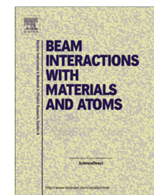
Nuclear Instruments and Methods in Physics Research B 372 (2016) 128–142

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb



Charge collection efficiency degradation induced by MeV ions in semiconductor devices: Model and experiment

E. Vittone [a,*], Z. Pastuovic [b], M.B.H. Breese [c], J. Garcia Lopez [d], M. Jaksic [e], J. Raisanen [f], R. Siegele [b], A. Simon [g,h], G. Vizkelethy [i,1]

[a] Department of Physics, NIS Research Centre and CNISM, University of Torino, via P. Giuria 1, 10125 Torino, Italy
[b] Centre for Accelerator Science (ANSTO), Locked bag 2001, Kirrawee DC, NSW 2234, Australia
[c] Centre for Ion Beam Applications (CIBA), Department of Physics, National University of Singapore, Singapore 117542, Singapore
[d] Centro Nacional de Aceleradores (CNA), Sevilla University, J. Andalucia, CSIC, Av. Thomas A. Edison 7, 41092 Sevilla, Spain
[e] Department for Experimental Physics, Ruder Boškovic Institute (RBI), P.O. Box 180, 10002 Zagreb, Croatia
[f] Department of Physics, University of Helsinki, Helsinki 00014, Finland
[g] International Atomic Energy Agency (IAEA), Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria
[h] Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Debrecen, Hungary
[i] Sandia National Laboratories (SNL), PO Box 5800, Albuquerque, NM, USA

ARTICLE INFO

Article history:
Received 20 September 2015
Received in revised form 13 December 2015
Accepted 20 January 2016
Available online 8 February 2016

Keywords:
Charge collection efficiency
Radiation damage
Ion Beam Induced Charge (IBIC)
Semiconductors
MeV ion beams

ABSTRACT

This paper investigates both theoretically and experimentally the charge collection efficiency (CCE) degradation in silicon diodes induced by energetic ions. Ion Beam Induced Charge (IBIC) measurements carried out on n- and p-type silicon diodes which were previously irradiated with MeV He ions show evidence that the CCE degradation does not only depend on the mass, energy and fluence of the damaging ion, but also depends on the ion probe species and on the polarization state of the device. A general one-dimensional model is derived, which accounts for the ion-induced defect distribution, the ionization profile of the probing ion and the charge induction mechanism. Using the ionizing and non-ionizing energy loss profiles resulting from simulations based on the binary collision approximation and on the electrostatic/transport parameters of the diode under study as input, the model is able to accurately reproduce the experimental CCE degradation curves without introducing any phenomenological additional term or formula. Although limited to low level of damage, the model is quite general, including the displacement damage approach as a special case and can be applied to any semiconductor device. It provides a method to measure the capture coefficients of the radiation induced recombination centres. They can be considered indexes, which can contribute to assessing the relative radiation hardness of semiconductor materials.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

While the effect of radiation induced defects on the properties of semiconducting and insulating materials and devices has been studied for many years, there are still significant gaps in the understanding of what types of defects are formed, how they can be detected and their effects on electrical and structural properties. This study is based on research conducted within an IAEA Coordinated Research Project (CRP, reference F11016 [1]). The main objective of this project was the enhancement of the understanding of which types of defects are created by high energy ion irradiation and what are their effects on electronic properties of semiconductors and insulators. A further objective is to develop means of defining and measuring radiation resistance of materials, with the ultimate aim of thereby improving it. This involves defining an experimental protocol to determine the key parameters for characterization of the effects of radiation damage on semiconductor materials and devices. Here we focus on the modified electronic properties of silicon, as being the most important and the most widely-studied semiconductor [2]. In Float Zone (FZ) silicon where

Abbreviations: DIB, damaging ion beam; PIB, probing ion beam; IBIC, Ion Beam Induced Charge; NIEL, non-ionizing energy loss; CCE, charge collection efficiency.

* Corresponding author.
E-mail address: ettore.vittone@unito.it (E. Vittone).

[1] Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

http://dx.doi.org/10.1016/j.nimb.2016.01.030
0168-583X/© 2016 Elsevier B.V. All rights reserved.