CERN Physics Department PH-DT Detector Technologies

Development of Radiation Tolerant Silicon Sensors for the SLHC

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Why do we need radiation hard sensors?

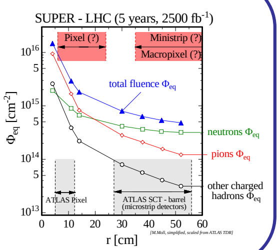
Upgrade to SLHC
Luminosity increases from $10^{34}cm^{-2}s^{-1}$ to $10^{35}cm^{-2}s^{-1}$ => fluence (at r=4cm, in 5 years) increases up to $1.6\cdot10^{16}cm^{-2}$

Replacement of LHC components
LHCb Velo detector, ATLAS Pixel B-layer

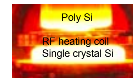
Linear collider experiments (generic R&D)

RD50 collaboration

- approved 2002 by CERN research board
- over 250 members from 50 institutes
- challenges: Radiation hardness, fast signal collection, low mass, cost effectiveness



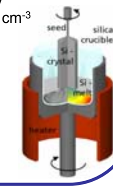
Different materials



Float Zone (Fz)
- standard detector material
- high purity and resistivity
- low oxygen content 5×10^{15} cm^{-3}.

(Magnetic) Czochralsky silicon (MCz)
- used in IC industry
- difficult to achieve high resistivity
- high oxygen content $5\text{-}10 \times 10^{17}$ cm^{-3}

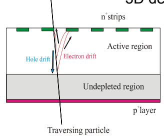
Epitaxial silicon (EPI)
- silicon layers up to 150 µm
- chemical vapour deposition

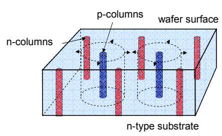


How do make devices more radiation hard?

Materials
Defect engineering on silicon
New materials (Diamond)

New detector designs
n-in-p detectors
3D detectors



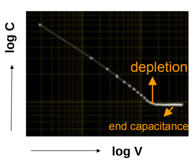


Variation of detector operational conditions
RD39: Cryogenic Tracking Detectors

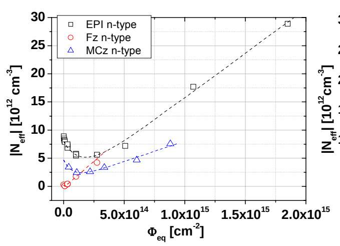
Depletion voltage

- material dependence
- particle dependence
- type inversion possible

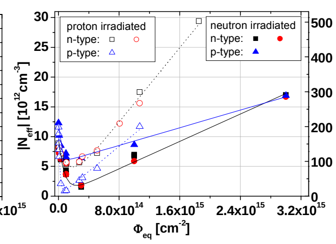
Effects on detetors
- electric field grows from back side
- under-depletion



Determining the depletion voltage



Comparison of different materials after proton irradiation. The higher oxygen concentration in MCz leads to a slower increase with fluence compared to Fz and 150 µm thick EPI.



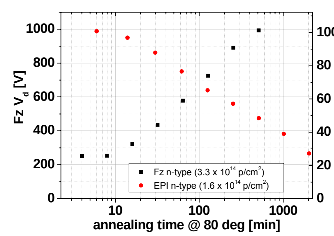
Comparison of 150 µm EPI n- and p-type material after proton and neutron irradiation. After proton irradiation, the depletion voltages increases three times faster than after neutron irradiation.

Annealing

- detector characteristics change with time
- time constant depends on temperature
- study at elevated temperatures

Depletion voltage

- development depends on material type after irradiation (i.e. type inversion plays a role)
- in standard Fz increase after initial decrease =>detectors have to be cooled at all time

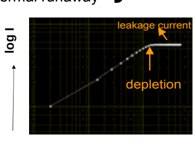


Leakage current

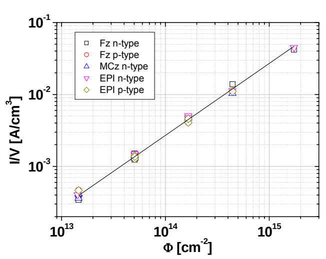
- same for all materials
- depends on particle type
- temperature dependent
- linear increase with fluence

Effects on detectors
- increased noise
- power dissipation
- thermal runaway

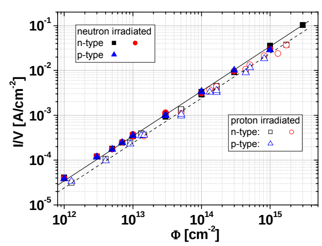
} cooling



Leakage current vs. voltage



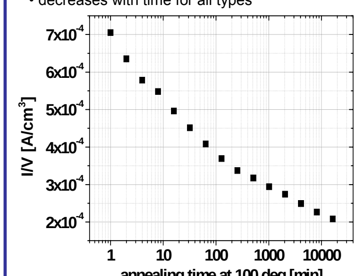
Leakage current per volume for different silicon materials after proton irradiation. No material or type (n or p) dependence is observed



Leakage current for EPI material after proton and neutron irradiation. From the different damage constants the hardness factor needed for scaling to equivalent fluences is obtained.

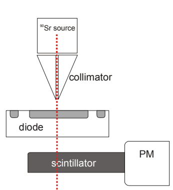
Leakage current

- decreases with time for all types

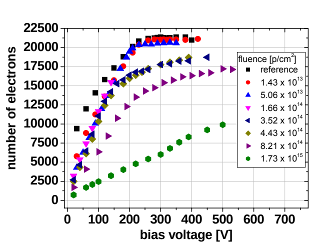


Charge collection efficiency

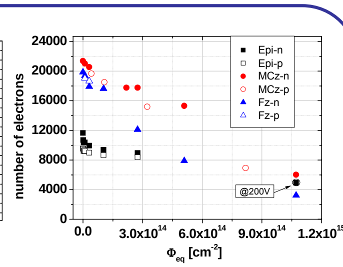
Loss of signal due to trapping



Schematics of the CCE setup using a β-source



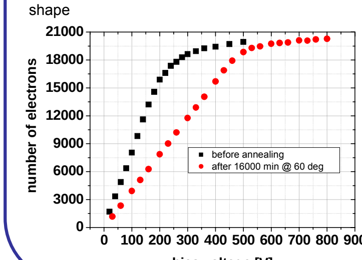
Collected charge vs. bias voltage in MCz n-type after proton irradiation.



Different materials after proton irradiation. EPI of 150 µm thickness, rest 300 µm.

Charge collection efficiency

- maximum doesn't change
- change of depletion voltage reflected in curve shape



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