AIDA-2020-POSTER-2019-005

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Advanced European Infrastructures for Detectors at Accelerators

Poster

Radiation damage in p-type EPI silicon pad diodes irradiated with different particle types and fluences

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20 February 2019

The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package **11: Irradiation test facilities**.

EP-DT Detector Technologies

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Radiation damage in p-type EPI silicon pad diodes irradiated with different particle types and fluences

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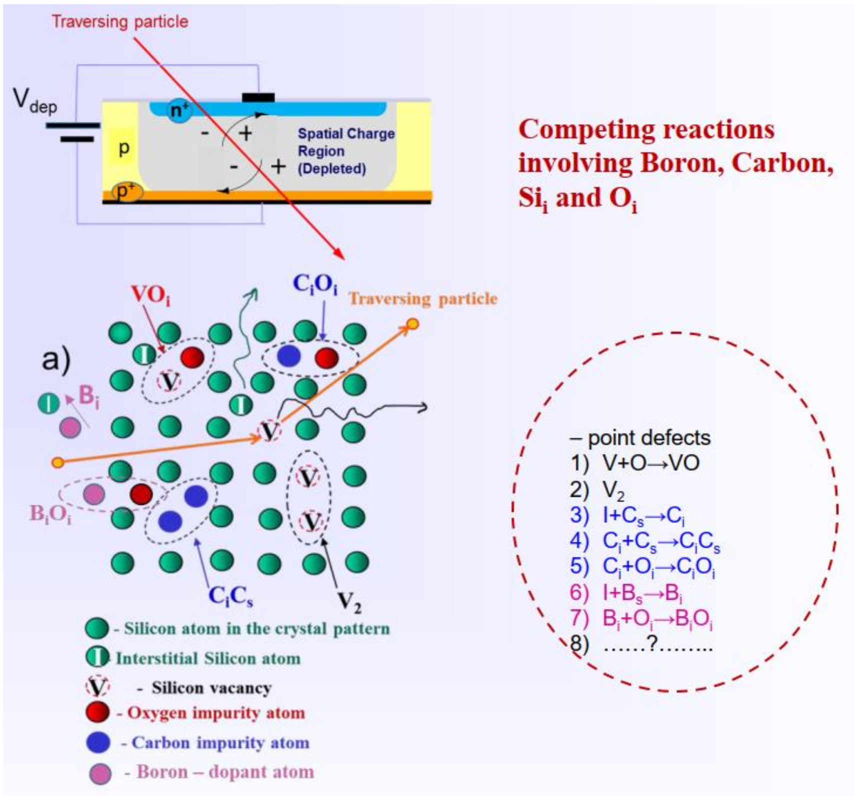
Motivation and Background

Acceptor removal in p-type silicon (Si): radiation induced de-activation of Boron (B) as a shallow dopant with increasing particle fluence (Φ_{eq}) leads to a change of depletion voltage (V_{dep}) and effective doping concentration (N_{eff}).

Impact: removal of B in low-resistivity p-type Si devices is responsible for the loss of amplification gain in Low Gain Avalanche Detectors (LGADs) and for the change of depletion depth in HV-CMOS sensors. Both devices are of high interest for future HEP experiments. Understanding and potentially mitigating the acceptor removal effect is essential for those developments.

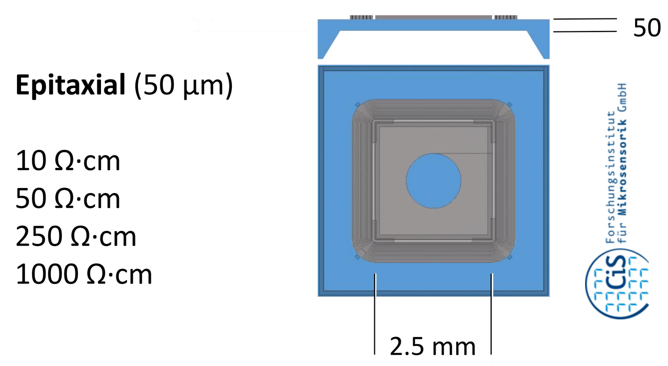


Origin: The origin of device degradation is found in the formation of microscopic crystal defects. Boron is bound into defect complexes like the BiOi (Boron interstitial – Oxygen interstitial) which no longer exhibits the shallow acceptor properties.

Materials and samples

Within *RD50* systematic study is being conducted using a large number of identical sensors with variation of thickness, doping (Boron concentration) material type and irradiation.

Simple p-type pad diodes



Irradiation

	IRRAD (PC protons 24 GeV/c)		Institut "Jožef Stefan" (reactor neutrons)			
Φ_{eq} (n_{eq}/cm^2)	7.80E12	3.86E13	7.80E13	3.32E14	7.32E14	7.02E15

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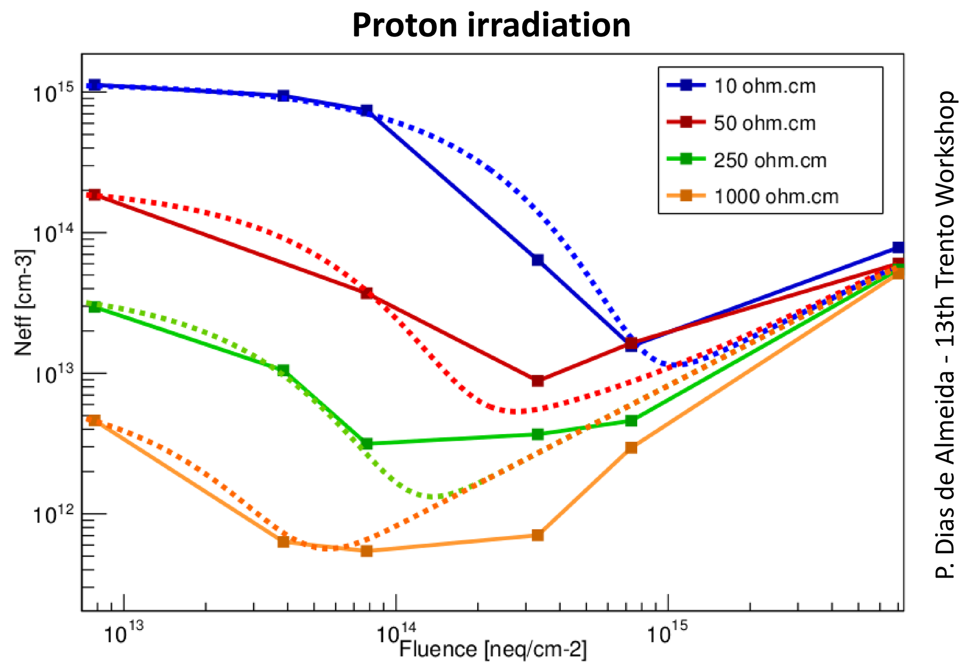
Methods of characterization

- Standard electrical characterizations (I-V, C-V)
- TCT (Transient Current Technique)
- TSC (Thermally Stimulated Current) techniques
- Annealing studies

Macroscopic measurements results

Proton irradiation



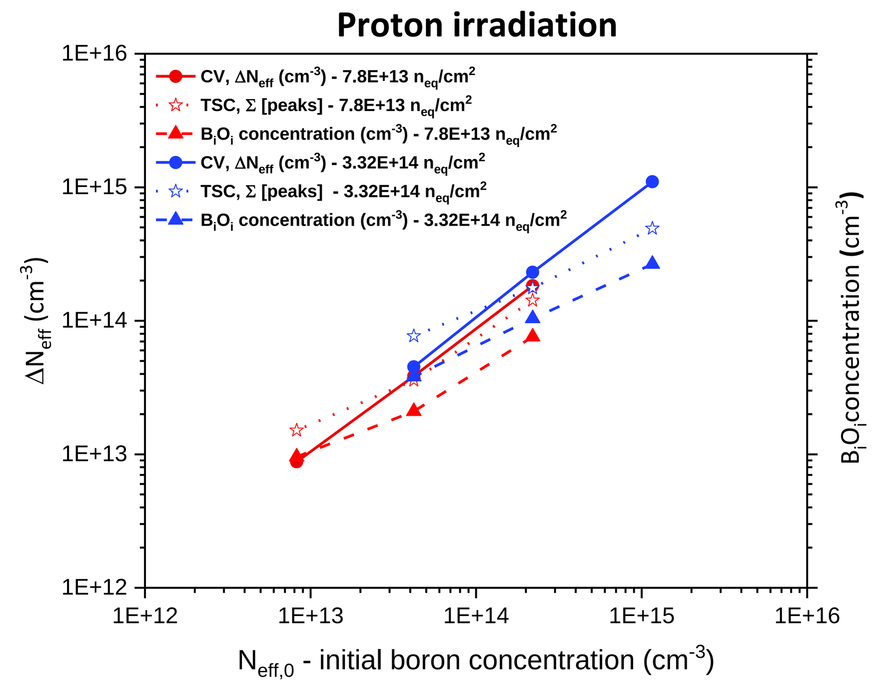
Fluence- and material resistivity-dependent N_{eff} from C-V measurement

- Leakage current increases with fluence Φ_{eq}
- V_{dep} estimated from C-V curves changes with fluence Φ_{eq} ⟶ change in effective doping

$$V_{dep} = \frac{q_0}{\varepsilon\varepsilon_0}|N_{eff}|d^2$$

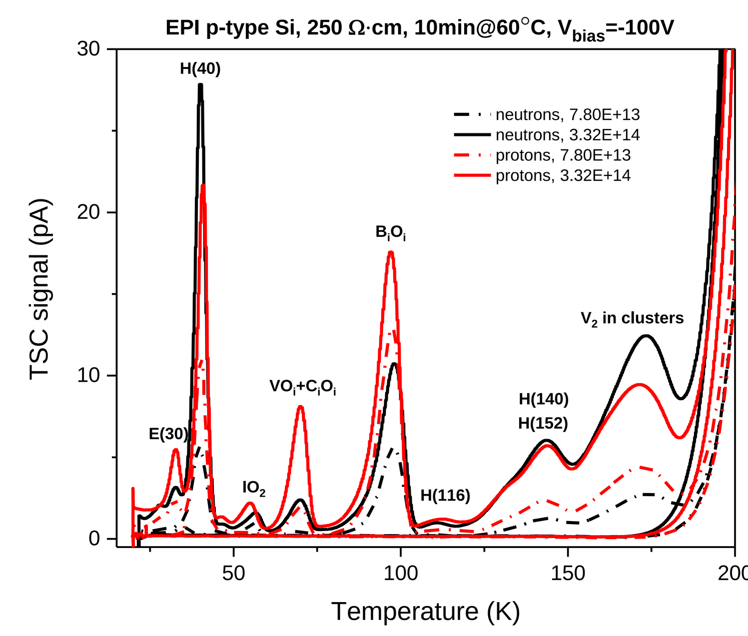
Macroscopic vs. Microscopic data

Proton irradiation



Microscopic defects cause change in Macroscopic properties

Microscopic measurements results

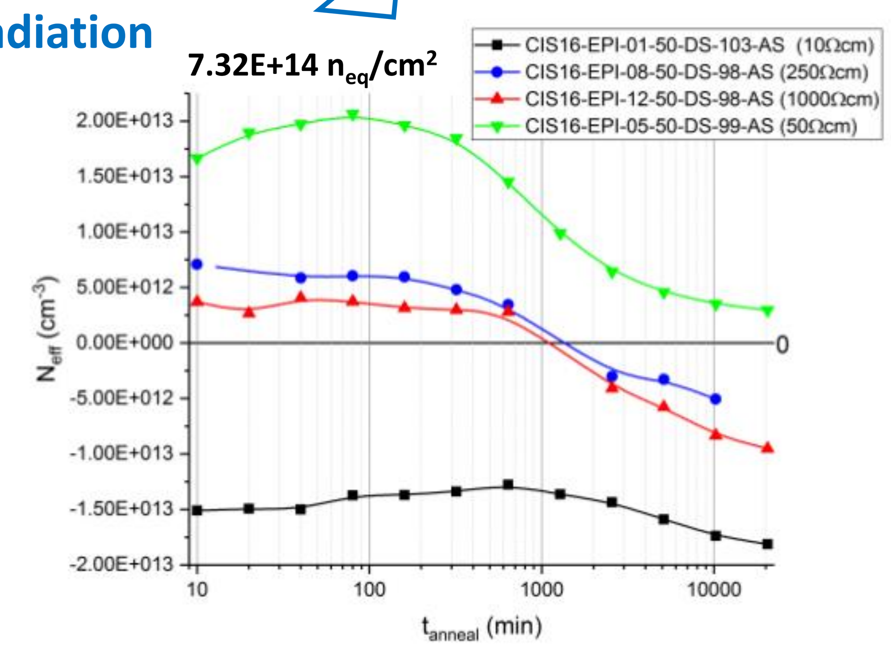


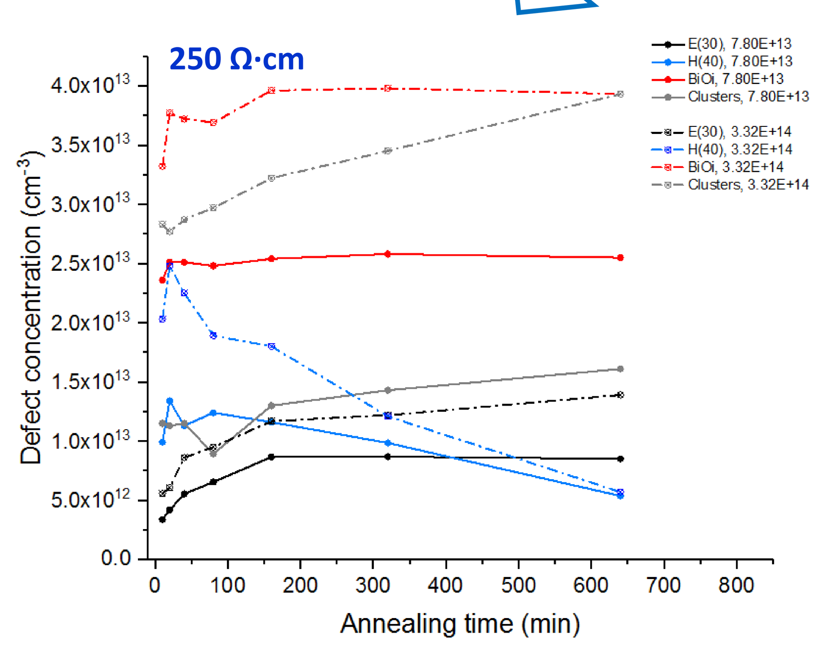
Material resistivity- and particle type-dependent TSC scan at two fluences

- Clusters (V-related) defects contributing to leakage current (both increasing proportional with fluence)
- Defects with impact on space charge:
  + donors: E(30) and B_iO_i
  - acceptors: H(116), H(140) and H(152)
  ± H(40) with unknown impact

Isothermal Annealing @60°C. Proton irradiation

Lower resistivity sensors show space charge sign inversion (type inversion) via proton irradiation and long-term annealing (proved by TCT measurements)



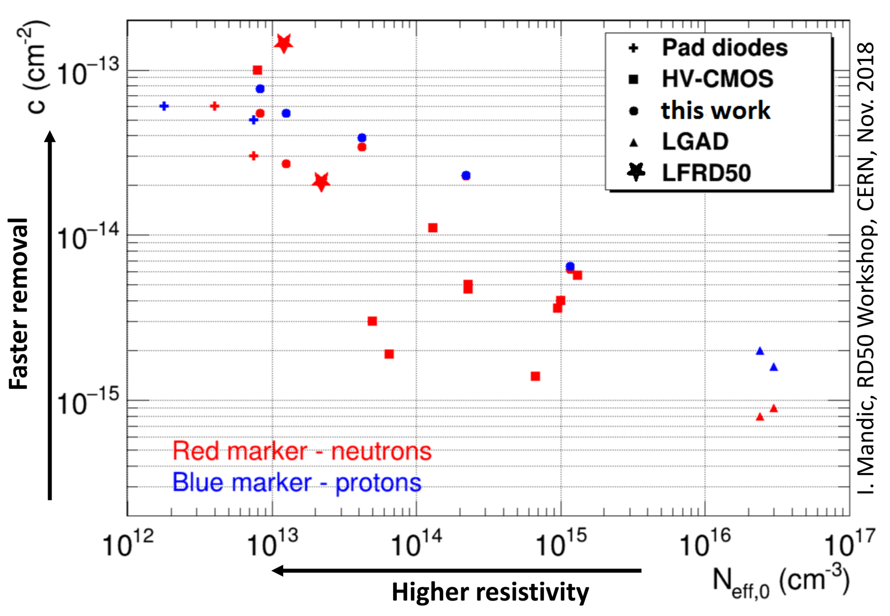


B_iO_i concentration stays stable, not affected by isothermal annealing @60°C (in line with annealing study on LGADs)

A complete set of results can be found here: *Y. Gurimskaya et al., 33rd RD50 Workshop*

Change in N_{eff} (C-V measurements) and concentration of the defects with an impact on the space charge (TSC measurements) vs annealing time

Parameterization of acceptor removal



Parameterization as $\Delta N_{eff}(\Phi) = N_{c0}e^{-c\Phi}$ with complete acceptor removal ($N_{c0} = N_{eff,0}$) for proton irradiation and incomplete – for neutron irradiation.

- *c* drops with increasing $N_{eff,0}$
- *c* higher after proton irradiation (higher [BiOi] concentration after p-irradiation)

Compilation of available data on the acceptor removal parameter *c* as a function of initial acceptor concentration $N_{eff,0}$. Data obtained in this work after 24 GeV/c proton and reactor neutron irradiation on epitaxial silicon sensors is included.

Conclusions

- Parameters from I-V, C-V, TSC measurements on irradiated p-type Si sensors are compared
- Results from electrical characterization campaign for proton and neutron irradiated EPI pad diodes agree with other recently published results
- TSC spectra obtained for proton and neutron irradiated sensors with various fluences leads to the formation of the same defects for both particle types differing however in the absolute and relative defect introduction rates
- Clear correlation between the concentration of defects contributing to the space charge (E(30), deep acceptors, B_iO_i) and the acceptor removal effect as a function of irradiation type and fluence, material type and resistivity was observed
- Further DLTS and TSC measurements are foreseen (light and forward current injection, γ irradiation, isochronal annealing study)