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Degradation of the charge collection efficiency of an *n*-type Fz silicon diode subjected to MeV proton irradiation

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ABSTRACT

We present the analysis of the charge collection efficiency (CCE) degradation of float zone grown *n*-type silicon detectors irradiated with 1.3, 2.0 and 3.0 MeV protons. The analysis was carried out by irradiating small regions ($50 \times 50\ \mu m^2$) with a proton microbeam at fluences ranging from 10^{11} to $4{\cdot}10^{12}$ ions/cm^2 and probing the effect of irradiation by measuring the 4.5 MeV Li ion induced charge in full depletion conditions. The CCE degradation as function of the proton fluence shows an unexpected deviation from the linear behavior predicted by the Shockley–Read–Hall model of carrier recombination. The build-up of excess hydrogen related donors due to proton irradiations is suggested to be the cause of a significant perturbation of the electrostatic properties of the diode, which drastically change the electron trajectories and hence the induced charge mechanism.

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1. Introduction

The understanding of the mechanisms underlying the damage in semiconductors induced by ionizing radiation is fundamental to evaluate the lifetime of electronic devices in radiation harsh environments and therefore, significant efforts have been made to implement experimental and theoretical methodologies for an exhaustive characterization of radiation induced defects.

Recently, the International Atomic Energy Agency (IAEA) has promoted a Coordinated Research Project entitled "Utilization of ion accelerators for studying and modeling of radiation induced defects in semiconductors and insulators", which aims at gaining a deeper understanding of how different types of radiation influences the short and long term electronic properties of materials and devices.

Within this project, an experimental protocol [1] has been developed to determine the key parameters for the characterization of radiation damage effects on semiconductors. The protocol is based on the selective damage of small regions created by focused ion beams at different fluences and, subsequently, on the measurement of the charge collection efficiency (CCE) degradation by means of the Ion Beam Induced Charge (IBIC) technique [2,3], using probing light ions.

This paper describes an experiment based on the abovementioned protocol for the characterization of radiation damage induced by 1.3, 2.0 and 3.0 MeV protons with fluences ranging from 10^{11} to $4{\cdot}10^{12}$ protons/cm^2 on a *n*-type Float Zone (Fz) silicon detector. To evaluate the CCE degradation, 4.5 MeV Li ions were used to probe the damaged regions. The use of short range ion probes and the full depletion conditions were chosen because they provide ideal conditions to apply a simplified model for CCE degradation based on the Shockley–Read–Hall recombination mechanism integrated within the Shockley–Ramo–Gunn theory of the induced charge signal formation in semiconductors. However, in this paper, we show that this theoretical approach has serious limitations to model the CCE degradation, and the cause of this inadequacy is due to the considerable perturbation of the applied electric field induced by the build-up of hydrogen-related donors.

2. Experimental

The sample (#29) under analysis [4,5] was prepared by Helsinki Institute of Physics and consists of a p^+ (B implanted, 3.5 μm thick)/n^-

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