Radiation hard silicon: microscopic damage, effective doping and dark current.

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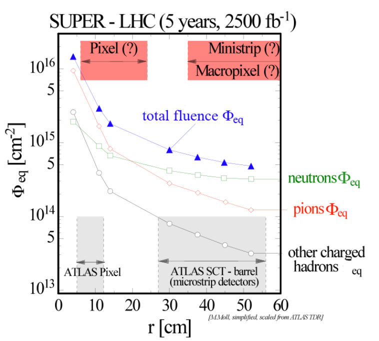
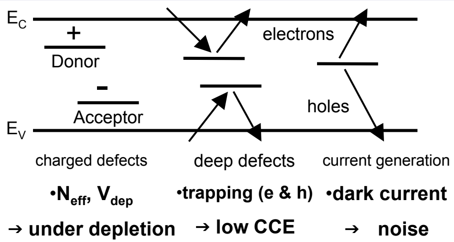
Motivation

sLHC fluences after 5 years



- $\Phi(r=4\text{cm}) \approx 1.6 \times 10^{16}\text{cm}^{-2}$
- hadron irradiation

Irradiation produces bulk damage



1. approach:
environmental conditions

- N_{eff}: cooling during beam off
- trapping: cooling does not help
- I_{dep}: cooling during operation

2. approach: defect engineering

aims

- identification of damage induced defects
- kinetics of defect formation
- Defect engineering and operational conditions

methods

- combined microscopic and macroscopic measurements
- defect analysis by DLTS and TSC
- detector properties by CV/IV characteristics

Identifying defects with impact on sensor properties

microscopic techniques

1. Deep Level Transient Spectroscopy - for $\Phi_{eq} < 10^{12}\text{cm}^{-2}$
   - capacitance transients during the emission from filled traps
2. Thermally Stimulated Current - for $\Phi_{eq} > 10^{12}\text{cm}^{-2}$
   - current due to emission from filled traps

measured quantities:

- position in bandgap ΔE_T; capture cross sections $\sigma_{n,p}$; trap concentration

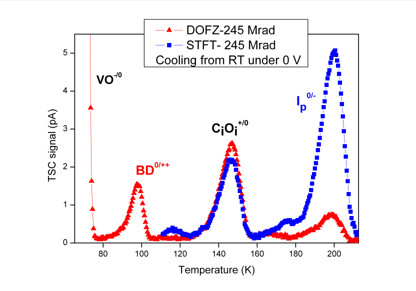
Then take defect concentrations and:

1. follow defect kinetics during the annealing
2. combine results with macroscopic measurements

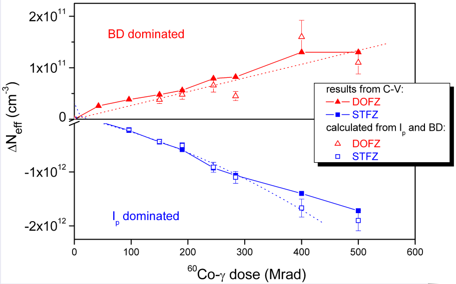
Example: oxygen rich material for LHC

- ^{60}C0-γ irradiation creates only point defects, no clusters

TSC-results



ΔN_{eff}

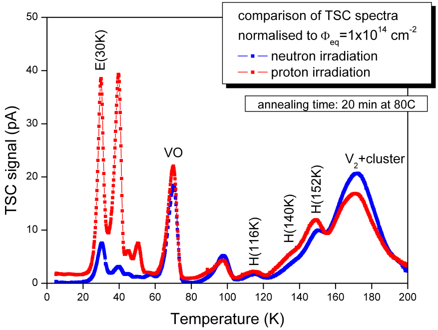


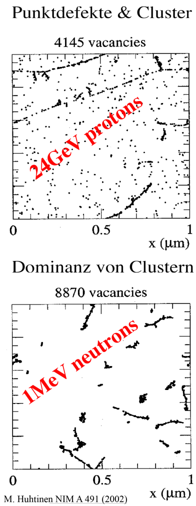
change of N_{eff} well described

First breakthrough in understanding the damage effects

Problem with hadron incuced damage: cluster defects

TSC results for EPI-DO after neutron and proton irradiation

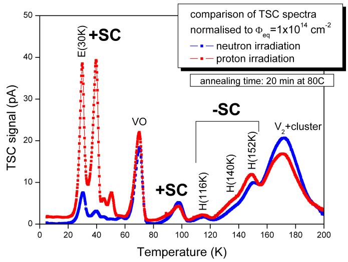




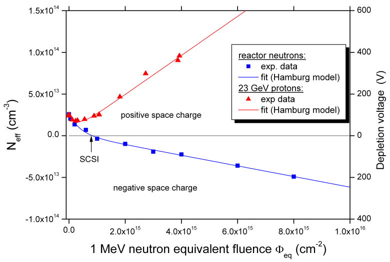
- cluster independent on material
- cluster most likely multiple vacancies

Influence of detected defects on N_{eff}

TSC results for EPI-DO after neutron and proton irradiation



development of N_{eff} for EPI-DO neutron and proton irradiation

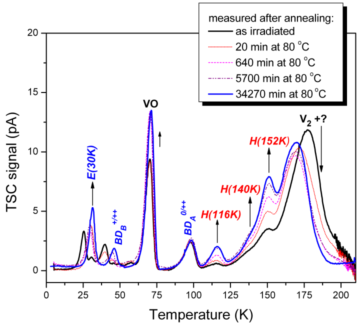


- SCSI after neutron but not after protons
- donor generation enhanced after proton irradiation

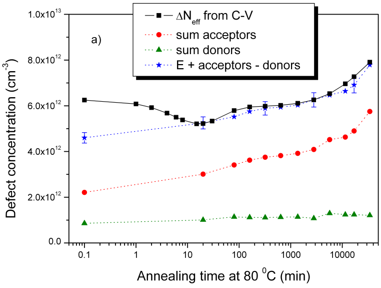
microscopic defects explain macroscopic effects

Isothermal annealing $\Phi_{eq} = 5 \times 10^{13} cm^{-2}$ (1MeV n)

TSC-results (EPI-DO)



microscopic vs. macroscopic

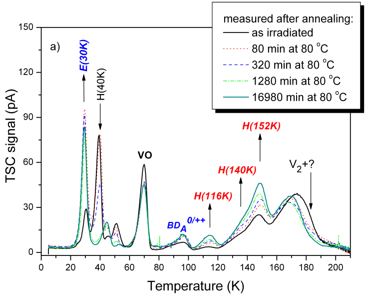


- acceptor generation dominates
- reverse annealing can be explained by deep acceptor traps

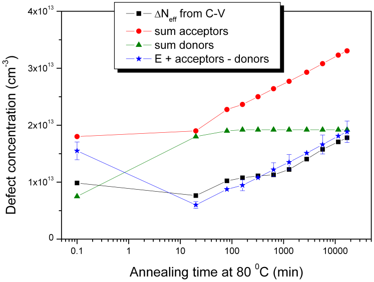
microscopic results predict macroscopic findings!

Isothermal annealing $\Phi_{eq} = 2 \times 10^{14} cm^{-2}$ (23 GeV p)

TSC-results (EPI-DO)



microscopic vs. macroscopic



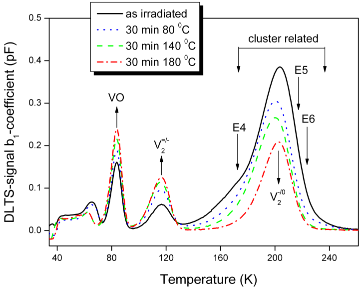
- donor generation enhanced relative to acceptor traps
- donor generation partly compensating acceptors

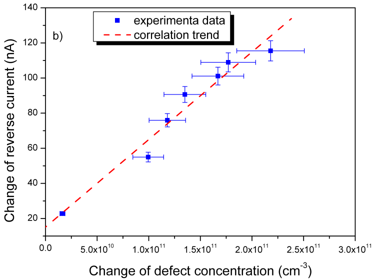
real breakthrough in understanding irradiation damage

Dark current correlates with deep electron clusters

DLTS study of MCz, $\Phi_{eq.} = 3 \times 10^{11} cm^{-2}$

only electron traps are shown





close correlation to cluster related deep electron traps

summary

- beneficial impact of oxygen enrichment related to point defects
- cluster related defects responsible for hadron damage
- complete understanding of defect kinetics achieved

outlook

- introducing hydrogen to passivate dangling bonds
- mixed irradiations - important for larger radii
- p-type material - no type inversion?