Silicon Detectors for the SLHC
Recent RD50 Results

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Poster summary

This poster presents the recent results obtained by RD50 collaboration from tests of several detector technologies and silicon materials at radiation levels corresponding to SLHC fluences.

INTRODUCTION

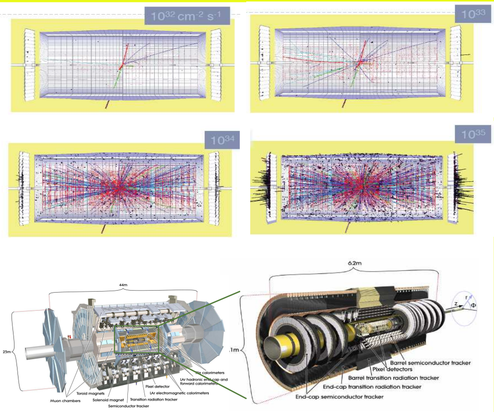
While the CERN Large Hadron Collider (LHC) is scheduled to start taking data this year, a machine upgrade to achieve a much higher luminosity is being developed:

Super-LHC (SLHC) → $L_{peak} = 10^{35}$ cm^{-2} s^{-1}

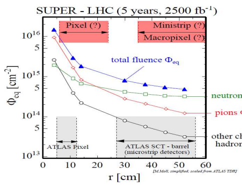
Starting around 2018, we aim to record 3000 fb^{-1} of good quality data after the start-up of the SLHC.

As radiation damage scales with integrated luminosity, the particle physics experiments at the SLHC will need to be equipped with a new generation of radiation hard detectors. This is of particular importance for the semiconductor tracking detectors located close to the interaction region, where the highest radiation dose occurs.

The ATLAS Experiment will require a new particle tracking system for SLHC operation. In order to cope with the increase in pile-up events by about an order of magnitude at the higher luminosity, a silicon detector with enhanced radiation hardness is being designed. Also CMS will need a replacement of silicon tracker.



The Difficulty



Comparison between LHC and SLHC:

- Higher radiation levels
  - Higher radiation tolerance required!
- Higher multiplicity
  - Higher granularity required!

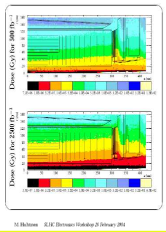
Need for new detectors & detector technologies

RD50 objectives

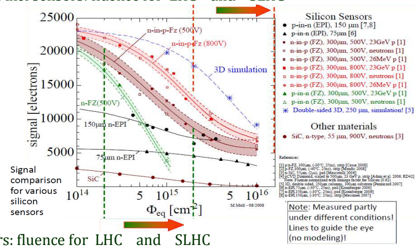
- Material characterization & defect engineering
  - Understanding of radiation damage
    - Macroscopic effects and microscopic defects
    - Irradiation with different particles (n, p, π)
  - Oxygen enrichment
    - DOFZ, Cz, MCz, EPI, (SIC & GaN evaluated/abandoned)
  - Understanding/tuning of influence of processing technology
- Device engineering
  - p-type silicon (n-in-p)
  - thin sensors
  - 3D detectors

→ Proposal/understanding which sensor material and/or sensor configuration can be used at which radius to the beam for the SLHC and beyond

Implications

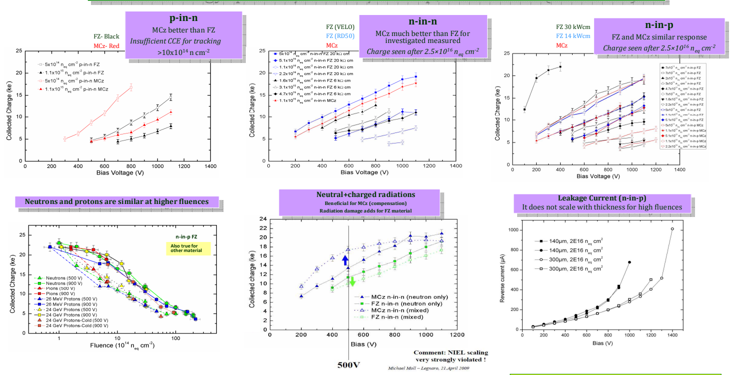


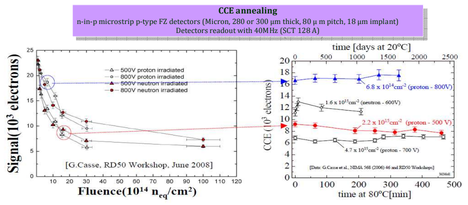
Pixel sensors: fluence for LHC and SLHC



Strip sensors: fluence for LHC and SLHC

Technology: p-in-n / n-in-n / n-in-p, FZ vs. MCz (selection)





No reverse annealing in CCE measurements for neutron and proton irradiated sensors

- CCE is crucial for very high fluences, but other important parameters have to be considered (SNR, efficiency, system aspects, price of technology, cooling, track resolution, reliability, ...)
- Different bulk materials irradiated with charged and neutral particles.
- p-in-n FZ/MCz not radiation tolerant enough for inner SLHC radii
- No CCE annealing observed for p-bulk
- Leakage current does not scale with thicknes at high fluences

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n-strip readout devices have sufficient CCE for even inermost SLHC radii

- Higher bias voltage, better cooling & lower threshold electronics are needed!

Device engineering → 3D

Introduced by: S.I. Parker et al., NIMA 395 (1997) 328

Short collection path/time: almost no trapping; charge of the complete volume is collected

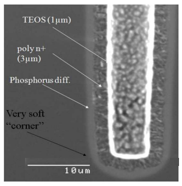
"3D" electrodes:
- narrow columns along detector thickness
- diameter: 10µm, distance: 50-100 µm

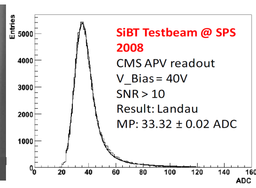
Lateral depletion:
- lower depletion voltage needed
- thicker detectors possible
- fast signal

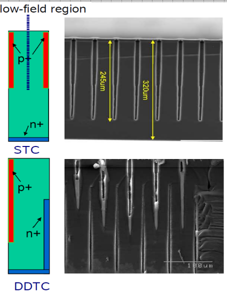
✓ Smaller trapping probability
- radiation hard

✗ Higher capacitances

1. 3D single column type (SCT)
   - Suffer from a low field region between columns
2. 3D double-sided double type columns (DDTC)
   - challenging
   - Full field

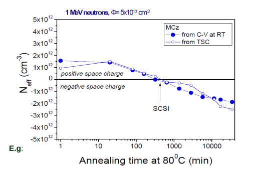




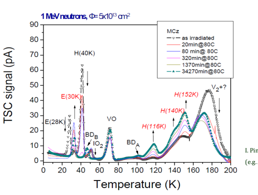


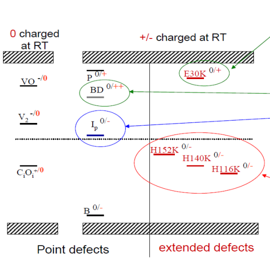
Microscopic studies RD50/WODEAN

Systematic studies to understand microscopic band levels correspondence to their macroscopic behaviour



- Neff follows concentration of acceptor levels (negative space charge) H116K, H140K, H152K which increase with annealing (see TSC plot)
- H116K, H140K, H152K do not form with γ radiation → cluster effects





Point defects
- $E_i^{BD} = E_c - 0.225$ eV
- $\sigma_n^{BD} = 2.3 \times 10^{-14}$ cm^2
- $E_i^I = E_c - 0.545$ eV
  - $\sigma_n^I = 2.3 \times 10^{-14}$ cm^2
  - $\sigma_p^I = 2.3 \times 10^{-14}$ cm^2

Cluster related centers
- $E_i^{116K} = E_v + 0.33$eV
- $\sigma_p^{116K} = 4 \times 10^{-14}$ cm^2
- $E_i^{140K} = E_v + 0.36$eV
- $\sigma_p^{140K} = 2.5 \times 10^{-15}$ cm^2
- $E_i^{152K} = E_v + 0.42$eV
- $\sigma_p^{152K} = 2.3 \times 10^{-14}$ cm^2
- $E_i^{30K} = E_c - 0.1$eV
- $\sigma_n^{30K} = 2.3 \times 10^{-14}$ cm^2

I. Pintilie, E. Fretwurst, G. Lindström, A. Junkes (e.g. Appl. Phys. Lett. 92, 024101, 2008)

Disclaimer: This poster cannot present all recent results of the whole RD50 collaboration, for more information please visit the website (see http://www.cern.ch/rd50)

Urmila Soldevila on behalf of CERN RD50 Collaboration, Orlando (Florida), October 2009.

Conclusions

- Radiation Damage in Silicon Detectors
  - Change of Depletion Voltage (type inversion, reverse annealing, …) (can be influenced by defect engineering!)
  - Increase of Leakage Current (same for all silicon materials)
  - Increase of Charge Trapping (same for all silicon materials)

Signal to Noise ratio is quantity to watch (material + geometry + electronics)

- CERN-RD50 collaboration working on:
  - Material Engineering (Silicon: DOFZ, MCz, EPI, …) (RD42: Diamond)
  - Device Engineering (3D, thin sensors, n-in-p, n-in-n, …) (RD39: Cryogenic, CI)

- Microscopic defects
  - Good understanding of damage after γ-irradiation (point defects)
  - Damage after hadron damage still to be understood (cluster defects), however enormous progress in last 2 years

→ To obtain ultra radiation hard sensors a combination of material and device engineering approaches depending on radiation environment, application and available readout electronics will be the best solution

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- At fluences up to 10^{15}ncm^{-2} (outer layers of SLHC detector) the main problems are the depletion voltage changing and the large area to be covered
  - MCz silicon detectors could be a solution (more work needed!)

    n-MCz: with mixed irradiation proton damage "compensates" part of neutron damage (Neff). More charge collected at 500V after additional irradiation !!
  - P-type silicon microstrip detectors show prommising results :

    CCE ≈ 6500 e$^-$; $\varphi_{eq} = 4 \times 10^{15}$cm^{-2}, V=500V, 300µm, immunity against reverse annealing!

    This is presently the baseline option for the ATLAS upgrade.
- Diamond has become an interesting option for the innermost pixel layers (no part of RD50 project)

- At fluences of 10^{16}ncm^{-2} (inner SLHC layers) the active thickness of any silicon material is significantly reduced due to trapping.

  Collection of electrons at electrodes essential: Use n-in-p or n-in-n detectors!
  - Recent results show that planar silicon sensors might still give sufficient signal (still some interest in epitaxial silicon and thin sensor options)
  - 3D detectors: looks promising, drawback : technology has to be optimized!

    Many collaborations and sensor producers working on this.

Remarks

- n-strip readout (n-in-n or n-in-p) looks promising
- Trapping is the main villain at high fluences
  - Consider high voltage (800-1000V) operation to achieve adequate CCE
- High and homogeneous oxygen content (e.g. MCz) is more radiation tolerant vs. charged particle radiation (see already RD48)
- p-material does not show significant annealing behaviour for CCE
- In all cases, RD50 gives only recommendation:
  - Especially SNR with specific electronics, final geometry and process technology must be considered
  - All simulation fit parameters need adaptations to the specific case