THE THERMAL NEUTRON DETECTION USING 4H-SiC DETECTORS WITH ^{6}LiF CONVERSION LAYER

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1. Introduction

Silicon carbide (SiC) is a promising material for high-temperature electronics, high-frequency devices and radiation-resistant electronics. The capability of SiC to function under extreme conditions can improve many systems and applications [1] and SiC can also be used as a sensor of ionizing radiation [2-4]. The 4H-SiC polytype is prospective due to its high breakdown voltage of about 2×10^{6} V/cm, electron mobility of about 900 $\mathrm{cm^{2}V^{-1}s^{-1}}$ and saturation drift velocity 2×10^{7} cm/s. The band gap energy of 4H-SiC is 3.26 eV at room temperature (RT).

Detectors based on the 4H-SiC epitaxial layer can attain high quality X-ray spectroscopic data at room as well as at increased temperatures. One of the best spectra of ^{55}Fe radioisotope and the noise energy of 196 eV FWHM (Full Width at Half Maximum) at RT for 5.9 keV photopeak were reported in [5, 6]. The detection efficiency is, however, limited primarily by a low thickness of the active region (typically below 100 μm) and by a low linear absorption coefficient, almost identical with silicon detectors. Very good radiation hardness was acquired in work [7], where detectors were exposed to gamma radiation produced by ^{137}Cs with doses up to 5.5 MGy and no significant deterioration in detection of α-particles emitted by ^{238}Pu radioisotope was observed. In addition, our previous work [8] showed only a weak deterioration of the detected gamma spectrum from ^{241}Am after fast neutrons and gamma irradiation. Characterizations of the depletion region length of 4H-SiC Schottky detector using a ^{90}Sr β-source have also been realized [9]. A 100 % CCE (Charge Collection Efficiency) and fully depleted detector thickness was observed. Also in studies using α-particles, detectors achieve 100 % CCE, diffusion length of holes up to 13 μm and energy resolution 0.38 % (FWHM) for an optimized detector in terms of material and contact thickness [10]. Our best 4H-SiC Schottky contact detector reached 0.25 % energy resolution for 5.5 MeV α-particles generated by ^{241}Am [11]. SiC detectors can be utilized for detection of neutrons, using a converter layer of ^{6}LiF and ^{10}B for thermal neutrons while HDPE (High Density Polyethylene) increases the detection efficiency of fast neutrons. In the case of thermal neutrons the converter layer transforms neutrons to heavy charged particles (alpha, triton, etc.), which are easily detected with high precision [12]. Since silicon and carbon are light atoms, the SiC detector is directly able to detect fast neutrons through elastic scattering of carbon and silicon ions and produce a measurable signal. The detection efficiency can be increased using an HDPE converter layer transforming fast neutrons to protons [13].

In this paper we have examined 4H-SiC detector using a thermal neutron source and studied its detection properties. The detector was exposed to neutrons generated by ^{238}Pu-Be radiation source. The detection properties of 4H-SiC detectors were evaluated considering the use of the ^{6}LiF conversion.

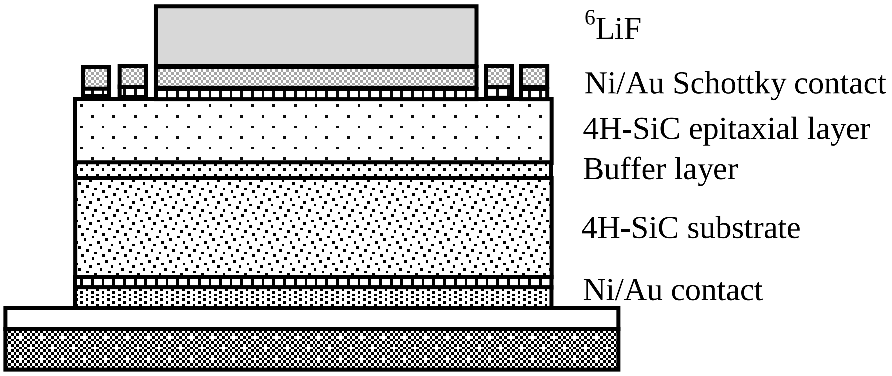

Fig. 1. *Schematic cross-sectional view of the Schottky barrier 4H-SiC detector for thermal neutrons.*

2. Detectors preparation and experimental methods

Several detector structures were prepared from a 70 μm thick nitrogen-doped 4H-SiC layer (with donor doping of about 1×10^{14} cm^{-3}) grown by LPE (liquid phase epitaxy) on a fragment of a 3” 4H-SiC wafer (donor doping level ~2×10^{18} cm^{-3}, thickness 350 μm), by growing a 0.5 μm thick n++-SiC buffer layer with donor concentration of 1×10^{18} cm^{-3}. The radiation detector surfaces were prepared by evaporation of a double layer of Au-Ni/4H-SiC with a thickness of 90/40 nm on both sides of the wafer fragment using a high vacuum electron gun apparatus. The Schottky barrier contact with a diameter of 4.5 mm was formed on the epitaxial layer using photolithography masking. Around the Schottky contact two guard rings was also created. A full area contact of Ni/Au double layer was evaporated on the other side (substrate). Prior to evaporation, the sample was cleaned in boiling acetone and isopropyl alcohol, washed in deionised water and dried by nitrogen flow. Schematic cross section of the detector is depicted in Fig. 1.

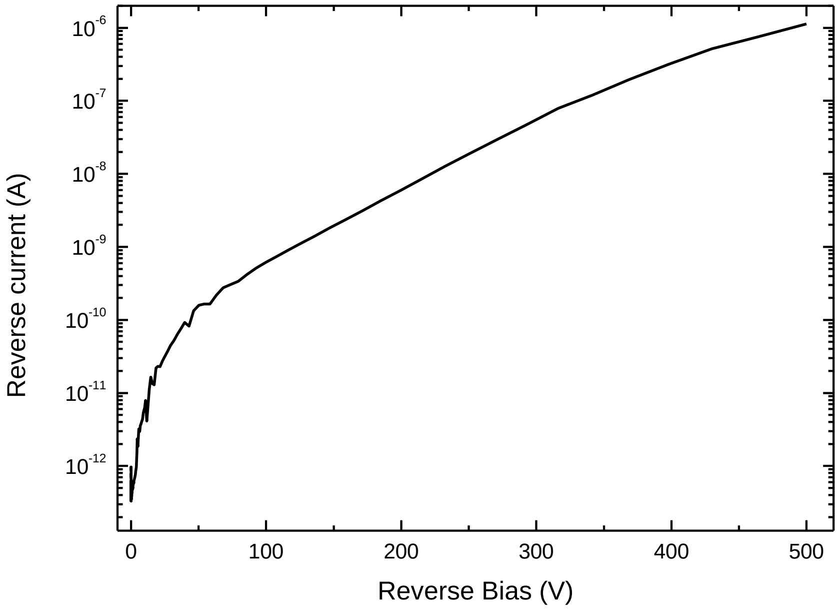

Fig.2: *Reverse current-voltage of 4H-SiC Schottky contact detector.*

Current-voltage measurements were carried out in the dark at temperature of 298 K to determine operating region. Than the detector was connected to the spectrometric set-up and using alpha particles (of 5.5 MeV) from ^{241}Am its detection performance was tested. Following ^{6}LiF conversion layer was applied on the detector Schottky contact and detection of thermal neutron from ^{239}Pu-Be radiation source was carried out.

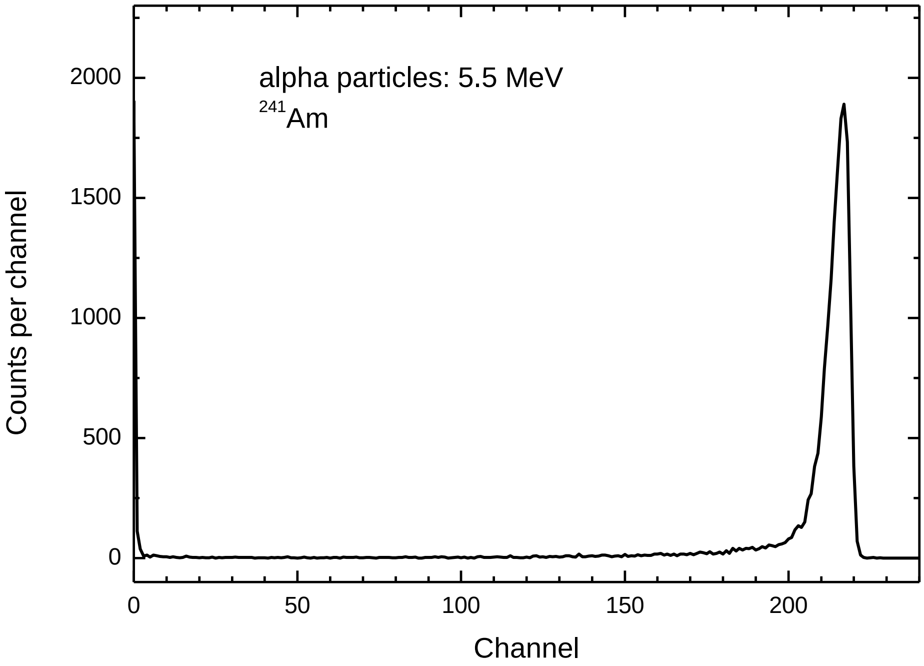

Fig.3: *The detection spectrum of alpha particles using 4H-SiC Schottky contact detector.*

3. Results and experiments

The current-voltage characteristic of the detector structure was measured. Fig. 2 shows the reverse current for bias up to 500 V at room temperature. The suitable operating region of detector lies between 100 V and 400 V. The detector was following tested using alpha particle generated by ^{241}Am source. The detected spectrum at -200 V is depicted in Fig. 3 and shows good detection characteristic even though the measurement was done without vacuum. The distance between alpha particle source and the detector was below 3 mm.

The detector Schottky contact was covered by ^{6}LiF conversion layer. The products of nuclear reaction between ^{6}Li and thermal neutron are an alpha particle (2.05 MeV) and triton (2.73 MeV) which are emitted in opposite directions. These charged particles are easily detected. In the experiment we used of 15 mg/cm^{2} of ^{6}LiF conversion layer which is slightly beyond theoretical maximum of thermal neutron detection efficiency [14]. The detected spectrum of thermal neutrons is shown on Fig. 4. We can clearly resolve individual products (α and tritons) above mentioned nuclear reaction.

4. Conclusions

We prepared 4H-SiC Schottky contact detectors based on high-quality of epitaxial layer. The current-voltage characteristic show operating region between 100 V and 400 V. The detector was connected to the spectrometric set-up and used for detection of alpha particles from ^{241}Am. Following the ^{6}LiF conversion layer was applied on the Schottky contact of detector and the detection of thermal neutrons was performed. We are able to resolve alpha particles and tritons which are products of nuclear reaction between thermal neutrons and conversion layer. Also bare detector was used for neutron detection to clearly show significant influence of the used conversion layer.

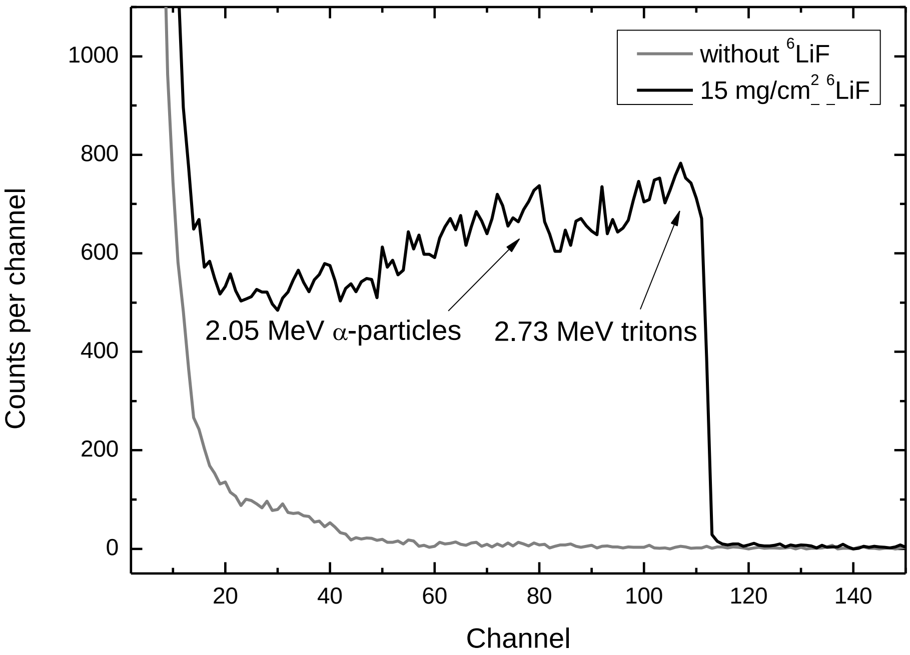

Fig.3: *The detection spectrum of thermal neutrons using 4H-SiC detector with and without ^{6}LiF conversion layer.*

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