADs - 50 µm thick sensors

Gain over voltage: Performance in ETL





- Sensors close the the beam will receive higher radiation doses
- In order to compensate the acceptor removal (→ less gain) more bias voltage needs to be appied to have a similar collected charge as with unirradiated material

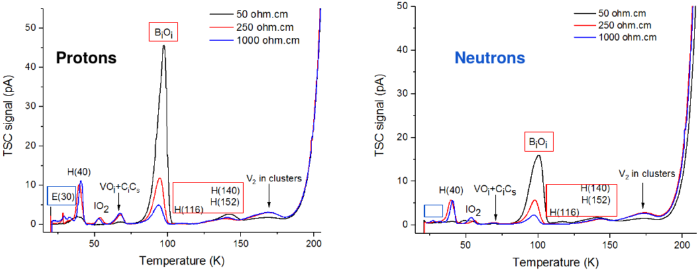
[Cartiglia, 33rd RD50 workshop CERN 2018]

1. Defect and material characterization

LGADs

Microscopic scale

Annealing 10 min at 60 °C, $\Phi = 7.8 \times 10^{13}\,n_{eq}/cm^2$

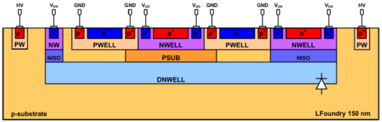


[Gurimskaya, 33rd RD50 workshop CERN 2018]

- TSC comparison spectra for thin EPI diodes with different resistivity
- B_iO_i seems to be the responsible for acceptor removal

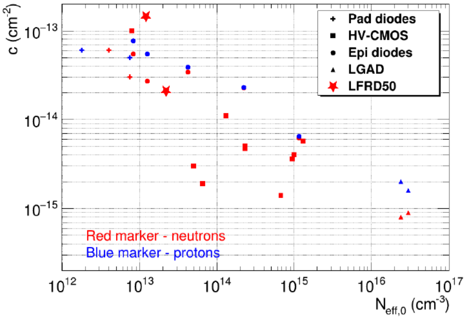
3. New structures

HVCMOS



- Common fabrication of RD50-MPW1 LFoundry process

Acceptor removal constant for LGADs and CMOS



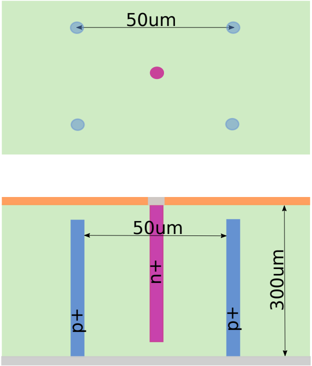
$$N_{eff} = N_{eff0} - N_c \cdot \left[1 - e^{(-c \cdot \Phi_{eq})}\right] + g_c \cdot \Phi_{eq}$$

[Mandić 33rd RD50 Workshop, 2018 CERN]

3. New structures

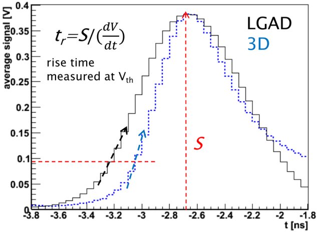
3D

- Well known technology, now in IBL working nicely
- New results show that they might work as a timing sensors also



Time comparison with LGAD

- Similar results for the 3D and LGAD samples



[Kramberger 33rd RD50 Workshop, 2018 CERN]

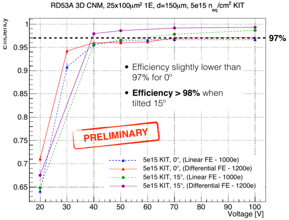
4. Full detector systems

Test beams, timing applications

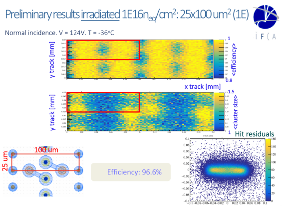
HL-LHC will have to recognize 200 simultaneous interactions

- Larger pile - up
- Higher particle fluence

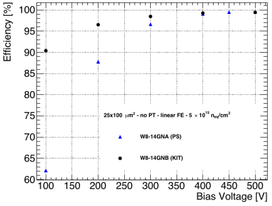
→ RD53A chip prototype for HL-LHC - Testbeam results at SPS



[Giannini 33rd RD50 Workshop, 2018 CERN]



[García Alonso 33rd RD50 Workshop, 2018 CERN]

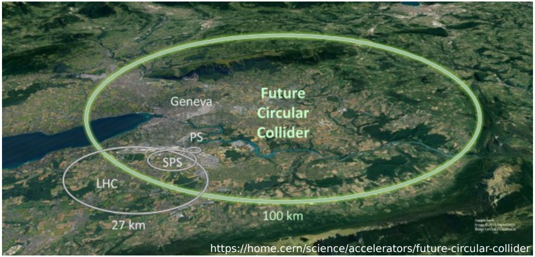


[Macchiolo 33rd RD50 Workshop, 2018 CERN]

Conclusions

- RD50 is an active collaboration and growing, check last workshops!
- New projects are ongoing, preparing for new silicon detectors for the HL-LHC phase II upgrade

Future work



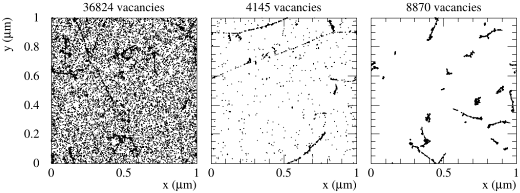
FCC fluence $> 7 \times 10^{17}\, n_{eq}/cm^2$

Backup

Huhtinen defect type

Projections of vacancy positions

Project through 1 μm of depth after fluence 10^{14} cm^{-1}



10 MeV Proton **24 GeV/c Proton** **1 MeV Neutron**

10 MeV protons

Mainly isolated point defects (remember depth dimension)

24 GeV/c protons

Isolated point defects and clusters

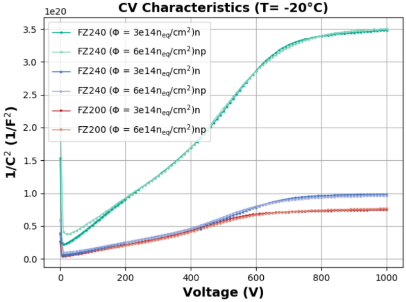
1 MeV neutrons

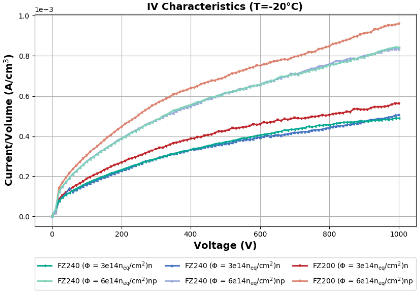
Almost only clusters

[Huhtinen CERN 2001, Si-RadHard Workshop]

Mixed irradiation

Also for n-in-p samples





[Gosewisch 33rd RD50 Workshop, CERN 2018]

Annealing steps

Annealing steps

Step number	Time [min]	Temperature [°C]	Time at RT [h]
0	0	0	0
1	20	60	91
2	20	60	167
3	40	60	318
4	76	60	650
5	15	80	1871
6	30	80	4894
7	60	80	10007