Radiation hardness investigation of thin and low resistivity bulk Si detectors

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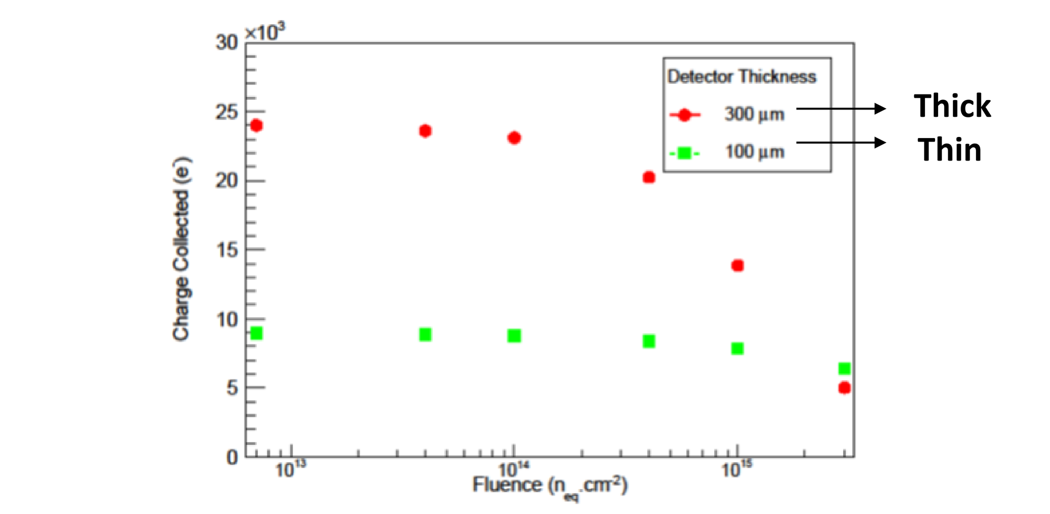
Si detectors in HEP experiments

- Placed close to particle collision point
- Widely used in tracking and vertexing
- Reasonably radiation harder than other detectors
- However, **drastic degradation of charge collection with fluence** [1,2]
- Also confirmed by simulation result

Charge Collection for N_h = 1 x 10^{12} cm^{-3}



[1] G. Casse et al., New operation scenarios for severely irradiated silicon detectors, PoS (Vertex) 008 (2009).
[2] G. Kramberger, Comparison of pad detectors produced on different silicon materials after irradiation with n, p & pions, NIM A 612 (2010) 288 - 295.

Motivation for the study

- Future HEP experiments to have even higher radiation environment
- **Development of new Si detector technology mandatory**
- New design must be able to collect reasonable charge at high fluence

- **A possible candidate:**

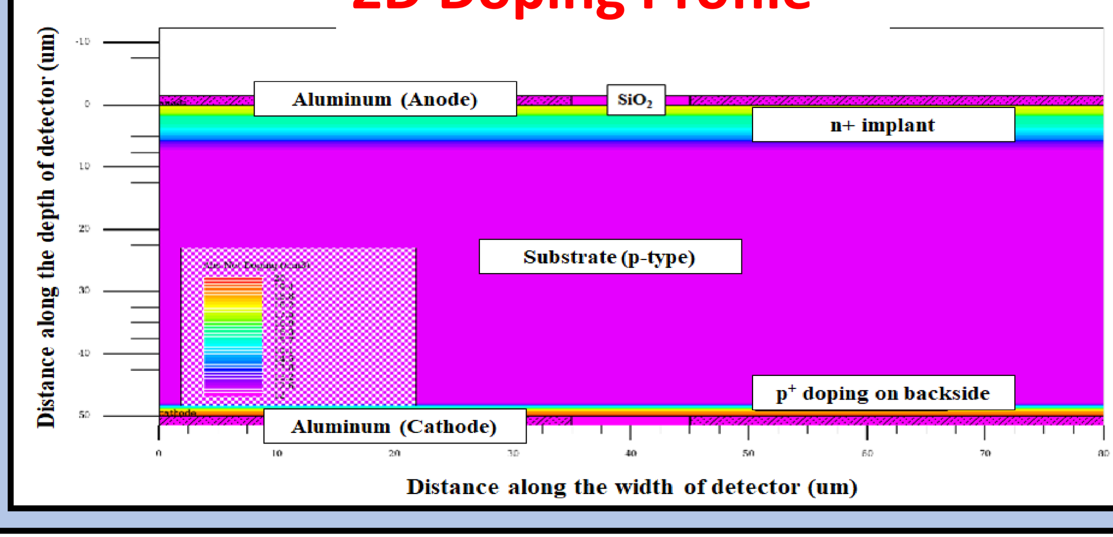
Low resistivity (ρ) or High bulk doping concentration (N_b) Si substrate

Principle of operation:
- Building up of a stronger frontside junction → Localized high electric field
- Internal charge multiplication occurs
- Larger charge may be collected at high fluence.

TCAD Silvaco Simulation Tool

Simulation Parameter	Value
Device Type	n-on-p type
Geometry	Plane parallel
Operating temperature	253 K
Laser Illumination for CC	Infrared (1064 nm)

2D Doping Profile



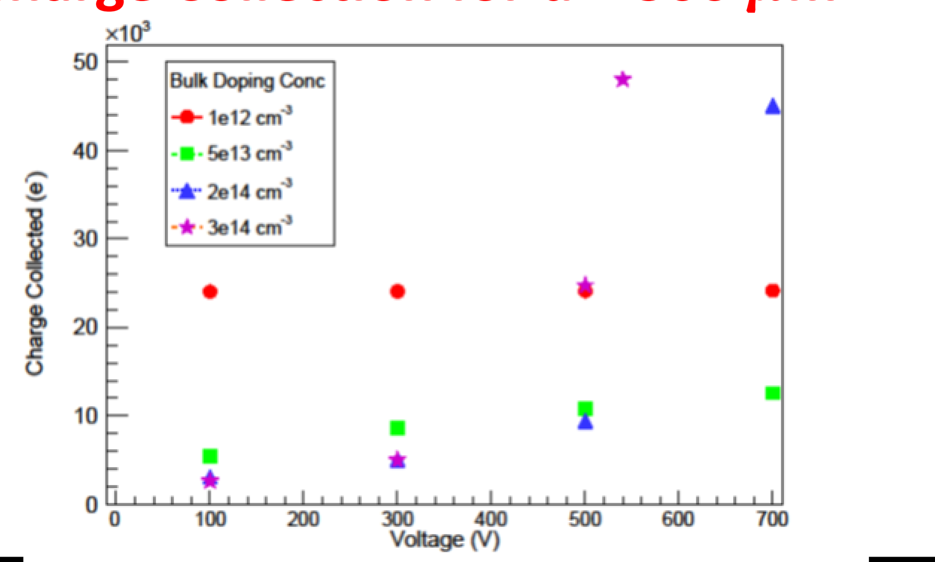
Proton Radiation Damage Model [3]

Trap	Energy Level	Density (cm^{-3})	σ_e (cm^{-2})	σ_h (cm^{-2})
Acceptor	E_C - 0.51 eV	4 X fluence	2.0 x 10^{-14}	3.8 x 10^{-14}
Donor	E_V + 0.48 eV	3 X fluence	2.0 x 10^{-15}	2.0 x 10^{-15}

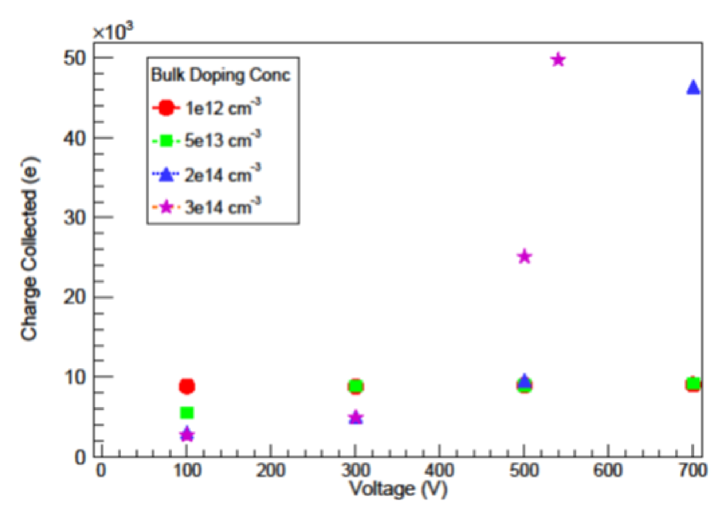
[3] R. Dalal, G. Jain, et al., Simulation of Irradiated Si Detectors, PoS **030** (2014).

Non-Irradiated Behaviour

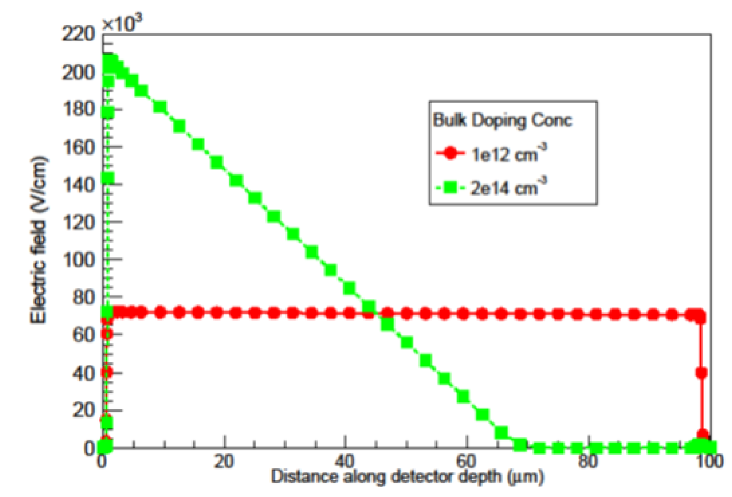
Charge Collection for d = 300 μm



Charge Collection for d = 100 μm



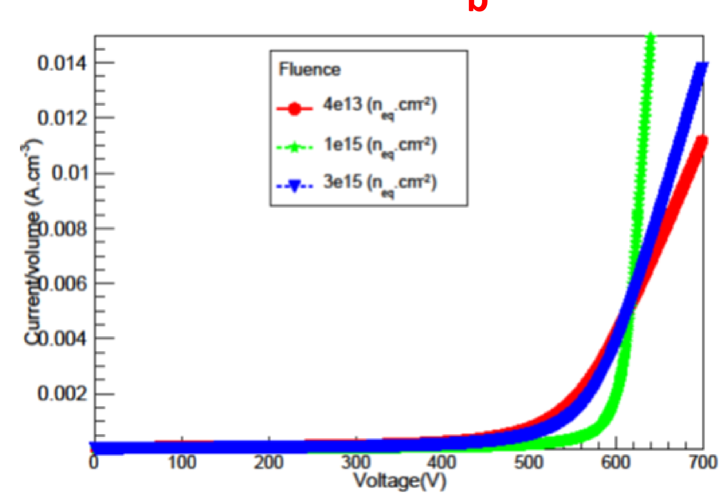
E.Field Profile for d = 100 μm @ 500 V



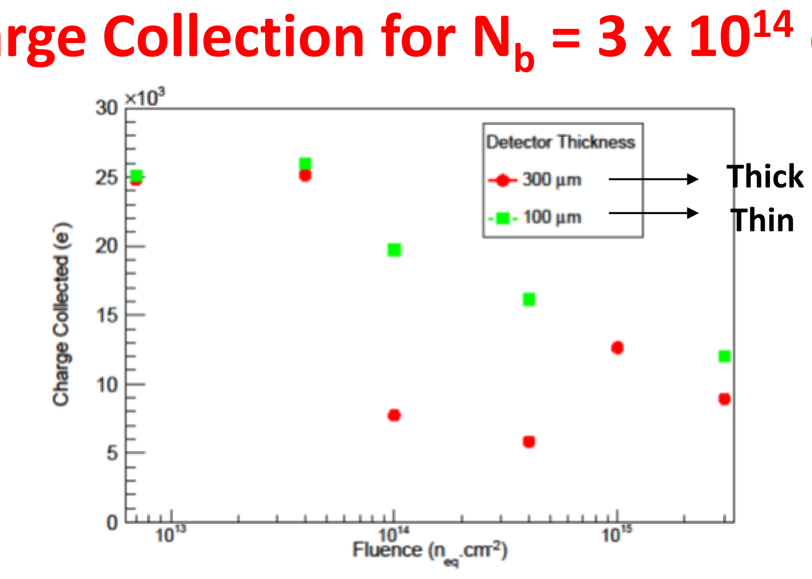
- High charge collection (CC) is observed at large N_b after a certain bias voltage. Thin detector radiation harder than thick detector.
- **Reason for high CC:** E.field peaks at frontside due to stronger PN junction → leads to charge multiplication, thereby high CC.

Irradiated Behaviour

IV Characteristics for N_b = 3 x 10^{14} cm^{-3}



Charge Collection for N_b = 3 x 10^{14} cm^{-3}



- IV characteristics demonstrate breakdown greater than 500 V of applied voltage.
- CC decreases, increases, before gradually decreasing – which is an observed characteristic for high N_b [4].

Summary

→ **Thin low ρ (High N_b) substrate radiation harder than high ρ, if operated at a certain value of bias voltage (below breakdown voltage).**

→ **Survives at high fluence.**

→ **Need systematic investigation to understand better.**

[4] A. Affloder et al., CC studies in irradiated HV-CMOS particle detectors, JINST **11** (2016) P04007.

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La Biodola, Isola d'Elba (Italy). May 27 – June 2 2018.