Effect of X-ray Doses on the Electric field Distribution in p^+n Si Pixel detector

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Science requirements of the radiation hard p^+n Si pixel detector are challenging for the next-generation photon science requirements. A high voltage radiation-hard Si p^+n pixel detector is required for the long-term operation of the experiment and to get high charge collection efficiency. In this present work, we have studied the x-ray dose dependency on the E-field distribution at oxide-silicon interface in a p^+n Si pixel detector using Cogenda (Visual) TCAD device simulator to get a high breakdown voltage.

1. Introduction

The next-generation photon science experiments require a high dynamic range of p^+n Si pixel detectors. The high x-rays radiation environment or doses degrades the macroscopic performance of the pixel detector. The x-ray surface radiation damage increases the oxide charge (N_{ox}) and interfaces traps (N_{it}) at the Si-SiO_2 interface. It leads to an increase of the surface current (I_{surf}) and E-field in the detector. Several papers have studied the effect of x-ray doses on the electrical performance of the Si detector [1-3]. The major challenge is to design the high voltage multiple guard ring equipped p^+n Si pixel detector for the experiment.
Finally, we have extracted the microscopic parameters from the experiment [1-2] that can be fed into TCAD to simulate the surface damage effects in the p^+n Si pixel detector.
In this paper, we have studied the electric field distribution in the x-ray irradiated 450 x 180 μm^2, <111> oriented p^+n Si pixel detector.

2. Device Model and Simulation

In the present TCAD device simualtion using Cogenda, we have considered the 450 x 180 μm^2 , <111> oriented n type uniformly phosphorous doped Si substrate with doping concentration of $1x10^{12}$ cm^{-3}. The p^+ pixel (consider as a strip) at the surface of the detector are gaussian doped with doping concentration of 5 x $10^{19}cm^{-3}$ with X_j (junction depth) of 1µm, t_{ox} (oxide + nitride thickness) is 0.3µm + 0.05µm (see Fig.1) . The back side of the detector is uniformly n-type doped and metallized to create Al ohmic contact. The simulation was done for the temperature of 300 K using drift diffusion model. In order to understand the real physical behaviour of the device several physical models have been used in the TCAD device simulation such as high field mobility model, Selberherr model for Impact ionization, band gap narrowing model and Hurkx model for band to band tunneling [3,4]. The x-ray radiation dose and its damage parameters, which are implemented in TCAD device simulation are shown in table 1 [1]. Fig. 1 shows the schematic of p^+n Si pixel detector used in present simulation work.

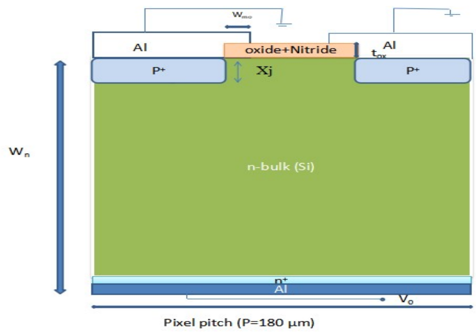


Fig. 1 Cross- section of p^+n Si pixel detector used for TCAD simulation

Table 1: X-ray radiation damage parameters implemented in TCAD simulation[1].

Dose [MGy]	N_{ox} [cm^{-2}]	Sr [cm/s]
0	1×10^{11}	8
5	2.4×10^{12}	7500
10-1000	3×10^{12}	12040

3. Simulation Results and Discussion

To study the surface damage effects in p^+n Si pixel detector it is required to observe the behaviour of electric field distribution across the Si-SiO_2 interface. Here we have shown the impact of N_{ox} on electric field distribution for the different doses see fig.2.

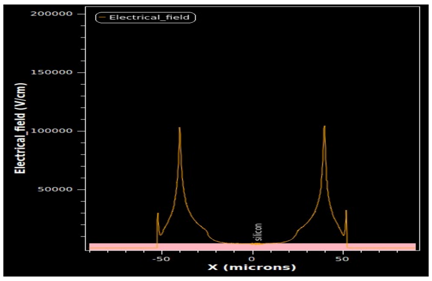
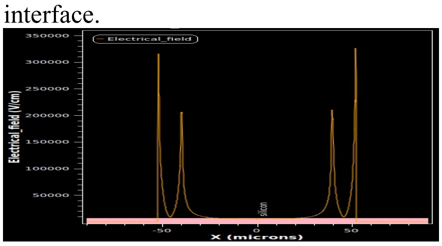


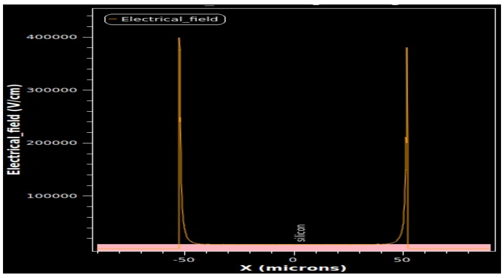
Fig. 2 Electric field distribution at 220V in the p^+n Si Pixel detector (cut Y=100 nm) from the Si-SiO_2 interface for $N_{ox}=1\text{x}10^{11}cm^{-2}$.

It can be seen from the fig.2 that the electric field distribution is less than the critical field for Si material i.e $3\text{x}10^5$ V/cm at an applied bias voltage of 220V. Hence, it can be assumed that the detector has not shown any breakdown for the $N_{ox}=1\text{x}10^{11}$ cm^{-2}.

However, the detector has shown an avalanche breakdown for $N_{ox} \geq 2.4 \times 10^{12}$ cm^{-2}. The high value of N_{ox} decreases the value of V_{bd} as shown in fig. 3(a,b) due to high electric field (3.3x 10^5 and $4\text{x}10^5$V/cm respectively) at the interface.



(a)



(b)

Fig. 3 Electric field distribution at **(a)** 220V for $N_{ox}=2.4\text{x}10^{12}$ cm^{-2} **(b)**17V for $N_{ox}=3\text{x}10^{12}cm^{-2}$ in the p^+n Si Pixel detector (cut Y=100 nm) from the Si-SiO_2 interface.

For the high voltage operation of the p^+ n Si pixel detector up to 800V, the multiple guard-ring p^+n Si detector can be optimized using TCAD device simulation.

Acknowledgments

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References

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