3D Simulation Of An Amorphous Silicon Photodiode For Particle Therapy

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Abstract

Proton and Radiotherapy are leading particle therapy tactics used to combat chronic and malignant cancers [1]. Ultra-high dose rate (UHDR) flash therapy is a new treatment modality that is currently being studied by several groups. The treatment delivers high doses in a short period of time (40 Gy/s) and is highly effective against tumor cells while maintaining healthy cells. Moreover, particle therapy also has radiobiological advantages compared to conventional therapy [2]. UHDR dosimetry presents a crucial challenge to detectors when performing proper quality assurance (QA) measurements.
This work aims to build a high-resolution semiconductor-based 2D flat panel (FP) detector that is compatible with low-dose radiotherapy and flash proton therapy. Among semiconductor materials, amorphous Silicon (a-Si) is notable for its high radiation tolerance and ability to produce large-area pixels at low cost [3]. State-of-the-art X-ray FP detectors employ a-Si pixels coupled with a thin-film transistor (TFT) technology. On the other hand, CMOS detectors that use crystalline Silicon (c-Si) are limited by wafer size and radiation hardness but experience fast and accurate signal acquisition [4]. An in-depth study of the behavior of a-Si and c-Si under particle beams for QA will be conducted.
Focusing on a-Si and using the Semiconductor Module, COMSOL Multiphysics was employed to simulate the perspective photodiodes and understand the behavior of such technology. Starting from a simple block of thickness 1.2 µm and width ~ 5µm, the predefined built-in material Silicon in COMSOL was edited to fit the parameters of a-Si and then assigned to the block. Using the Analytical Doping Model, background acceptor doping of N_bkg~10^11 cm^-3 is set to the domain. Additionally, an n-doping and p-doping layer, each with a concentration of 10^20 cm^-3, were added using the Box distribution of the Analytical Doping Model, creating a 3D PIN a-Si photodiode. A square is added to the top p-layer and added as a Metallic Contact to introduce a reverse-bias voltage, and the bottom n-layer is grounded. This is represented in Figure 1. The stationary study is performed with an auxiliary sweep to sweep through different reverse-bias voltages, with the finite element discretization. Effectively, the I-V curve and electric field across the junction of the diode are resolved, as shown in Figures 2 and 3.

In addition, Garfield++ [5], a Monte Carlo (MC)-based simulation toolkit that specializes in gas and semiconductor-based detectors, was interfaced with COMSOL to perform signal and charge analysis. Using the dedicated class Garfield::ComponentComsol(), the mesh file and electric potential files were exported from COMSOL into Garfield++, and the exact solution of the electric field at each mesh point was used to simulate the particle track and electric signal induced on the electrodes. Figure 4 shows the current signal from irradiation normalized to a single 100 MeV proton event at different reverse-bias voltages.

COMSOL Multiphysics proves to be a very reliable and efficient toolkit to simulate the working principles of a-Si photodiodes. Further in-depth simulations will be done to build an a-Si TFT in 3D and compare all the results with an existing sample.

Keywords: Semiconductor Module, aSi TFT, Medical Dosimetry, Quality Assurance.

Reference

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Figures used in the abstract

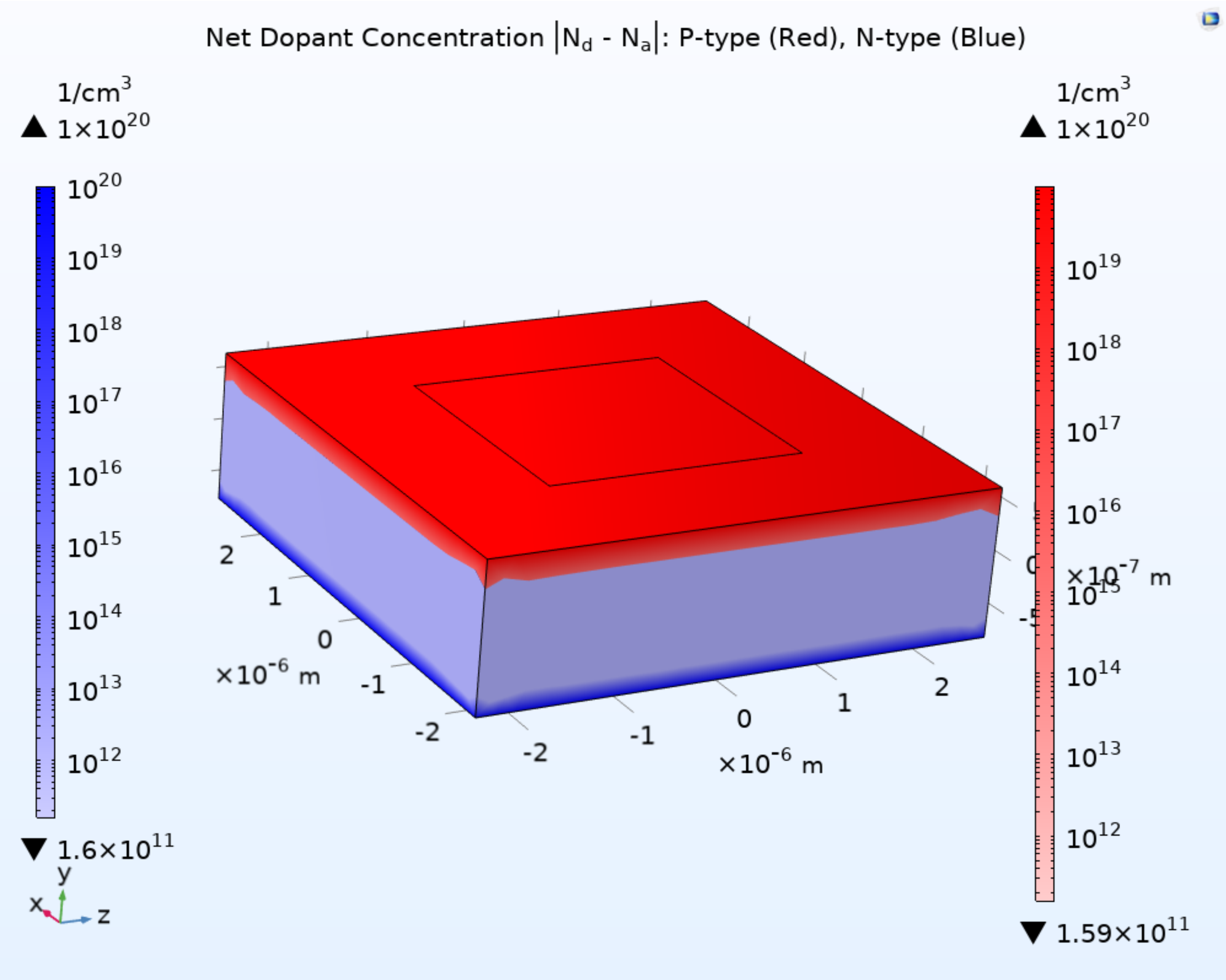

Figure 1 : Figure 1: The Net dopant concentration of a PIN diode shows the top p-doped layer and the bottom n-doped layer.

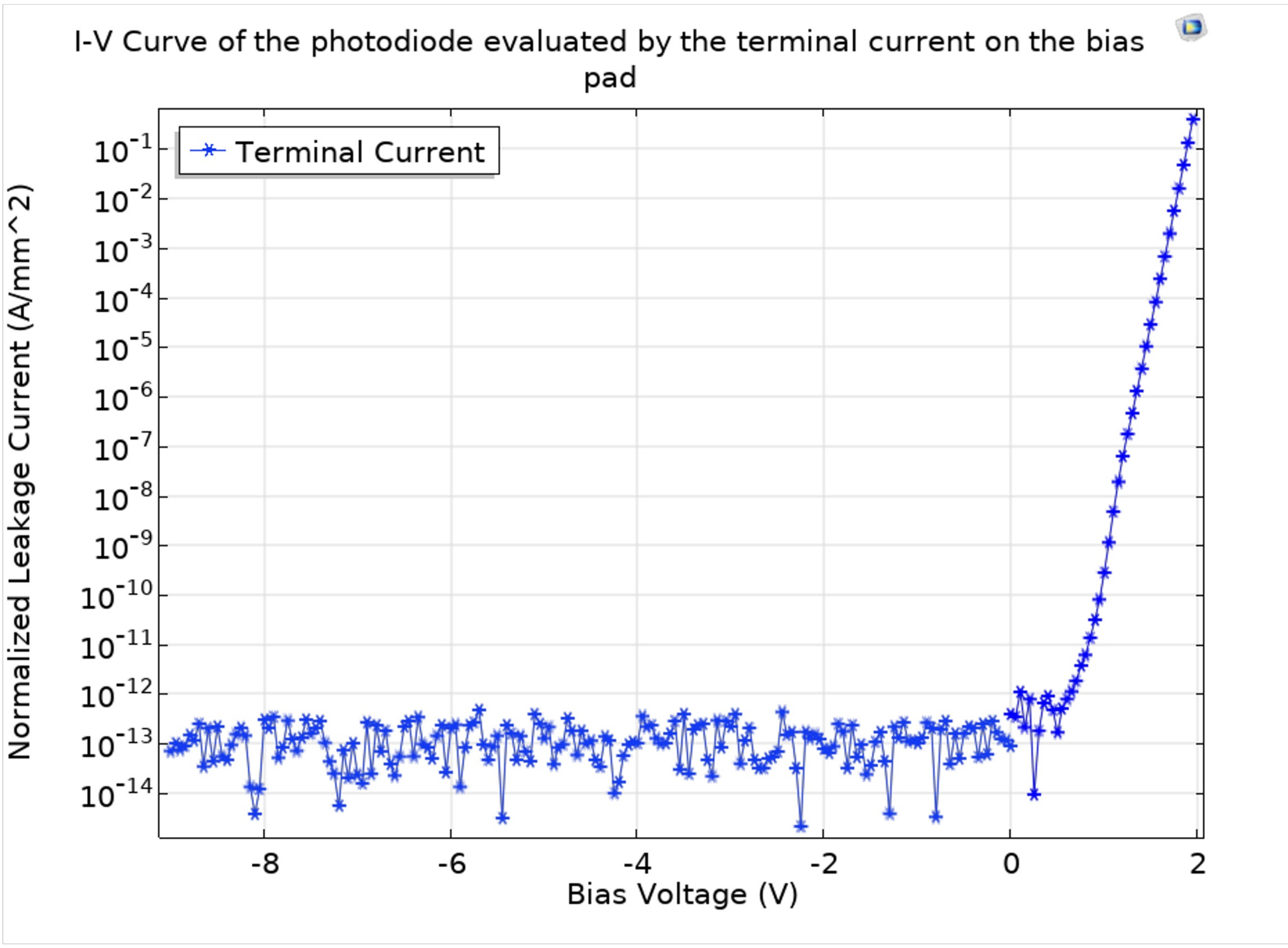

Figure 2 : Figure 2: The terminal current of the simulated PIN diode with respect to different bias voltages.

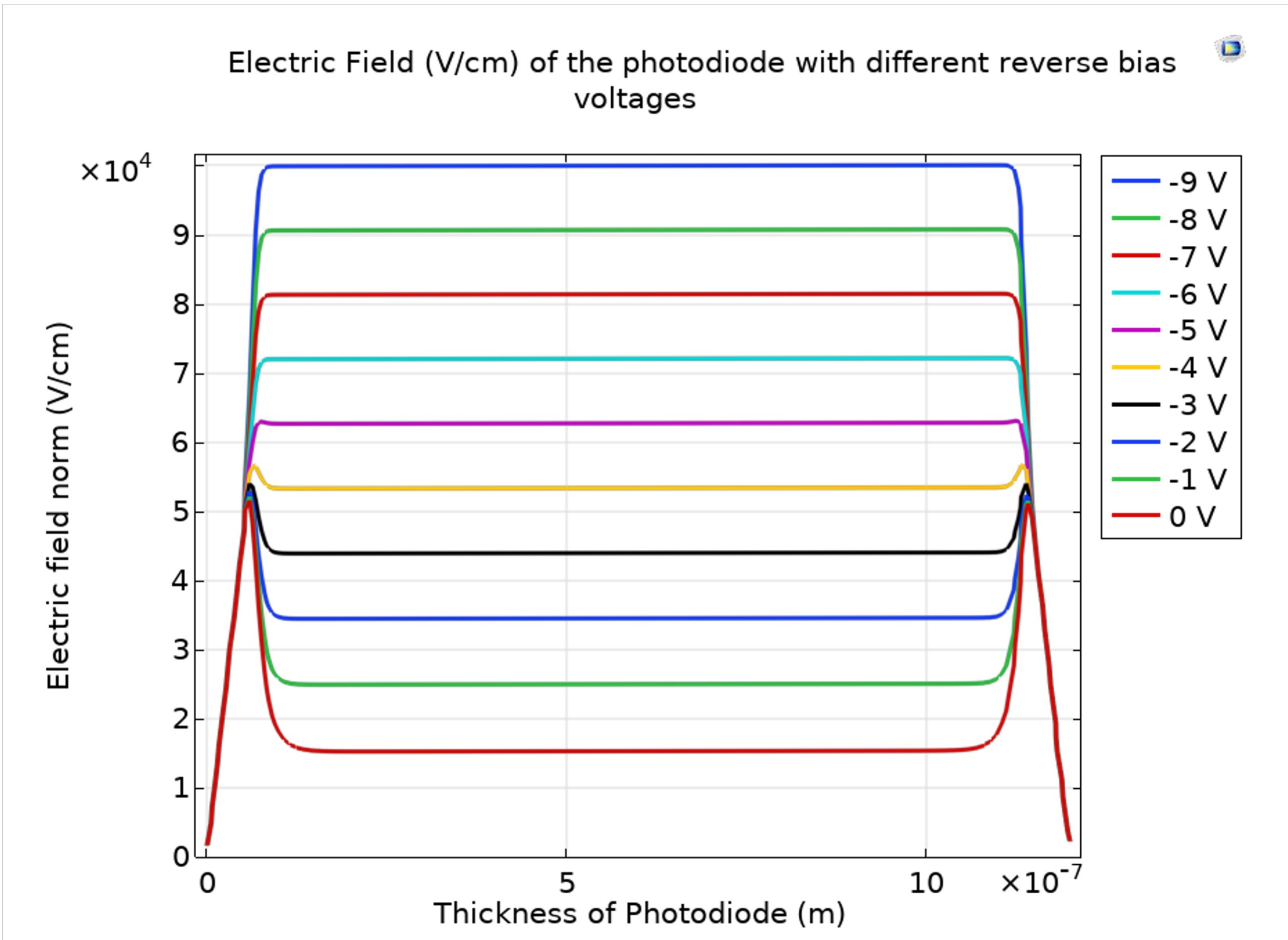

Figure 3 : Figure 3: The electric field across the z-junction junction of the diode at different reverse bias voltages.

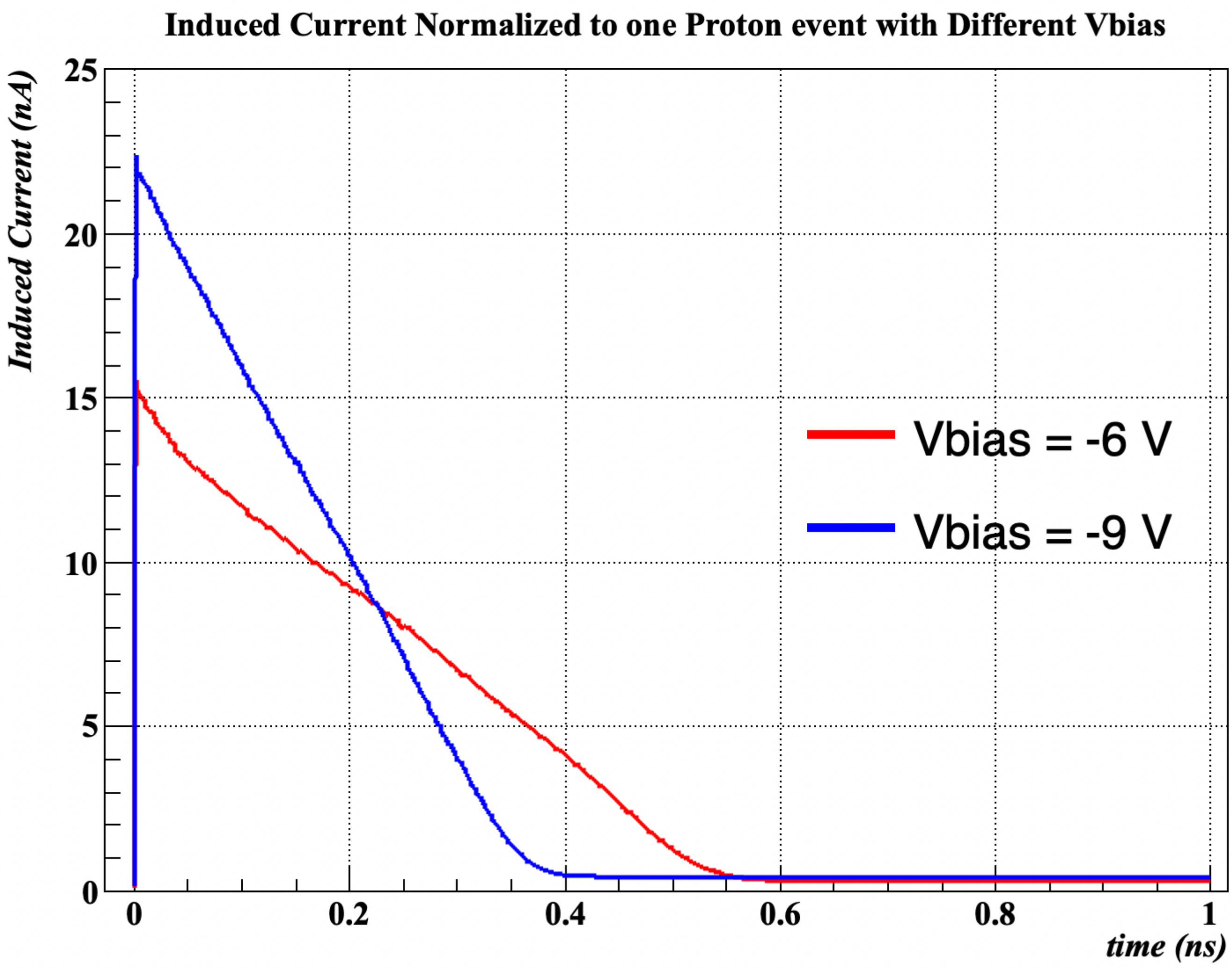

Figure 4 : Figure 4: The induced current normalized to one 100 MeV proton event at two reverse bias voltages.