Available online at www.sciencedirect.com

SCIENCE DIRECT®

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 518 (2004) 338–339

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

Lithium ion-induced damage in silicon detectors

A. Candelori[a,*], D. Bisello[a], P. Giubilato[a], A. Kaminski[a], A. Litovchenko[a],
M. Lozano[b], M. Ullán[b], R. Rando[a], J. Wyss[c]

[a] *Dipartimento di Fisica and INFN Sezione di Padova, Via Marzolo 8, I-35100 Padova, Italy*
[b] *Institut de Microelectrònica de Barcelona (IMB-CNM-CSIC), Cerdanyola del Valles, E-08193 Barcelona, Spain*
[c] *Dipartimento di Meccanica, Struttura, Ambiente e Territorio, via DiBiasio 43, I-03043 Cassino (FR), Italy*

Abstract

Silicon diodes processed by CNM on standard and oxygenated silicon substrates have been irradiated by 58 MeV lithium ions. The radiation-induced effects are very similar to the one observed after proton irradiation: substrate space charge sign inversion (SCSI), lower increase of the effective substrate doping concentration after SCSI for the oxygenated devices. The experimental radiation hardness factor has been determined to be 45.01, within 8.2% with the expected value. These results suggest that 58 MeV Li ions are a suitable radiation source for radiation hardness studies by ions heavier than protons for the future very high luminosity hadron colliders.

Keywords: Semiconductor diodes; Radiation detectors; Radiation damage

---

1. Introduction

The next generation silicon detectors for future very high luminosity colliders or a possible LHC upgrade scenario will require radiation-hard detectors for fluences up to 10^{16} 1-MeV neutrons/cm^2 [1]. These high fluences present strong constraints because long irradiation times are required at the currently available proton irradiation facilities. Energetic (58 MeV) lithium ions present a hardness factor that is about 27.3 (84.7) times higher than 27 MeV (24 GeV) protons, and consequently are a new promising radiation source for investigating radiation hard silicon detectors up to very high particle fluences. In this study, in the framework of the CERN RD-50 Collaboration, we present for the first time the characteristics of the degradation (leakage current density and depletion voltage variations) induced in silicon diodes processed on standard and oxygenated silicon substrates by 58 MeV Li ions.

2. Experimental procedures

Tested devices are p^+-n silicon diodes processed by CNM on n-type high resistivity ($\rho = 4\,\mathrm{k}\Omega \times \mathrm{cm}$) 280 μm thick standard and oxygenated (by diffusion at 1150°C for 12 h) substrates. Devices have been irradiated by 58 MeV Li ions, whose range in silicon is 400 μm, at the SIRAD irradiation facility of the INFN National Laboratory of Legnaro, with an ion flux of $\approx 2.5 \times 10^9$ Li/cm^2. The particle fluence inaccuracy is within 10%. After irradiation devices were electrically characterized before and after the annealing at 80°C for 4 min by 10 kHz

---

*Corresponding author. Tel.: +39-049-8277215; fax: +39-049-8277237.

E-mail address: candelori@pd.infn.it (A. Candelori).

0168-9002/$ - see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2003.11.014

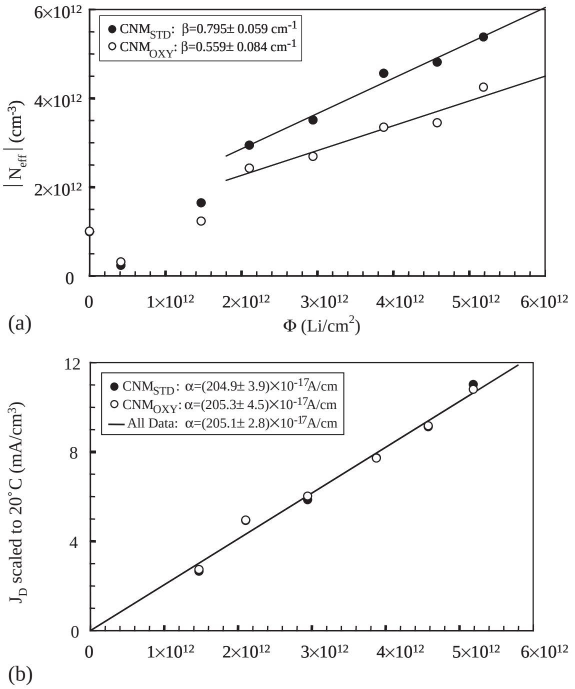

Fig. 1. Absolute value of the effective substrate doping concentration N_{eff} (a) and diode current density at full depletion J_{D} scaled to 20°C (b) as a function of the Li ion fluence for standard (close symbols) and oxygenated (open symbols) diodes. The slope of each linear fit, i.e. the acceptor introduction rate β for N_{eff} and the current density increase rate α for J_{D}, is also reported. The α and β errors refer to the fit inaccuracy.

capacitance–voltage (C–V) and current–voltage (I–V) measurements, in order to determine the depletion voltage (V_{dep}) and the reverse current density at full depletion (J_{D}) [2].

3. Experimental results

The effective substrate doping concentration ($N_{\mathrm{eff}} = 2\varepsilon V_{\mathrm{dep}}/qW^2$ where ε is the Si dielectric constant, q is the electron charge and W is the diode thickness) as a function of the Li ion fluence is shown in Fig. 1a. Similarly to proton irradiation effects [2]: (1) $|N_{\mathrm{eff}}|$ initially decreases and then increases as a function of the particle fluence, i.e., space charge sign inversion (SCSI) occurs; (2) after SCSI, $|N_{\mathrm{eff}}|$ has a linear dependence on the Li ion fluence and both the slope in the linear region, i.e. the β parameter, and $|N_{\mathrm{eff}}|$ are lower for the oxygenated devices.

After the annealing at 80°C for 4 min, the results are similar to the ones in Fig. 1a, but the β parameter decreases to $0.373 \pm 0.031\,\mathrm{cm}^{-1}$ and $0.337 \pm 0.036\,\mathrm{cm}^{-1}$ for the standard and oxygenated devices, respectively.

The diode current density at full depletion (J_{D}) scaled to 20°C as a function of the Li ion fluence after the annealing at 80°C for 4 min is reported in Fig. 1b. Similarly to proton irradiated devices [2], J_{D} does not present any dependence on the substrate oxygenation and it linearly increases as a function of the particle fluence. The slope of the linear fit of all the experimental data, $\alpha = (205.1 \pm 2.8) \times 10^{-17}$ A/cm, allows to determine the radiation hardness factor (H) of 58 MeV Li ions in the NIEL scaling hypothesis, i.e., $H = \alpha(58\,\mathrm{MeV\ Li})/\alpha(1\,\mathrm{MeV\ neutrons}) = 45.01$, where $\alpha(1\,\mathrm{MeV\ neutrons}) = 4.56 \times 10^{-17}$ A/cm [3]. This value is agreement within 8.2% with the value (49.1) expected from SRIM simulation.

References

[1] RD50 proposal, CERN, LHCC 2002-003, 15 February 2002.
[2] A. Candelori, et al., IEEE Trans. Nucl. Sci. NS-48 (2001) 2270.
[3] M. Moll, et al., Nucl. Instr. and Meth. B 186 (2002) 100.