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An upgraded drift–diffusion model for evaluating the carrier lifetimes in radiation-damaged semiconductor detectors

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ABSTRACT

The transport properties of a series of n- and p-type Si diodes have been studied by the ion beam induced charge (IBIC) technique using a 4 MeV proton microbeam. The samples were irradiated with 17 MeV protons at fluences ranging from 1×10^{12} to 1×10^{13} p/cm^2 in order to produce a uniform profile of defects with depth. The analysis of the charge collection efficiency (CCE) as a function of the reverse bias voltage has been carried out using an upgraded drift–diffusion (D–D) model which takes into account the possibility of carrier recombination not only in the neutral substrate, as the simple D–D model assumes, but also within the depletion region. This new approach for calculating the CCE is fundamental when the drift length of carriers cannot be considered as much greater that the thickness of the detector due to the ion induced damage. From our simulations, we have obtained the values of the carrier lifetimes for the pristine and irradiated diodes, which have allowed us to calculate the effective trapping cross sections using the one dimension Shockley–Read–Hall model. The results of our calculations have been compared to the data obtained using a recently developed Monte Carlo code for the simulation of IBIC analysis, based on the probabilistic interpretation of the excess carrier continuity equations.

1. Introduction

Since its development in the early 1990's [1], the ion beam induced charge (IBIC) technique has found widespread applications to measure and study the transport properties of semiconductor materials and devices [2]. Different theoretical frames have been developed for calculating the charge pulse signal produced by semiconductor detectors. Those models include the use of TCAD simulations [3], the solution of an adjoint carrier continuity equation [4], or the implementation of a simple one-dimensional charge transport by drift and diffusion [5]. In this paper, the drift–diffusion model is revisited to consider the possibility of carrier recombination not only in the electroneutral part of the detector, as stated in [5], but also in the depletion region. The results are applied to a series of Si diodes subjected to radiation damage produced by high energy protons. The present work has been done in the framework of the IAEA Coordinated Research Project F11016 "Utilization of ion accelerators for studying and modeling of radiation induced defects in semiconductors and insulators".

2. Experimental

The samples studied in this work consist of 300 μm thick n- and p-type Floating Zone Si diodes with doping concentration of $\sim 10^{12}$/cm^3 fabricated by the Helsinki Institute of Physics (HIP). Fig. 1 shows a scheme of a p-type diode with the doping profile (red line) extracted from the *C–V* curve determined at the Sandia National Laboratories (SNL) [6]. The inset represents the width of the depletion region vs. reverse bias voltage, as found out in [6].

The irradiations were carried out at the external beam of the compact cyclotron of the CNA, placing the samples in air at 15 cm from the 150 μm thick kapton exit window. Although the cyclotron delivers 18 MeV protons, the actual proton energy at the sample's surface after traversing the kapton foil and the air was 17 MeV, as calculated using the SRIM code [7]. The homogeneous proton beam (∅ = 15 mm) was partially blocked with a 2 mm thick graphite collimator (∅ = 10 mm), which was connected to a Brookhaven 1000c current integrator for fluence measurements. A second collimator made of 2 mm thick Al

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