TCAD Simulation and Design Optimization of Radiation Hard n-MCz and n-Fz Si Microstrip Detector for the HL-LHC

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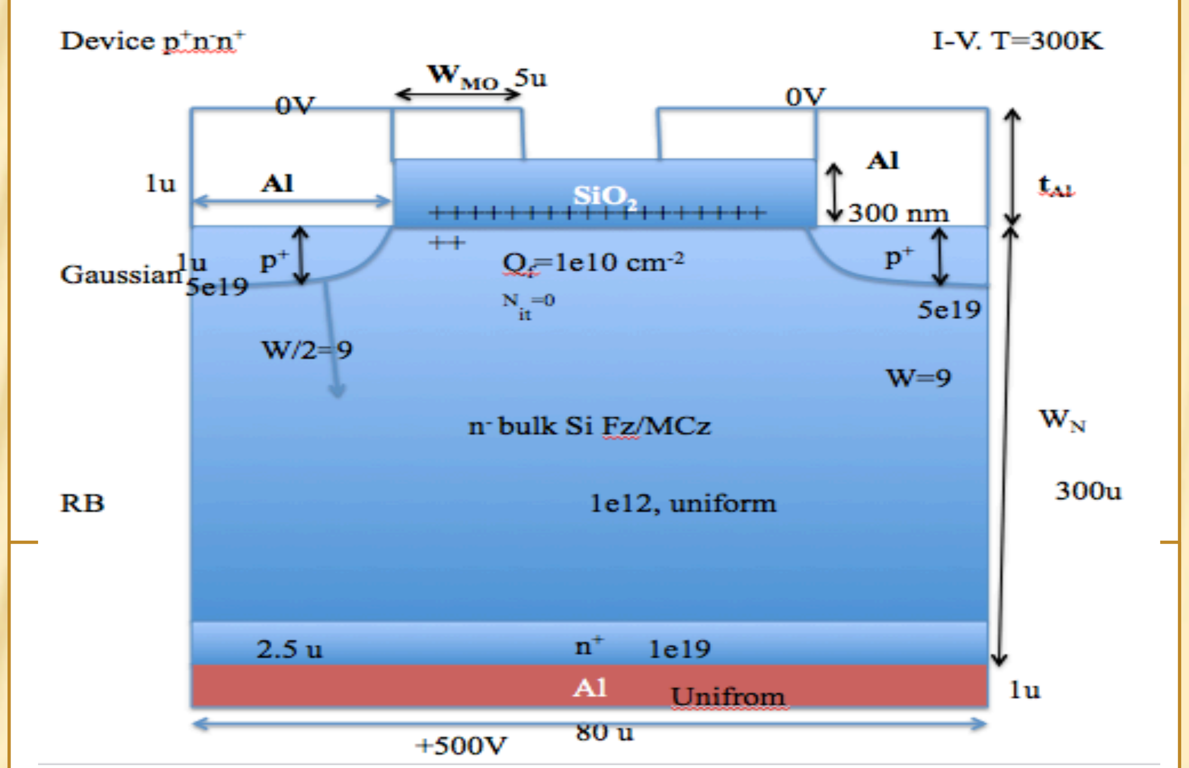
Abstract

A radiation hard Si detector is used in the new CMS tracker detector at HL-LHC. It has been observed that n-MCz and n-Fz Si as a material can be used for the Si microstrip detector. The detector design for this material should be simulated and optimized to get high CCE. In order to understand the charge collection behavior of the n-MCz/n-Fz Si detector, it is required to simulate and compare the radiation damage effects in the mixed irradiated n-MCz Si and proton irradiated n-Fz Si microstrip detector equipped with metal overhang and multiple guard rings.
In this paper,we have done analysis and optimization of the radiation hard n-MCz Si/n-Fz Si strip detector design for the HL-LHC experiment in order to get high CCE.

n-Fz/n-MCz Silicon (Si) Strip Detector Model



➢ Cross-section of the 0.0625 cm² x 200/300µm n-Fz/n-MCz Si strip detector /PAD diodes used in the present study for SRH calculations and TCAD device simulation

❑Multiple Guard Rings (MGR) Layout for t n-MCz Silicon Strip Detector (Proposed)

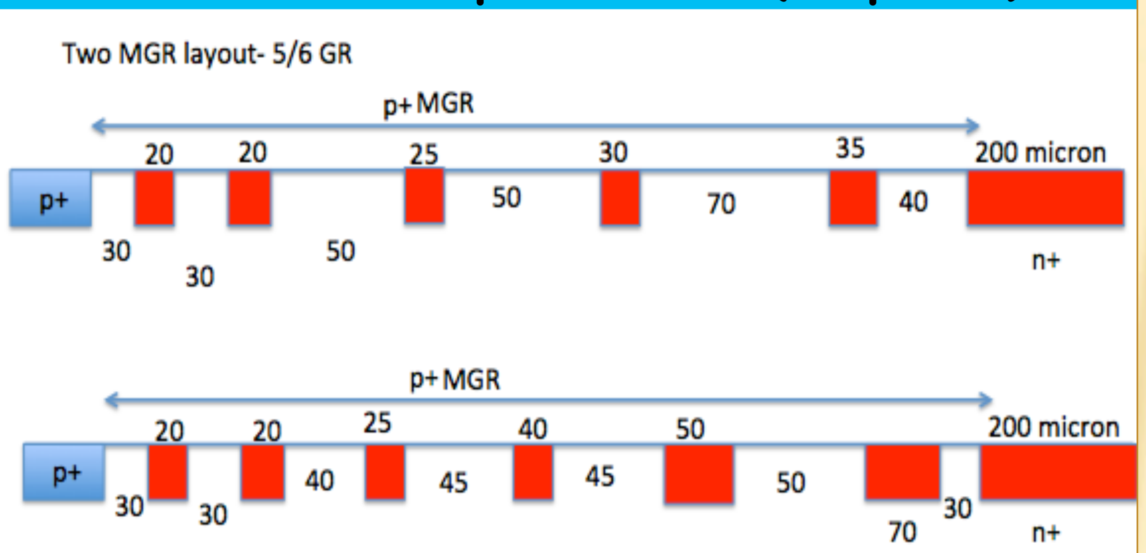


Table.1 List of Physical Parameters

S.NO.	Physical parameters	Values
1.	Doping concentration (N_D)	5 x10^{12} cm^{-3}
2.	Oxide +nitride thickness (t_{ox})	0.3+.05 µm, nitride added to prevent physical damage on the interface surface
3.	Junction Depth (X_j)	1 µm
4.	Device depth (W_n)	200/300 µm
5.	Fixed oxide charge (Q_f)	1.5x 10^{12} cm^{-2}

SRH Calculations [1]

$$N_{eff} = N_D + \sum n_T^{donor} - \sum n_T^{acceptor},$$

$$n_T^{donor,acceptor} = N_T^{donor,acceptor} \frac{e_{p,n}}{e_p + e_n}$$

$$I(V_{FD}) = q_0 A d \left(\sum e_n n_T^{acceptor} + \sum e_p n_T^{donor} \right) \approx q_0 A d \frac{n_i}{\tau_{g,eff}}$$

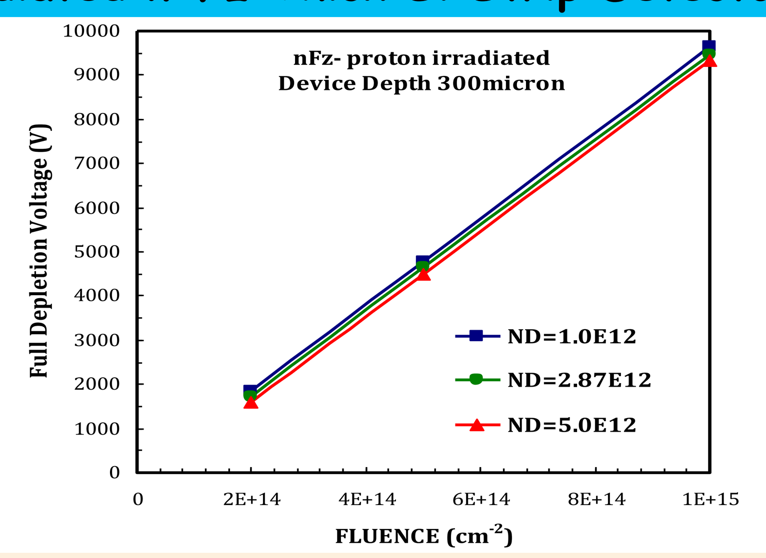
Hamburg Penta Trap Model (HPTM) for Proton Irradiation in n-FZ Si Strip Detector[2]

Defect	Type	Energy	g_{int} (cm^{-1})	σ_n (cm^2)	σ_p (cm^2)
E30K	Donor	E_C-0.1 eV	0.0497	2.300E-14	2.920E-16
V_3	Acceptor	E_C-0.458 eV	0.6447	2.551E-14	1.511E-13
I_p	Donor	E_C-0.545 eV	0.4335	4.478E-15	6.709E-15
H220	Donor	E_V +0.48 eV	0.5978	4.166E-15	1.965E-16
CiOi	Donor	E_V +0.36 eV	0.3780	3.230E-17	2.036E-14

Four Level Deep Trap Mixed Irradiated Radiation Damage Model for n-MCz Si Strip Detector [3]

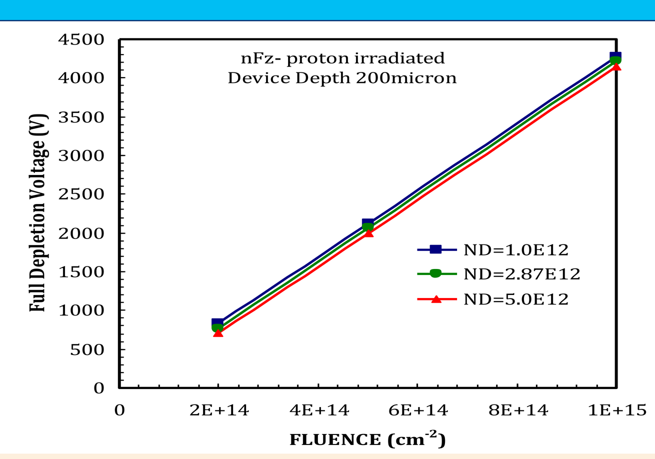
➢ Used Hamburg Penta Trap model (HPTM) for proton radiation damage effect [2] in n-Fz and Mixed-irradiated n-MCz model in thin/thick Si strip detector in the present analysis.

❑Full depletion voltage as a function of the Fluence in Proton Irradiated n-Fz Thick Si Strip Detector



➢ Hamburg Penta Trap Model (HPTM) model can reproduce the experimental data in n in p, here we used in 300 µm n-Fz proton irradiated Si strip detector as shown in (1), V_{fd} estimated from SRH calculations (2) and decreases with increasing doping concentration
➢Significant increase in V_{fd} with the proton radiation fleunces (Φeq,n (fluence), equivalent to 1 MeV neutron) in n-Fz detector using HPTM model (1)

❑Full Depletion Voltage as a function of the Fluence in Proton Irradiated n-Fz Thin Si Strip Detector

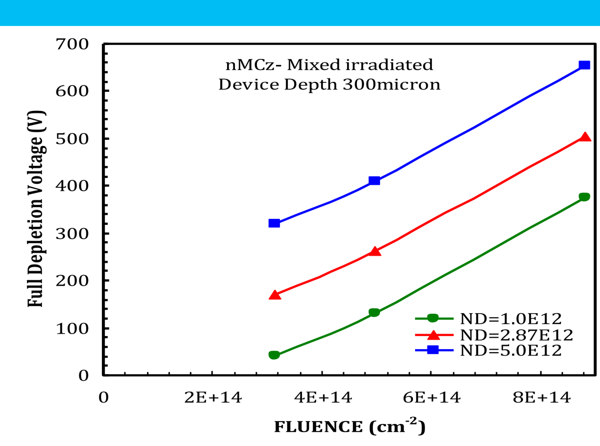


➢HPTM model can used to get V_{fd} in 200 µm n-Fz proton irradiated Si strip detector, 50% less V_{fd} have been obtained in 200 µm n-Fz proton irradiated Si strip detector than 300 µm strip detector irradiated by protons

➢Significant increase in V_{fd} using HPTM observed using SRH calculations in the proton irradiated detector by 24 GeV/c protons, HPTM needs to tune the parameters to reproduce the macroscopic measurements for the good agreement in the experimental data and simulation data on n Fz Strip detector/diodes too using Silvaco ATLAS TCAD

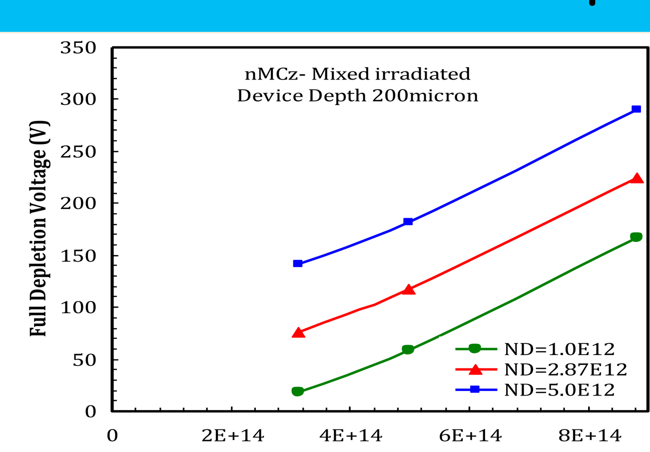
➢For the 5x10^{12} cm^{-3} doping of n-Fz bulk, less full depletion voltage (705V) obtained for the fluence of 2x10^{14} cm^{-2} than other fluences

❑Full Depletion Voltage as a function of the Fluence in Mixed Irradiated n-MCz Thick Si Strip Detector



➢ V_{fd} increases with the mixed irradiated fluences for the three doping concentrations in thick n-MCz Si strip detector, less full depletion voltage obtained than other n-Fz proton radiated detectors , less V_{fd} observed due to the compensation of the deep traps in n-MCz as compared to n-Fz Si strip detector

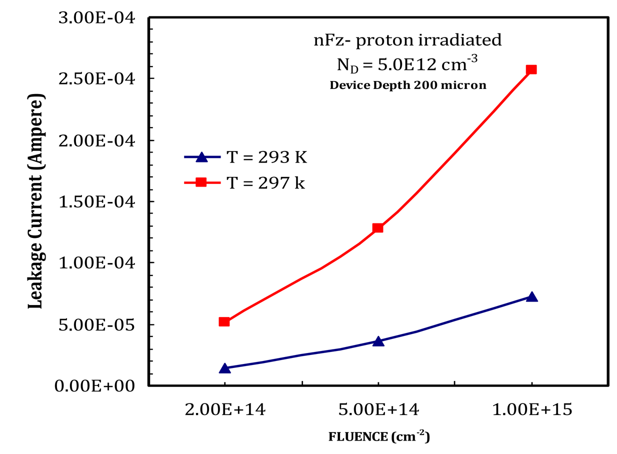
❑ Full Depletion Voltage as a function of the Fluence in Mixed Irradiated n-MCz Thin Si Strip Detector



➢V_{fd} increases with the mixed irradiated fluences for the three doping concentrations in thin n-MCz Si strip detector too, less full depletion voltage obtained than 300 µm Mcz Si strip detectors , less V_{fd} observed in the 1x10^{12} cm^{-3} n-MCz Si strip detector, although for comparison and isolation in between strips (with n⁺ in p detector) of the effect on the macroscopic performance and E-field distribution, have taken high doping 5x10^{12} cm^{-3} in the n-MCz strip detector design that is giving < 300 V full depletion voltage.

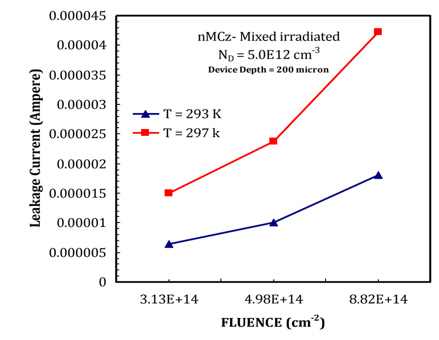
➢ Thin n-MCz Si strip detector can be operated at an applied bias of 500 V.

❑Leakage Current as a function of the Fluence in Proton Irradiated n-Fz thin Si Strip Detector at two Temperatures



➢ Leakage current increases with fluences at 293 (RT) , and 297 K (Rt+4K) that shows the experimental results a per (3)

❑Leakage Current as a Function of the Fluence in Mixed Irradiated n-MCz Thin Si Strip Detector at two Temperatures

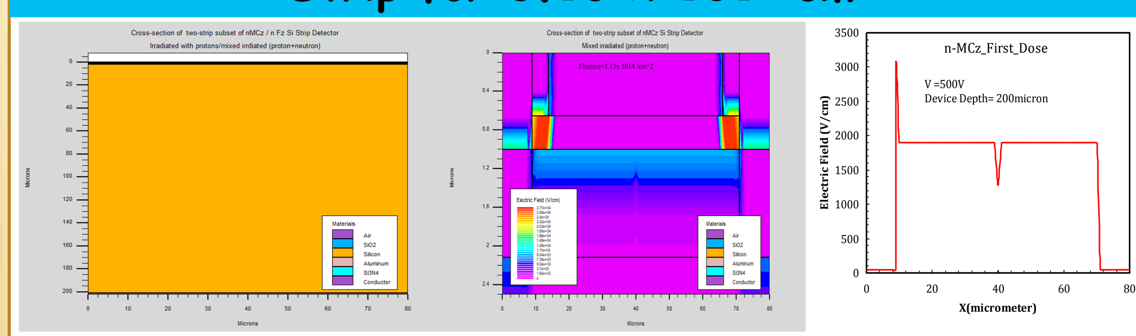


➢ Leakage current increases with fluences at 293 (RT) , and 297 K (RT+4K) that shows the experimental results as per reference (3)
➢Less Leakage current showed in the nMcz Si strip detector than n Fz strip detector at two temperatures (293 K, 297 K)

TCAD Simulation Results

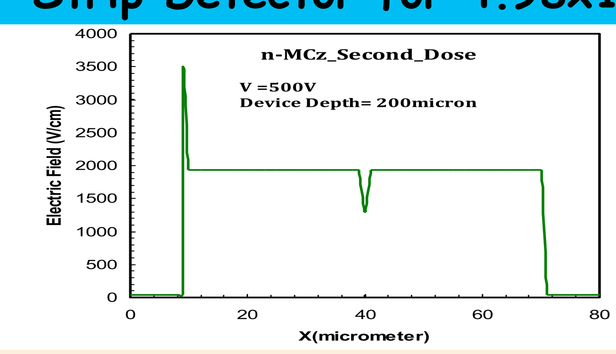
➢Used physical Model in Silvaco ATLAS-SRH Recombination, Doping dependent mobility, Impact ionization, Interface, Band gap narrowing, High field, Band to band tunneling, Trap Assisted tunneling (Hurks model),

Electric Field of Mixed Irradiated n-MCz Thin Si Strip for 3.13 x 10^{14} cm^{-2}



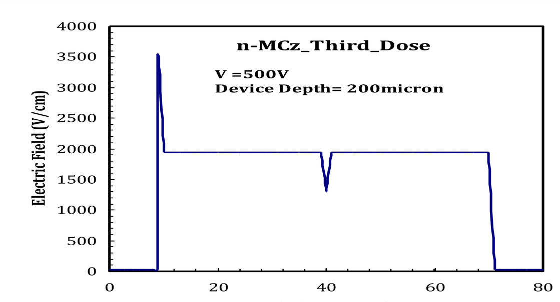
➢ Low E-field obtained in the base region of the detector, and E-field gutter observed in the Centre of the detector (X=40 µm, cut X=2.3 micron)

Electric Field of Mixed Irradiated n-MCz Thin Si Strip Detector for 4.98x10^{14} cm^{-2}



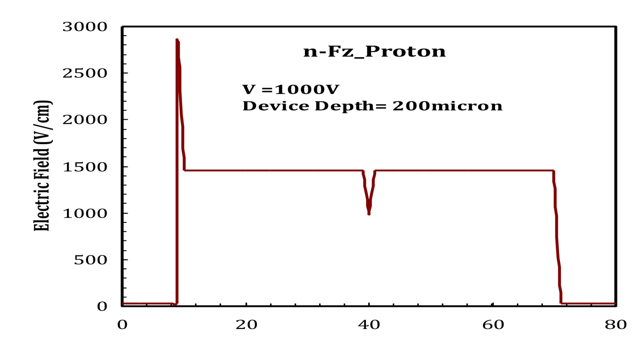
➢ E-field increases at curvature of junction and slightly increase at E-field gutter, X=40 µm

Electric Field of Mixed Irradiated n-MCz Thin Si Strip Detector for 8.82 x10^{14} cm^{-2}



➢ With an increasing mixed doses, E-field at curvature of junction saturates and at E-field gutter, X=40 µm too
➢E-field gutter can be cause of trapping of charge carrier

Electric Field of Proton Irradiated n-Fz Thin Si Strip Detector for 2x10^{14} cm^{-2}



➢ Less E-field at curvature of junction and in the base region of the detector, and also less E-field at E-field gutter than mixed irradiated n-MCz Si Strip detector
➢ High CCE expected in thin n-MCz than n-Fz Si strip detector, traps modifying E-field in the base region of the detector

Conclusion

➢SRH calculations explained the full depletion voltage and leakage current in n-MCz and n-Fz Si strip detector, less V_{fd} observed in thin MCz than thin Fz

➢ 200 µm n-MCz thin Si microstrip detector as design showed, high CCE expected than n-Fz, MGR proposed for the design – nMCz Si strip detector

References

1. Ajay K. Srivastava, *"Si Detectors and Characterization for HEP and Photon Science Experiment: How to Design Detectors using TCAD Device Simulation", Springer Nature Switzerland AG, Switzerland, ISBN:978-3-030-19530-4, 2019.*
2. J.Schwant et al., "A new model for the TCAD simulation of the silicon damage by high fluence proton irradiation", Arxiv:1904. 10234v1, 2019.
3. *A.Sharma, N.Saini, S.Patyal, B.Kaur, A.K. Srivastava, "Performance characteristics of mixed Irradiated n-MCz thin Si microstrip detector for the HL-LHC experiments", arXiv: 2103.02318v1, 2021.*

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