Investigation of Mixed Irradiation Effects in p-MCz Thin Silicon Microstrip Detector for the HL-LHC Experiments

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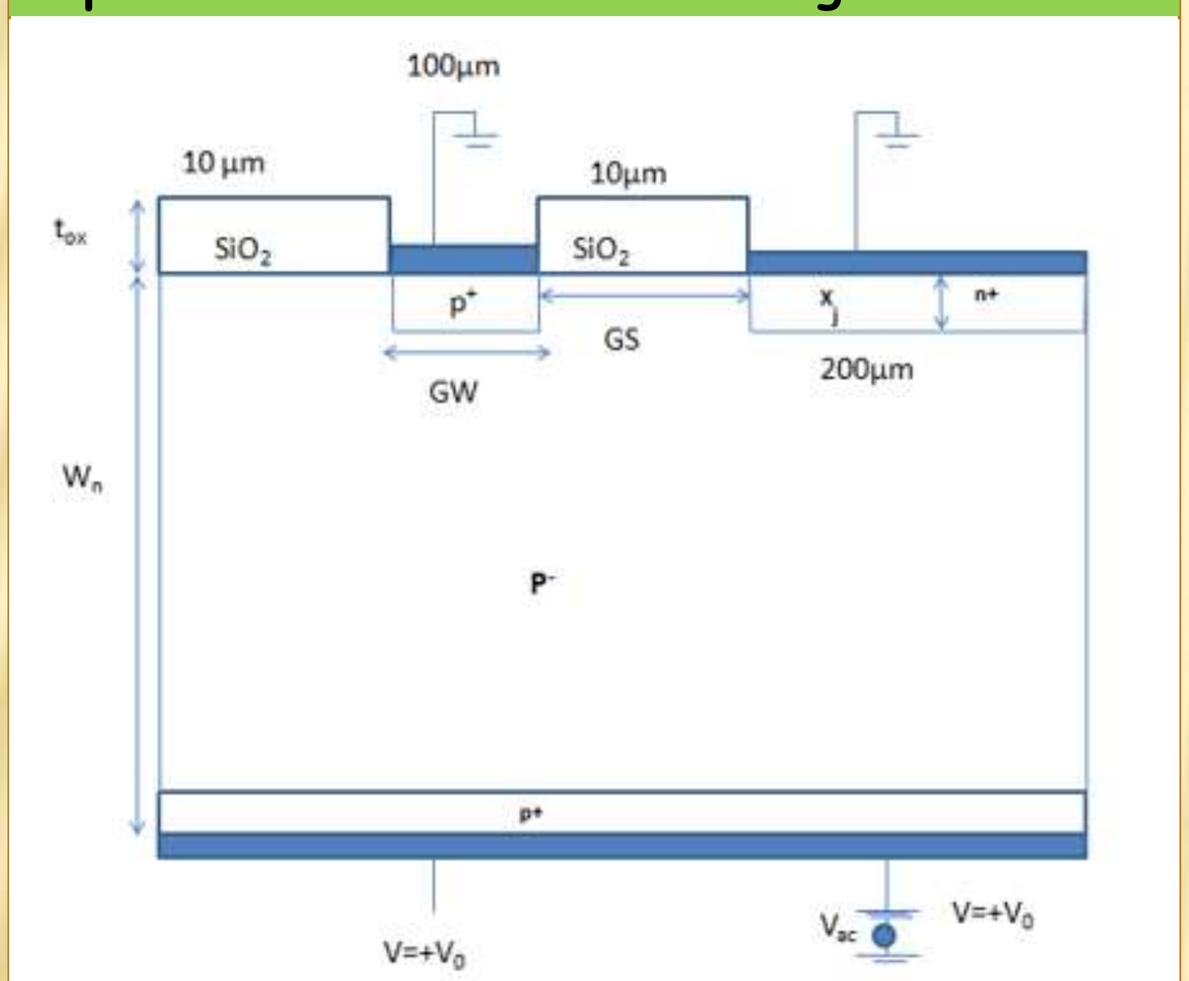
ABSTRACT: A lot of R & D work is carried out in the CERN RD50 Collaboration to find out the best material for the Si detectors that can be used in the harsh radiation environment of HL-LHC, n and p-MCz Si was identified as one of the prime candidates as a material for strip detector that can be chosen the phase 2 upgrade plan of the new Compact Muon Solenoid tracker detector in 2026. For the very first time, in this work, an advanced four level deep-trap mixed irradiation model for p-MCz Si is proposed by the comparison of experimental data on the full depletion voltage and leakage current to the Shockley Read Hall recombination statistics results on the mixed irradiated p-MCz Si PAD detector.
In this work, we have determined the effective introduction rate η_{eff} of shallower donor deep traps E30K using SRH theory calculations for exp. N_{eff} and that can shown the behavior of space charges and electric field distribution in the p-MCz Si strip detector and compared its value with the η_{eff} of shallower donor deep trap E30 K in the n -MCz Si microstrip detector.
Prediction uncertainty in the p-MCz Si radiation damage mixed irradiation model considered in the full depletion voltage and leakage current. A very good agreement is observed in the experimental and SRH results. This radiation damage models also used to extrapolate the value of the full depletion voltage at different mixed (proton + neutron) higher irradiation fluences for the thin p-MCz Si microstrip detector.

p-MCz Si PAD Detector Design Model



➢ Cross-section of the 0.0625 cm^2 x 300µm p-MCz Si PAD detector model used in the present study for SRH/ calculations and TCAD device simulation

➢MCz-p Si pad detector irradiated with mixed irradiation proton and neutron mixed irradiated model [1-3]

Table.1 List of Physical Parameters

S.No.	Physical parameters	Values
1.	Doping concentration (N_D)	2.87 x 10^{12} cm^{-3}
2.	Oxide thickness (t_{ox})	0.5 µm
3.	Junction Depth (X_j)	1 µm
4.	Guard ring spacing (GS)	10 µm
5.	Guard ring width (GW)	100 µm
6.	Device depth (Wn)	300 µm
7.	Fixed oxide charge (Q_f)	1x 10^{12} cm^{-2}
8.	Resistivity(ρ)	1.5 KΩ-cm

SRH Calculations [2]

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

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

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

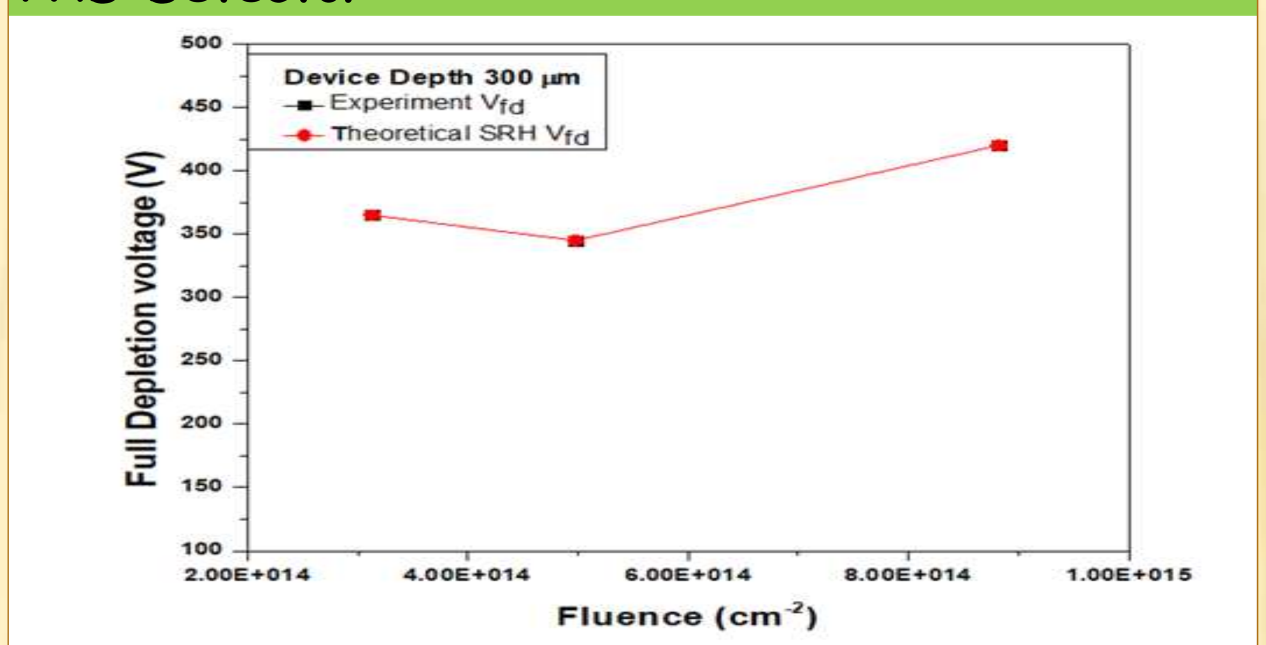
Four Level Deep Trap Mixed Irradiated Radiation Damage Model for p-type MCz Si

Defect/type	Effects on the macroscopic parameters	Energy level (eV)	σ_n (capture crossection of electrons) [cm^2]	σ_p(capture crossection of holes) [cm^2]	η (introduction rate)[cm^{-1}]
E5/Acceptor	Increase of leakage current	E_c-0.46 eV	1.41E-15	2.79E-15	12.4
H (152K)/Acceptor	-ve space charge	E_v+0.42 eV	4.58E-13	6.15E-13	0.04
CiOi /Donor	+ve space charge	E_v+0.36 eV	2.08E-18	2.45E-15	1.1
E (30K) / Donor	+ve space charge	E_c-0.10 eV	2.30E-14	2.00E-15	Observed with in increasing fluences see fig.5

❖ Proposed Four level deep traps mixed irradiated radiation damage model for p-MCz Silicon.

❖ The four-level deep trap mixed irradiation damage model shows the good comparision of the experimental data and theoretical SRH calculations/TCAD.

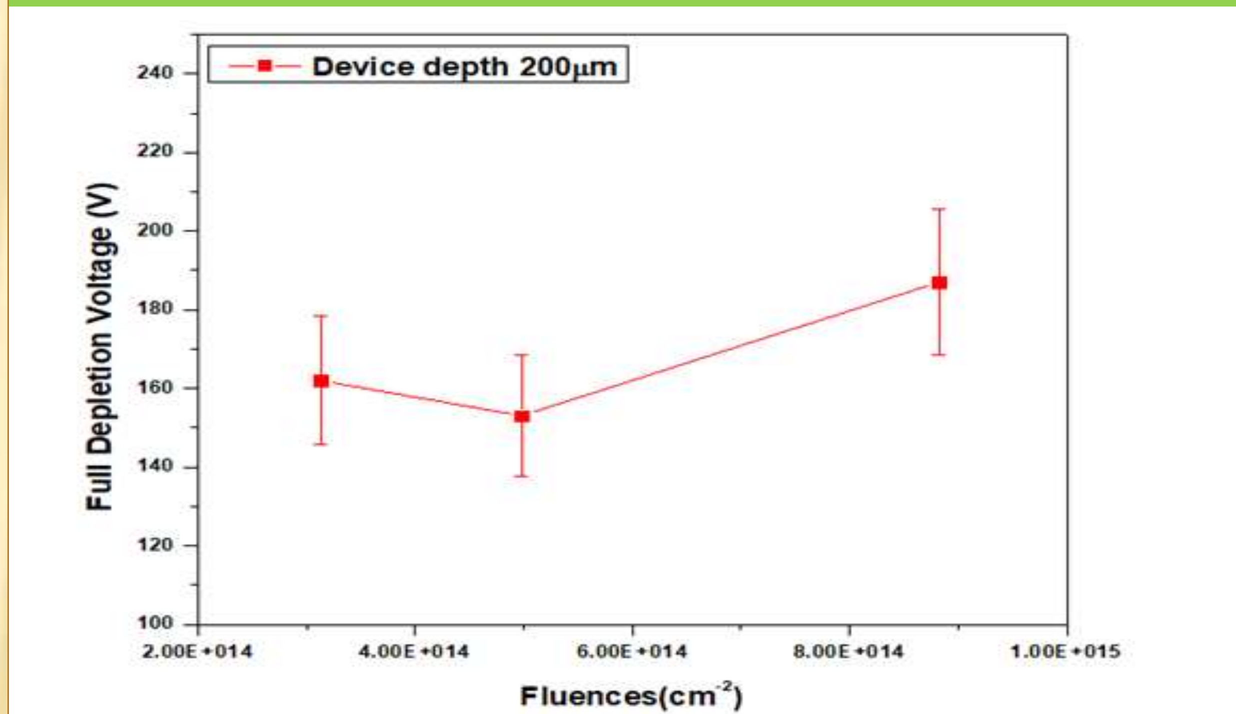
Comparison of Experimental and SRH value of Full Depletion Voltage (V_{fd}) for Thick p-MCz Si PAD Detector



❑The SRH calculation has been done on the mixed irradiated p-MCz Si PAD detector using our mixed irradiated radiation damage model

❑ The Experimental and SRH values of V_{fd} for the 300µm thick p-MCz PAD detectors shows a good agreement

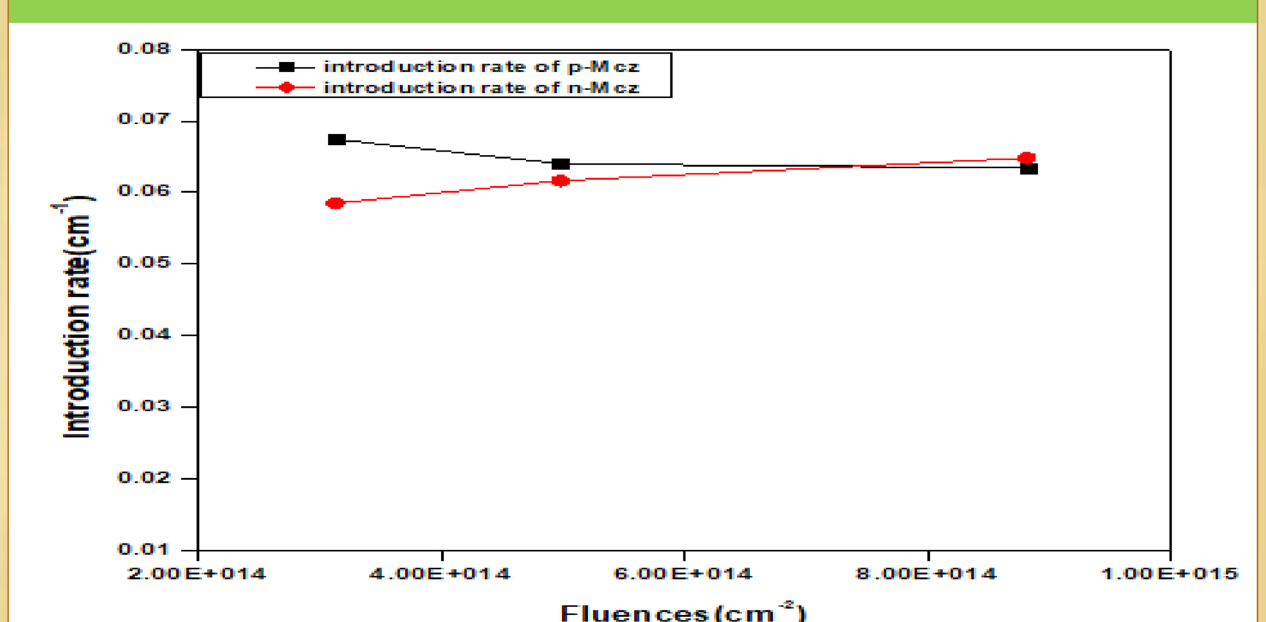
Effect of Mixed Irradiated fluence on Full Depletion Voltage of Thin p-MCz Si PAD detector



➢ Damage accumulated at higher mixed fluences (>4.96 x 10^{14} cm^{-2}) in p-MCz Si PAD detector

➢The V_{fd} for thin p-MCz Si strip detector almost 50% less (< 200V) as compare to V_{fd} of 300 µm thick p-MCz Si PAD detector for the same equivalent fluence

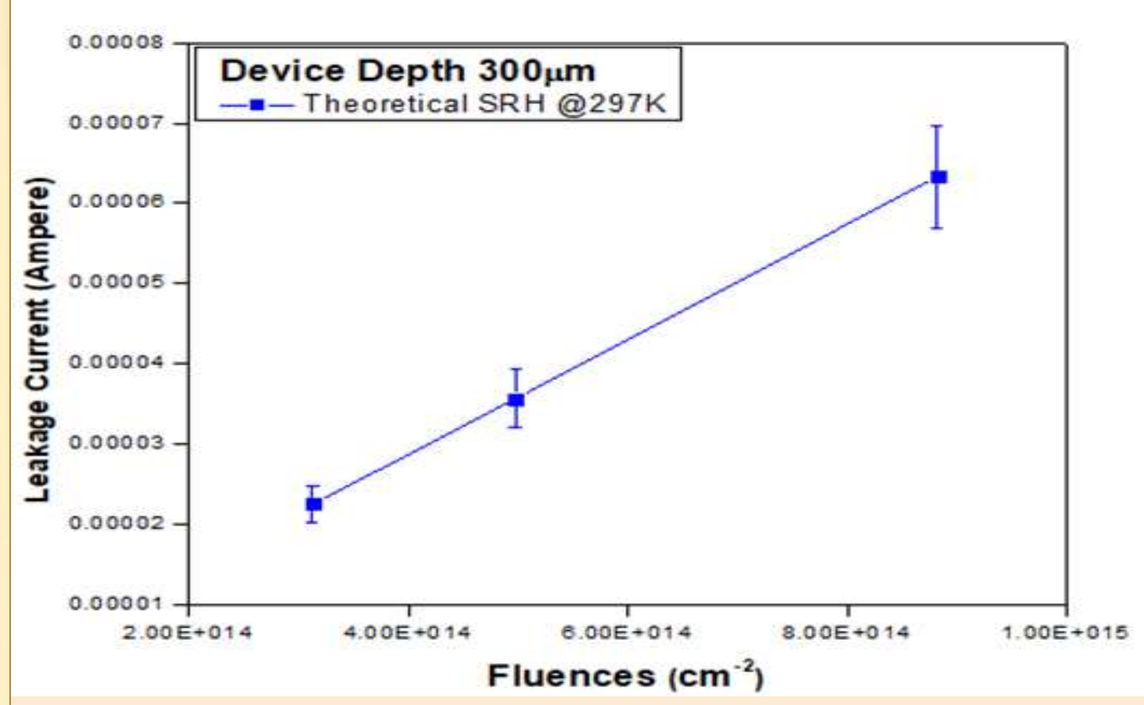
Comparison of Introduction rate E (30K) in Mixed Irradiated n-MCz [4] and p-MCz Si PAD Detector



➢ Introduction rate of E30K tuned for the comparison of experimental data with theoretical SRH data

➢ Introduction rate of E(30K) in n-MCz or in p-MCz Si plays an important role and that can be a key trap to explain the macroscopic performance of the n/p-MCz pad detector

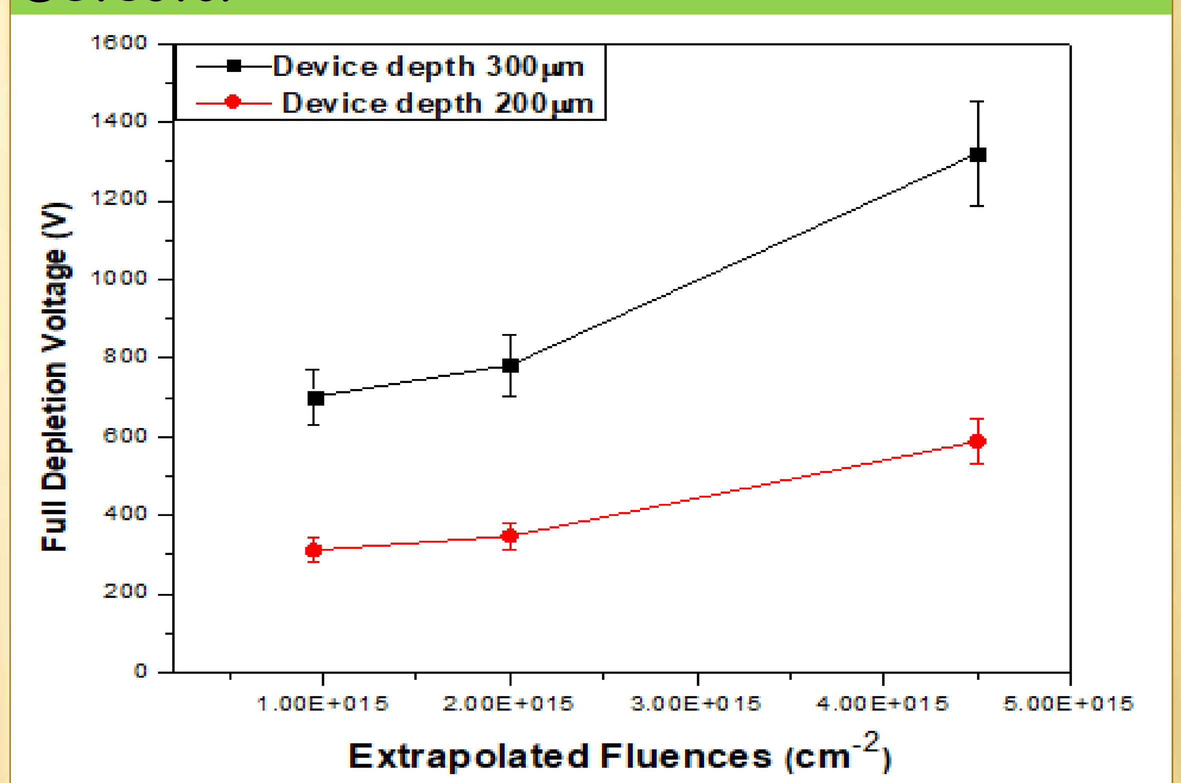
Leakage current in Mixed Irradiated p-MCz Si PAD Detector



➢ Leakage current @297K [4] (shows the good agreement with experimental data's at RT+4K) increases with irradiation fluence for 300 µm p-type Si PAD detector.

➢Using multiple field guard rings structure on outer surface of the detector and by cooling the detector system in the CMS experiment up to -20⁰C to -30⁰C we can control the increased leakage current.

Extrapolated V_{fd} for thick (300µm) and thin (200µm) in mixed irradiated p-MCz Si Strip Detector



➢ The extrapolated value of V_{fd} is nearly 1300V at a fluence 4.5x10^{15} for the 300µm mixed irradiated detector

➢ In 200µm thin mixed irradiated p-MCz Si strip detector the V_{fd} is around 500 V

Conclusions

❖First time within the detector consortium in the world, we have proposed a four level deep-trap mixed irradiation damage model for the p-MCz Si strip detector
❖ Good agreement in experimental and SRH value of Full depletion voltage observed
❖ Introduction rate of E30 K extracted from our mixed irradiated radiation damage model
❖The V_{fd} is the main macroscopic parameter that can determine the space charge behavior of the mixed irradiated detectors and <500V V_{fd} observed for 200 micron p-MCz Si strip detector for the mixed irradiated fluence of 4.5 x 10^{15} cm^{-2}
❖ Leakage current increases with fluences at 297 K as per [4]

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