HIGH ENERGY ION DETECTION USING 4H-SIC SEMICONDUCTOR DETECTOR

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1. Introduction

Silicon carbide (SiC) is a suitable material for fabrication of nuclear radiation detectors working in harsh environments. Mainly, 4H-SiC polytype is one of the mostly investigated. Detectors based on high-quality epitaxial layer show high spectroscopic performance for γ-rays (up to 60 keV) at room and also elevated temperatures [1, 2]. Characterizations of the depletion region length of 4H-SiC Schottky detector using a α, β and γ- radiation sources have also been realized [3, 4]. Studies using α-particles show also very promising results. Detectors achieve 100 % CCE, diffusion length of holes up to 13 μm and energy resolution up to 0.25 % (Full Width at Half Maximum, FWHM) for 5.48 MeV α–particles [5-7]. SiC detectors can be also utilized for detection of neutrons. The conversion layer of ^{6}LiF or ^{10}B is necessary to be used in the case of thermal neutron detection, while HDPE (High Density Polyethylene) for detection of fast neutrons. The thermal neutrons conversion layer transforms neutrons to heavy charged particles (α, $^{3}H^{+}$, etc.) which are easily detected [8, 10]. As silicon and carbide are light atoms, SiC detector can directly detect fast neutrons through elastic scattering. The HDPE converter layer converts fast neutrons to protons, which impinge upon the detector and increases the detection efficiency [11, 12]. The effect of proton irradiation on 4H-SiC detector properties, its influence on the quality of the rectification contact and elevated temperature were also investigated [13, 14]. Irradiation with 1 MeV neutrons shows a good spectrometric performance of the SiC detector up to a fluency of 10^{14} cm^{-2} [15]. The γ-irradiation indicates that detectors are able to operate up to doses about 5 MGy. The spectrometric performance of α-particles deteriorates minimal [16]. High energy electron irradiation and its influence on the diffusion length of minority carriers were studied and a non-negligible radiation damage recovery effect by low temperature annealing was observed [17].

At present, we study detection of high energy heavy ions using 4H-SiC detector. We found out several problems in heavy ions spectrometry which are also known from silicon detectors utilizing. The pulse height response of detector to heavy ions is different than that for light ions such as protons, at the same energy; the pulse height is lower for heavier ions. This Pulse Height Defect (PHD) is related most probably to phenomenon's like the window defect where heavy ions loss energy in the detector dead layer (contact metallization), nuclear stopping defect due to loss of energy by non-ionizing events and plasma effect where heavy ions create a dense “cloud” of electron-hole pairs in detector volume and the electric field created by the applied bias cannot penetrate this cloud. Only after the cloud has been sufficiently dispersed by ambipolar diffusion will the charge carriers begin to drift under the influence of the external electric field. These phenomenons have been studied in silicon detectors where influence of the electric field in detector and mass of ions to deposited energy was observed [18-21].

In this work we present results of heavy ion detection. Two types of detectors base on Si and 4H-SiC have been used. The energy calibration of detectors was accomplished using α-particle sources (^{226}Ra and ^{225}Ac). Calibrated detector was used for detection of ^{132}Xe^{23+} ions with three different energies of 165 MeV, 81.6 MeV and 44.5 MeV. The PHD for each detector was observed and evaluated.

2. Detector parameters

The 4H-SiC detector was prepared at our institute from a 70 μm thick nitrogen-doped 4H-SiC layer (with donor doping about 1×10^{14} cm^{-3} produced by ETC Catania) grown by LPE on a 3” 4H-SiC wafer with 0.5 μm thick n++-SiC buffer layer. The detector was prepared by evaporation of a double layer of Au/Ni with thicknesses of 90 and 40 nm on the epitaxial layer using a high vacuum electron gun apparatus. A Schottky barrier contacts with a diameter of 2 mm was formed on the epitaxial layer through a contact metal mask while a full area ohmic contact of Ti/Pt/Au was evaporated on the opposite side (substrate). The operation voltage was in the range from 50 to 250 V.

The silicon detector was used for comparison of the obtained results. The Si detector has the active area of 8×8 mm^2 and the thickness of 380 μm. The operation voltage was in the range from 20 to 70 V.

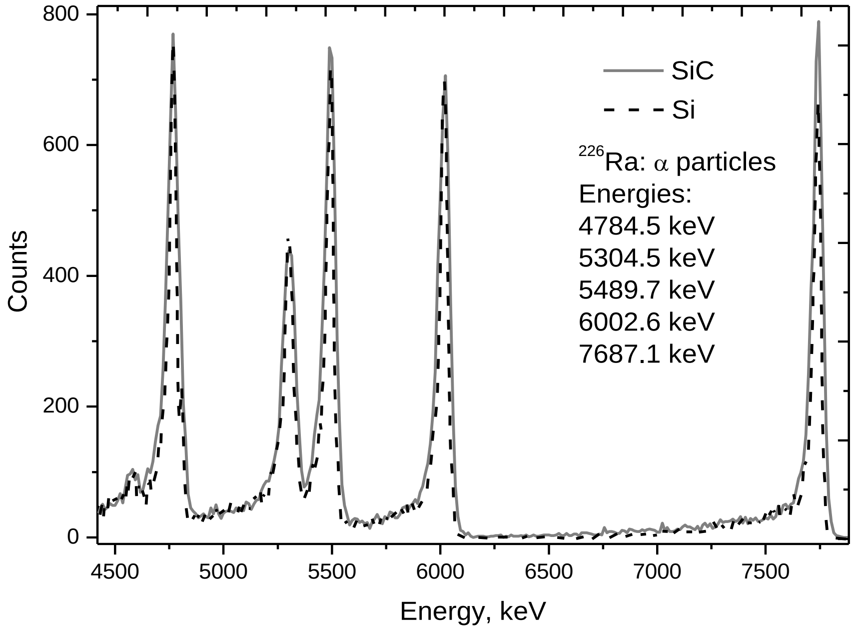

Fig.1: *Response of ^{226}Ra α-particle source measured with Si and SiC detector.*

3. Detector energy calibration and ^{132}Xe^{23+} detection

The α-particle source of ^{226}Ra was used for detector calibration and spectrometric performance evaluation. The radiation source generates α-particles with energies: 4784.5 keV, 5304.5 keV, 5489.7 keV, 6002.6 keV and 7687.1 keV. Fig. 1 shows spectra measured with Si and 4H-SiC detectors where the gray line represents the response of SiC detector and the dashed line the response of Si detector. Characteristics are almost identical in term of energy resolution. The amplitude of signal of the SiC detector is, however, more than 2 times lower comparing to Si detector because of different mean energy needed for creation of one electron-hole pair which is 3.6 eV for Si and 7.8 eV for SiC detector. The energy resolution is below 1% for each peak.

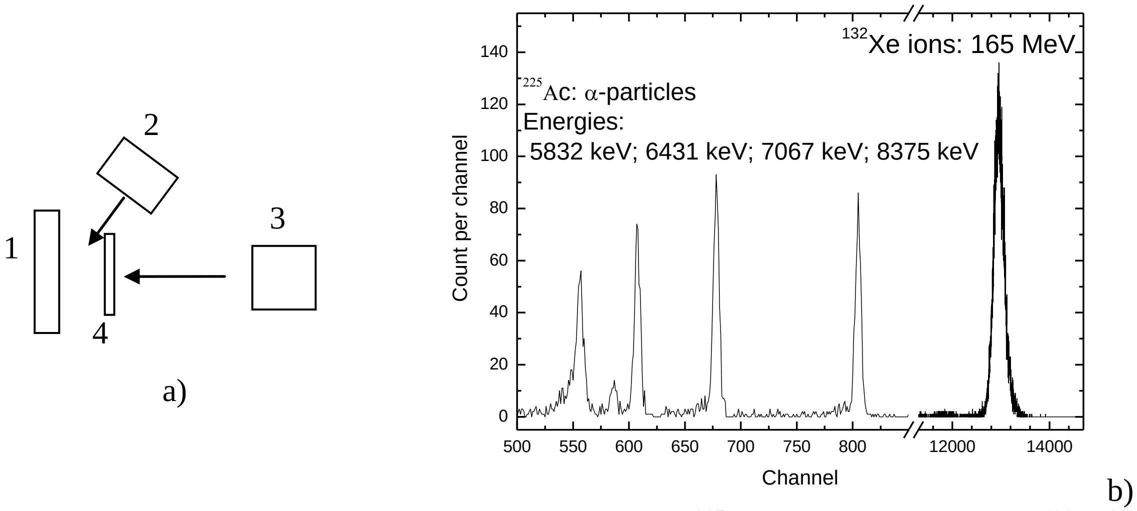

Fig.2: *a) The configuration of experiment: 1) detector, 2)* ^{225}*Ac α-particle source, 3)* ^{132}*Xe*$^{23+}$ *ions source,4) thin Al foil; b) Typical measured pulse height spectrum of detector.*

Aforementioned detectors were used for heavy ion detection at the Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research in IC-100 accelerator [22]. Detectors were placed in ^{132}Xe^{23+} ion beam with energy of 1.25 MeV/nucleon and pulse height spectra were measured. As the energy per nucleon cannot be changed we have used two thin Al foils (6 μm and 9.5 μm thick) to decrease the energy of Xe ions. Together with heavy ion detection we measured α-particles from ^{225}Ac source due to additional energy calibration. The α-particles from ^{225}Ac impinge upon the detector at an angle of 45 degrees. Fig 2a shows configuration of our experiment. The typical measured pulse height spectrum is depicted on Fig 2b. Using Al foil we have decreased the energy of ions down to 81.5 MeV and 44.5 MeV depending on its thickness. The energy loss of heavy ions passing through 4H-SiC detector contacts were calculated and are 5.5 MeV, 4.0 MeV and 1.5 MeV for energies 165 MeV, 81.5 MeV and 44.5 MeV, respectively.

4. Discussion and conclusion

Fig. 3 shows dependence of channel number versus energy of α-particle and Xe ions for Si and SiC detector. For better visibility of low energy α-particles (5.8 – 8.4 MeV) and high energy heavy ions (44.5 - 165.0 MeV) we used log-log scale. The dashed line shows calibration using α-particles and indicates where Xe ions peaks were awaited. The PHDs were calculated by following equation:

$$PHD = E_{Xe} - \Delta E_{CL} - E_M, \qquad (1)$$

where E_{Xe} is energy of Xe ion flying to detector, ΔE_{CL} is energy loss in detector contact and E_M is measured energy by detector. The calculated PHDs are shown in Table 1. The values of PHD (26.0 MeV, 15.4 MeV and 7.9 MeV) are about 18% of the energy of heavy ions for the Si detector and (63.1 MeV, 31.1 MeV and 17.4 MeV) about 39% for the SiC detector. More than 2 times higher PHDs of the SiC detector in comparison with the Si detector is probably due to the different energy needed for creation of one electron-hole pair which is also more than 2 times higher for the SiC detector.

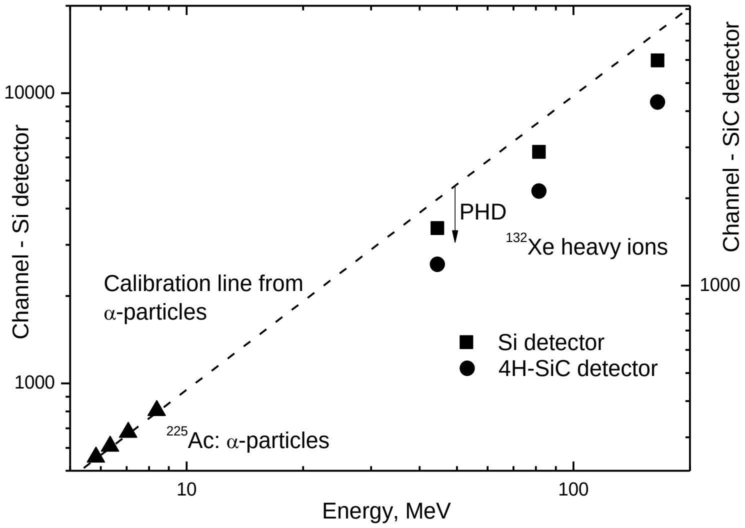

Fig.3: *The dependence of the ion energy on the measured channel of detector*

E_{Xe} [MeV]	165	81.6	44.5
E_M (Si) [MeV]	133.5	63.5	35.1
ΔE_{CL} (Si) [MeV]	4.1	3.0	1.1
PHD (Si) [MeV]	**27.4**	**15.1**	**8.3**
E_M (SiC) [MeV]	96.4	46.5	25.6
ΔE_{CL} (SiC) [MeV]	5.5	4.0	1.5
PHD (SiC) [MeV]	**63.1**	**31.1**	**17.4**

Table 1: *PHDs calculated for Si and SiC detector.*

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