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Silicon Carbide detectors for nuclear physics experiments at high beam luminosity

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Abstract. Silicon carbide is a very promising material for next generation nuclear physics experiments at high beam luminosity. Such activities require devices able to sustain high fluxes of particles (up to 10^{14} ions/cm^2) in order to determine the cross sections of very rare nuclear phenomena. One of these activities is the NUMEN project, which aims, through the double charge exchange reactions, to impact in the determination of nuclear matrix elements entering in the expression of half-life of the neutrino-less double beta decay. Due to the very low cross sections, these features can just be explored at fluences which exceed by far those tolerated in state of the art solid state detectors, typically used in this kind of experiments. The SiC technology offers today an ideal response to such challenges, giving the opportunity to cope the excellent properties of silicon detectors with the radiation hardness, thermal stability and visible blindness of SiC material.

Introduction

Silicon carbide (SiC) is one of the compound semiconductor which has been considered as a potential alternative to Silicon (Si) for the realization of charge particles detectors and dosimeters in high energy physics. The chemical and physical material properties are promising for high temperature and high radiation operation conditions [1]. SiC diodes are predicted to be radiation harder than Si due to the high displacement threshold energy and potentially used as radiation detectors in high radiation conditions. The recent progresses in the material growth [2] and device technology, allowed to realize high performances SiC detectors [3, 4]. The potentialities of SiC as detectors are many, they have been used to detect neutrons, X-rays, protons, alpha particles and heavy-ions [5, 6]. High collection efficiency and energy resolution in the range 0.29 % - 1.7 % was reported for the detection of alpha-particle in the energy range 3.0 - 5.5 MeV [7-9].
The radiation-hardness of the material make it particularly interesting for all those activities where high flux must be detected [10, 11, 12]. One of these activities is the NUMEN project [13]. NUMEN aims to get information on the nuclear matrix elements entering the expression of the half-life of the double beta decay by relevant cross sections measurements of heavy-ion induced double charge exchange (DCE) reactions, (^{18}O,^{18}Ne), (^{20}Ne,^{20}O) and (^{12}C,^{12}Be). The DCE reactions will be investigated with incident energies ranging from 10 to 70 MeV/A and the MAGNEX large acceptance magnetic spectrometer [14-

16] will be used to detect the ejectiles produced in the nuclear collisions with its Focal Plane Detector (FPD) [17]. The operating conditions of NUMEN project require an upgrade of the actually used FPD with the replacement of silicon detectors with a new generation stopping wall telescope, which could be realized with Silicon Carbide. Simulation studies [18] have been realized in order to define the appropriate characteristics of the telescope, especially in term of thickness of the two stages (ΔE and E detectors) composing the telescope. The best solution requires the use of ΔE stage with a thickness of the order of 100 μm and a thicker E stage (~ 1000-2000 μm in order to identify ions in the range between 10 to 70 MeV/A.

The Schottky junctions represent today the state of art for SiC devices while p^+-n^- junctions are instead a novel solution for SiC detectors, very promising in analogy to similar junctions based on silicon devices. The first step for the development of new devices is the realization of some 4H-SiC prototype detectors with performances suitable to monitor heavy ions at high energy and at high dose. SiC is considered to be radiation harder than Si, however a direct comparison between the two type of detectors is not reported in literature. So in the present paper we have studied the effects of very high energy irradiation on SiC and Si detector electrical characteristics. We performed energy resolution analysis on SiC Schottky diode using alpha particles beams to evaluate the detectors performances and studythe effects of very high energy irradiation on SiC and Si detector electrical characteristics.

2. Results and discussion

The detectors were irradiated with 740 MeV Carbon beam at a dose of 94 KGy, and current-voltage (I-V) measurements of not irradiated and irradiated diodes were compared. We used 4H-SiC Schottky diode detectors realized on a 38 μm thick n-type epitaxial layer with a doping concentration of 4.8×10^{14} cm^{-3}. Schottky diodes with an active contact area of 1 mm^2 and 2.25 mm^2 were used with a nickel silicide (Ni_2Si) as metal Schottky contact. The Silicon detectors were Micron Semiconductor diodes, with an intrinsic ($1.3 \times 10^{11} cm^{-3}$) epitaxial layer, 300μm thick and active area of 1x1 cm^2.

In Figure 1 the energy resolution analysis obtained on SiC Schottky diode detectors under the exposition at a three peaks alpha source particles (^{239}Pu – ^{241}Am – ^{244}Cm) is shown and in Table 1 the evaluated energy resolution is reported. An Ascom preamplifier (90 mV/MeV gain), a 572 Ortec amplifier (shaping-time 2 μs) and a multichannel system were used. The obtained resolution results are not very far from the values of Silicon commercial detectors resolution (0.3%), demonstrating a good performance of prototype SiC detectors.

The reverse electrical characteristics measured in not irradiated and irradiated SiC detectors are shown in Figure 2 (a). The leakage current density in the not irradiated diode is about 2×10^{-6} A/cm^2 and it increases of about a factor two after a dose of 94 KGy. Similar measurements were performed on Si detector and the reverse I-V characteristics are reported in Figure 2 (b). The leakage current density is about 10^{-5} A/cm^2 in the not irradiated diode and it increases of more than a factor 50 after a dose of 94 KGy. The comparison between the

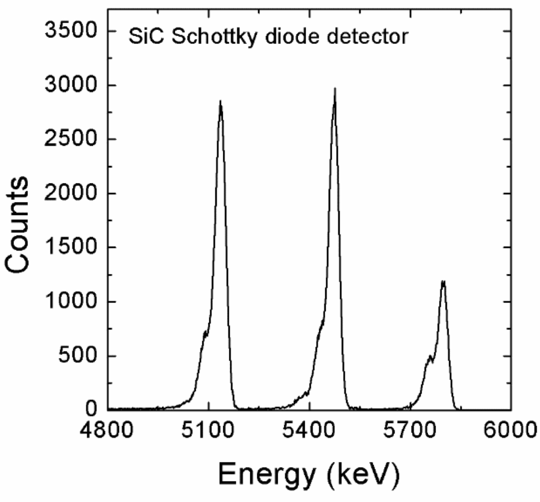

Figure 1 Response of SiC detector to a three peak α-source

Peak	Resolution (%)
^{239}Pu	0.74
^{241}Am	0.67
^{244}Cm	0.64

Table 1 SiC detector energy resolution

electrical measurements on SiC detectors and Si one reveals that at the same dose the effect on the SiC is one order of magnitude lower. Energy resolution analysis are in progress to evaluate the effect of irradiation on detector resolution.

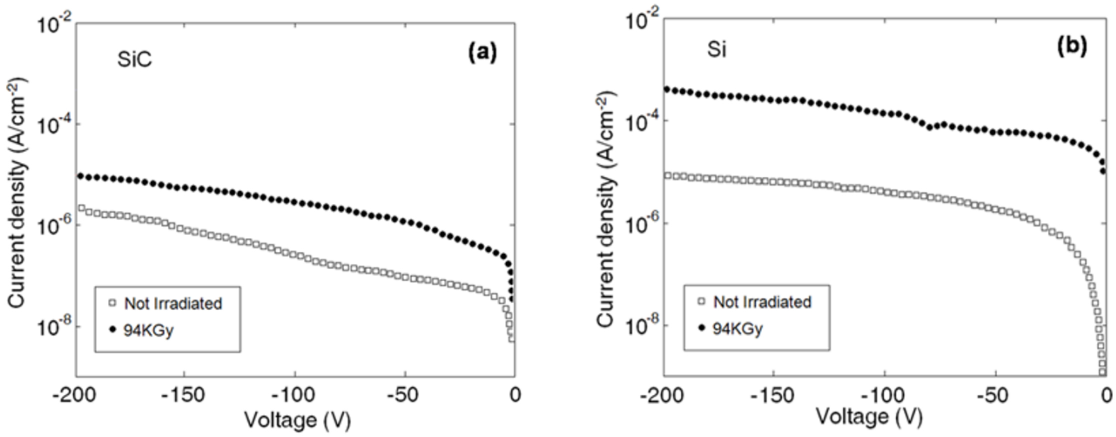

Figure 2 (a) SiC and (b) Si detector current-voltage characteristic in reverse bias

3. Conclusions

The effects of heavy ions irradiation on SiC detector was studied and compared with Si device, in particular the electrical characteristics after high dose irradiation have been compared. The high radiation hardness of SiC was demonstrated. Such results are preparatory for the development of innovative thick and large area SiC detectors useful for specific nuclear scopes.

References

[1] F. Nava, G. Bertuccio, A. Cavallini, E. Vittone, 2008 *Meas. Science Tech.* **19** 102010.
[2] F. La Via, M. Camarda, A. La Magna, 2014 *Appl. Phys. Rev.* **1** 031301.
[3] S. K. Chaudhuri, R. M. Krishna, K. J. Zavalla, K. C. Mandal, 2013 *Nucl. Instr. Meth. In Phys. Res. A* **701** 214.
[4] F. Moscatelli, A. Scorzoni, A. Poggi, M. Bruzzi, S. Lagomarsino, S. Mersi, S. Sciortino, R. Nipoti, 2005 *Nucl. Instr. Meth A* **546** 218.
[5] J. E. Lees, D. J. Bassford, E. J. Bunce, M. R. Sims, A. B. Horsfall, 2009 *Nuc. Instr. Meth. A* **604** 174.
[6] G. Bertuccio, R. Casiraghi, A. Cetronio, C. Lanzieri and F. Nava, 2004 *Nucl. Instr. Meth. A* **522** 413.
[7] S. K. Chaudhuri, K. J. Zavalla, K. C. Mandal, 2013 *Nucl. Instr. Meth. In Phys. Res. A* **728** 97.
[8] Y. B. Gurov, S. V. Rozov, E. A. Yakushev, L. Hrubcin,and B. Zat'ko, 2015 *Instr. and Exper. Tech.* **58** 22.
[9] L. Liu, J. L. Liu, L. Chen, Z. B. Zhang, P. Jin, J. L. Ruan, G. Chen, A. Liu, S. Bai, X. P. Ouyang, 2016 *Diamond and Related Materials* http://dx.doi.org/10.1016/j.diamond.2016.09.011
[10] F. Negoita, M. Roth, P. G. Thirlof, S. Tudisco, S. Mirfayzi, S. Kar, F. Hannachi, S. Moustaizis, I. Pomerantz, P. McKenna, J. Fuchs, K. Sphor, G. Acbas, A. Anzalone, P. Audebert, S. Balascuta, 17.05.2016 *Romanian Reports in Physics* **68** No. Supplement, p. S37-S144.
[11] F. Cappuzzello, C. Agodi, D. Carbone, M. Cavallaro, 2016 *Eur. Phys. T. A.* **52** 167
[12] F. Cappuzzello, C. Agodi, M. Bondì, D. Carbone, M. Cavallaro, A. Foti, 2015 *Jour. of Phys. Conf. Ser.* **630** 012018
[13] F. Cappuzzello et al 2018 *Eur. Phys. J.* A **54** 72
[14] F. Cappuzzello et al 2016 *Eur. Phys. J.* A **52** 167
[15] F. Cappuzzello et al 2014 *Nucl. Instr. and Meth.* A **763** 314

[16] A. Cunsolo et al. 2007 *Eur. Phys. J. A ST* **150** 343
[17] M. Cavallaro et al 2012 *Eur. Phys. J. A* **48** 59
[18] A. Muoio et al. 2016 *EPJ Web of Conferences* **117** 10006