TCAD simulation 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 micro strip 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-FzSi 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 micro strip 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.

KEYWORDS: Radiation-hard detectors; Si microstrip and pad detectors
1 Introduction

Radiation damage of the silicon strip detectors in upcoming hadron collider poses a major issue for its reliable operation for the long-term of the experiment. The combined radiation damage effects in the Si strip detectors in the new Compact Muon Solenid (CMS) tracker at the High-Luminosity Large Hadron Collider must be investigated (HL-LHC) [1]. For n in p Si detectors exhibit good performance for the new CMS Tracker at HL-LHC experiments in the CERN RD50 European collaboration [2]. The n-MCz (Magnetic Czochralski) Si material may be a good choice for the p in n Si strip detector [3–6]. As a result, radiation damage effects in thin p in n-MCz Silicon (Si) microstrip detectors must be investigated [3–6]. It was necessary to examine the macroscopic electrical performances of the p in n-MCz Si strip detectors for the new CMS tracker in order to design, develop, and optimise detectors for the HL-LHC investigations. The macroscopic and microscopic performance of these Si strip detectors measured using Current-Voltage (I/V), Capacitance-Voltage (C/V), Thermally Stimulated Current (TSC), Deep Level Transient spectroscopy (DLTS), Transient Current Technique (TCT) and Alibaba system SL, Barcelona, Spain set up.

For the bulk of the SFz (Si) detector, the model showed good observations of the experimental and simulation result for the fluencies of the order of $1 \times 10^{15} \text{n}_{eq}/\text{cm}^2$ 1 MeV equivalent neutrons [7]. The n-MCz four deep trap mixed irradiation model has been developed to simulate the radiation damage effects in mixed irradiated detectors up to $8 \times 10^{14} \text{n}_{eq}/\text{cm}^2$ 1 MeV equal neutrons [7]. The paper has discussed in three sections; section 2 presents Hamburg Penta Trap Model (HPTM) [8] for Proton irradiation in n-Fz Si strip detector and four level deep trap mixed irradiated radiation damage model for n-MCz silicon strip detector, SRH calculation for the full depletion voltage in the n-Fz/n-MCz thin silicon strip detector model and TCAD device simulation. Section 3 elaborates the results and discussion on the extrapolated values on the full depletion voltage in
mixed irradiated n-MCz and proton irradiated n-Fz thin silicon strip detectors. In section 4 we did the 2-D TCAD simulation using Silvaco ATLAS to get the electric field behaviour of n-Fz/n-MCz silicon strip detector.

2 Radiation damage model for proton and mixed irradiation

In this section, we have used the HPTM and mixed irradiated model for the radiation damage analysis in nFz and nMCz Si strip detector for the HL-LHC experiments.

2.1 Silicon strip detector model, SRH calculations and TCAD device simulation

A rectangular cell of $0.0625 \text{ cm}^2 \times 200 \mu\text{m}$ n-MCz silicon strip detector model is used for the SRH calculations (see figure 1) and the device and process parameters of the detector are shown in figure 1(b) (see table). The effective doping concentration, $N_{\text{eff}}$, at full depletion voltage, $V_{\text{FD}}$, can be calculated by the SRH theoretical expression [5], where symbols are having their usual meaning. Device simulations have been performed with Silvaco 2-D ATLAS TCAD device simulator [9]. The following physical models have been used for numerical simulation: these are Shockley–Read–Hall recombination, FLDMOB, CONMOB, Band gap narrowing, Trap Assisted Model (Hurks Model).

| S.No | Physical parameters | Values |
|------|---------------------|--------|
| 1.   | Doping concentration ($N_D$) | 1, 2.87, 5 $\times 10^{12}$ cm$^{-2}$ |
| 2.   | Oxide +nitride thickness ($t_{ox}$) | 0.3+0.05 $\mu$m |
| 3.   | Junction Depth ($X_J$) | 1 $\mu$m |
| 4.   | Device depth ($W_e$) | 200 |
| 5.   | Fixed oxide charge ($Q_f$) | 1.5$\times 10^{12}$ cm$^{-2}$ |

Figure 1. (a) Cross-section of the $0.0625 \text{ cm}^2 \times 200 \mu\text{m}$ n-Fz/n-MCz Si strip detector model used in the present study for SRH calculations and TCAD device simulation, (b) table device and process parameters of the detector model.

3 Results and discussion

In this section, we have used the SRH calculations and TCAD device simulation for the Charge Collection Efficiency (CCE) comparison of the n-Fz/n-MCz thin Si microstrip detector using $E$-field distribution in the irradiated detectors.
3.1 Full depletion voltage in n-Fz/n-MCz thin Si strip detector

In figure 2(a), we have used Hamburg Penta Trap Model (HPTM) in 200 μm n-Fz proton irradiated Si strip detector, it is shown that $V_{fd}$ decreases with an increasing doping concentration. Significant increase in $V_{fd}$ with the proton radiation fluences ($\Phi_{eq}$, n (fluence), equivalent to 1 MeV neutron) has observed in n-Fz detector using HPTM model [5]. It is observed from the figure 2(b) that $V_{fd}$ increases with the mixed irradiated fluences for the three doping concentrations in thin n-MCz Si strip detector, less full depletion voltage obtained than other n-Fz proton irradiated detectors, less $V_{fd}$ observed due to the compensation of deep traps.

![Figure 2](image)

**Figure 2.** (a) Full depletion voltage as a function of the fluence in proton irradiated n-Fz thin silicon (Si) strip detector. (b) Full depletion voltage as a function of the fluence in mixed irradiated n-MCz thin silicon (Si) strip detector.

4 TCAD device simulation of n-MCz and n-Fz Si microstrip detector for the HL-LHC

In this section, we have shown the $E$-field in the proton irradiated n-Fz and mixed irradiated n-MCz thin irradiated Si strip detector.

4.1 Electric field in mixed and proton irradiated n-MCz thin Si strip detector

It is observed form the figure 3(a) that low $E$-field obtained in the base region of the detector, and $E$-field gutter observed in the centre of the detector ($X = 40 \mu m$, cut $Y = 2.3$ micron).

It is observed from the figures 3(b) and (c) that $E$-field increases at curvature of junction and slightly increase at $E$-field gutter, $X = 40 \mu m$. With an increasing mixed doses, $E$-field at curvature of junction saturates and at $E$-field gutter, $X = 40 \mu m$ too $E$-field gutter can be cause of trapping of charge carrier.
Figure 3. Electric field in mixed irradiated n-MCz thin Si strip detector at 500 V for (a) \(3.13 \times 10^{14} \text{ cm}^{-2}\) (b) \(4.98 \times 10^{14} \text{ cm}^{-2}\), (c) \(8.82 \times 10^{14} \text{ cm}^{-2}\).

It is observed from the figure 4 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

In this paper we explained SRH calculation of full depletion voltage in n-Fz/n-MCz thin Si strip detector and TCAD device simulation results of proton and mixed irradiated nFz/n-MCz Si strip detector. It is observed after the SRH calculations the full depletion voltage of n-MCz thin silicon strip detector is less as compared to the thin n-Fz silicon strip detector. It is also revealed from the TCAD device simulation result 200 $\mu$m n-MCz thin Si microstrip detector consists high charge collection efficiency expected as compared to n-Fz thin Si microstrip detector. Therefore, the radiation hard thin n-MCz Si microstrip detector for the new CMS tracker detector system can be also designed and optimized for the HL-LHC experiments.

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