ANALYSIS OF 4H-SiC SCHOTTKY DIODE AS A DETECTOR OF IONIZING RADIATION

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1. Introduction

SiC is a promising material for radiation-tolerant electronics, high-temperature electronics and high-frequency and power devices. 4H-SiC is polytype with the electron saturation drift velocity of 2×10^7 cm/s and the breakdown voltage of 2×10^6 V/cm at RT (room temperature). This material is also a very good candidate as a sensor material in radiation detection [1, 2]. The band gap energy of 4H-SiC is 3.26 eV and the mean energy of electron-hole pair creation is 7.78 eV at RT. Detectors based on the 4H-SiC epitaxial layer can attain a very high spectrometry of X-rays at room and also at elevated temperatures. Bertuccio *et al.* acquired one of the best spectra of ^{55}Fe radioisotope and reported the noise energy of 196 eV FWHM (Full Width at Half Maximum) at 30 °C for 5.9 keV photopeak [3-6]. Results obtained by F. H. Ruddy and J. G. Seidel show very good radiation hardness of 4H-SiC detectors, where they were exposed to gamma radiation produced by ^{137}Cs with dose up to about 5.5 MGy and no significant deterioration in detection of ^{238}Pu alpha-particles was observed [7]. In addition, also our previous work showed only weak worsening of detected ^{241}Am spectrum after fast neutrons and gamma irradiation [8].

The present work deals with the surface barrier particle detector based on 4H-SiC high purity epitaxial layer. We analyze the active region of detector using three different methods. The first is capacitance-voltage measurements, second method is based on detection of alpha particles produced by ^{241}Am and the third uses dependence of the detection efficiency of 59.5 keV γ-photons versus reverse bias voltage.

2. Detector fabrication

Several detector structures were prepared from a 105 μm thick nitrogen-doped 4H-SiC layer (with donor doping of about 1×10^{14} cm^{-3} [8]) grown by the 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 the growing of 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 thickness of 80-40 nm on both sides of the wafer fragment using a high vacuum electron gun apparatus. The Schottky barrier contact with diameter of 1.4 mm was formed on the epitaxial layer through a contact metal mask while full area contact was evaporated on the other side (substrate). A simple topology without a guard ring was used. Prior to evaporation, the sample was cleaned in boiled acetone and isopropyl alcohol, washed in deionized water and dried by nitrogen flow. The current-voltage characteristics for forward and reverse voltages were measured at RT and can be seen in our previous paper [9]. The diode has a very high rectifying ratio. The reverse curve presents a sublinear saturation current region followed by a superlinear shape over about 100 V due to superposition of the injection and leakage currents. The use of a guard ring is necessary to control the current increase at higher voltages. The reverse current density at RT lies below 1×10^{-10} A/cm^2 at 100 V bias voltage.

3. Experimental results and discussion

Capacitance-voltage (*C-V*) measurement was carry out using Agilent 4234A Precision LCR Meter operating at 1 MHz. Figure 1 shows $1/C^2$ depending upon reverse voltage and corresponding thickness of active layer. Discovered $1/C^2$ dependence is not perfectly linear in measured range. Calculated free carrier density profile reveals expectable gradual rising of concentrations from 1.3×10^{14} cm^{-3} to 1.5×10^{14} cm^{-3}. The ATL (active layer thickness) is about 3 μm at zero voltage and about 18 μm at – 40 V. For fully depleted 4H-SiC material is required reverse bias of -1450 V to -1600 V with respect to measured free carrier density profile.

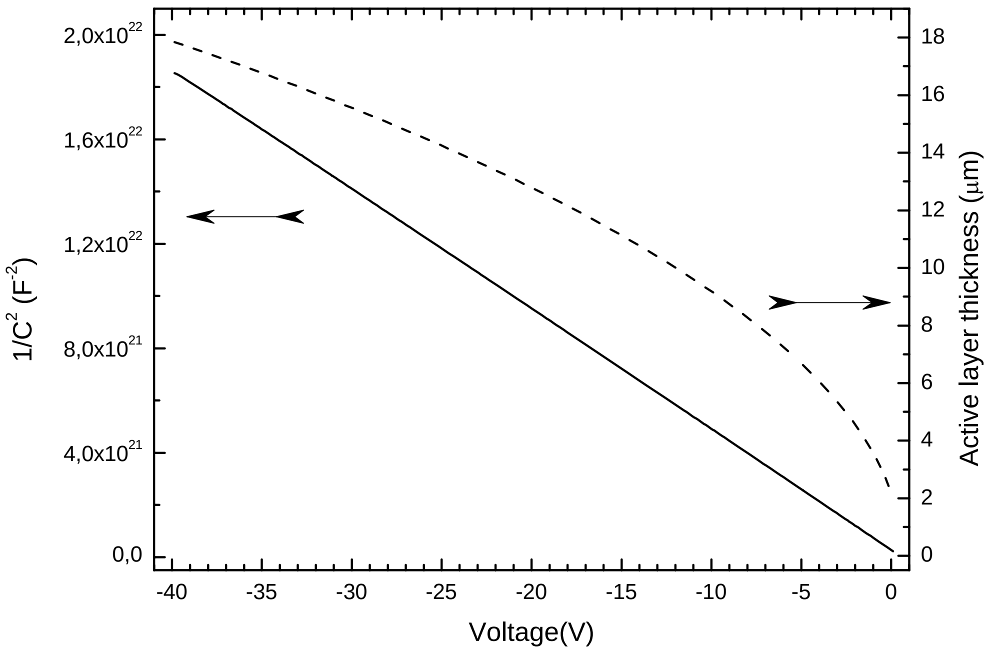

Fig.1. *$1/C^2$ profile and corresponding active layer thickness depending on voltage of 4H-SiC Schottky diode.*

Following study was performed using alpha particles detection. Alpha particle gradually loses its energy passing over detector material. The energy loss of heavy particle follows Bragg curve, which can be seen in Fig. 2. We applied SRIM simulation for energy loss of 5.5 MeV alpha particles in the studied SiC material. The maximum range is more than 19.5 μm. The detector we connected to the spectrometric chain based on ORTEC modules with the charge sensitive preamplifier, linear amplifier, ADC and multichannel analyzer. As a source we utilized ^{241}Am radioisotope. The spectra were measured at different reverse bias voltages up to 200 V. The calculated CCE (charge collection efficiency) was observed from measured spectra and according to Bragg curve we derived ATL of the fabricated 4H-SiC detector (Fig. 3). Comparing to *C-V* measurements, estimated ATL is greater in low voltages, because we have to add diffusion length of charge carriers, presenting several micrometers.

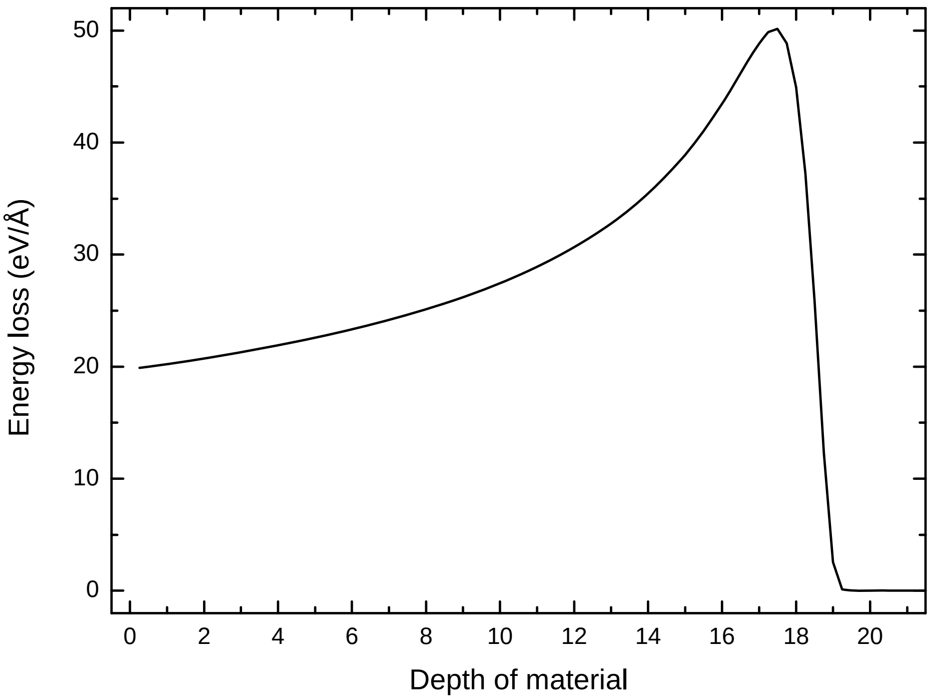

Fig.2. *Bragg curve of 5.5 MeV alpha particle in SiC detector material.*

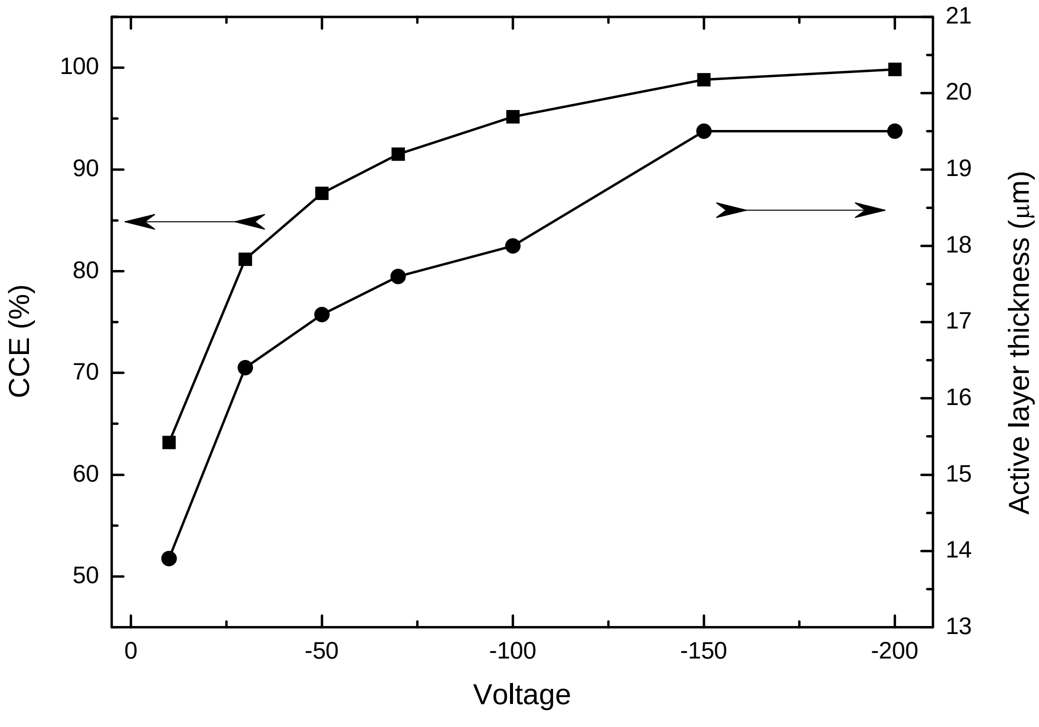

Fig.3. *Dependence of CCE vs. bias voltage and estimation of active layer thickness.*

The last method of the ATL estimation appeared from calculated detection efficiency of 59.5 keV γ-rays. As a source we again use ^{241}Am, but alpha particles were shielded with thin aluminium foil. Fig. 4 shows dependence of the total number of counts in 59.5 keV photopeak vs. reverse bias voltage and equivalent ATL. The fabricated Schottky barrier 4H-SiC detector can reach more than 70 μm ATL at -500 V.

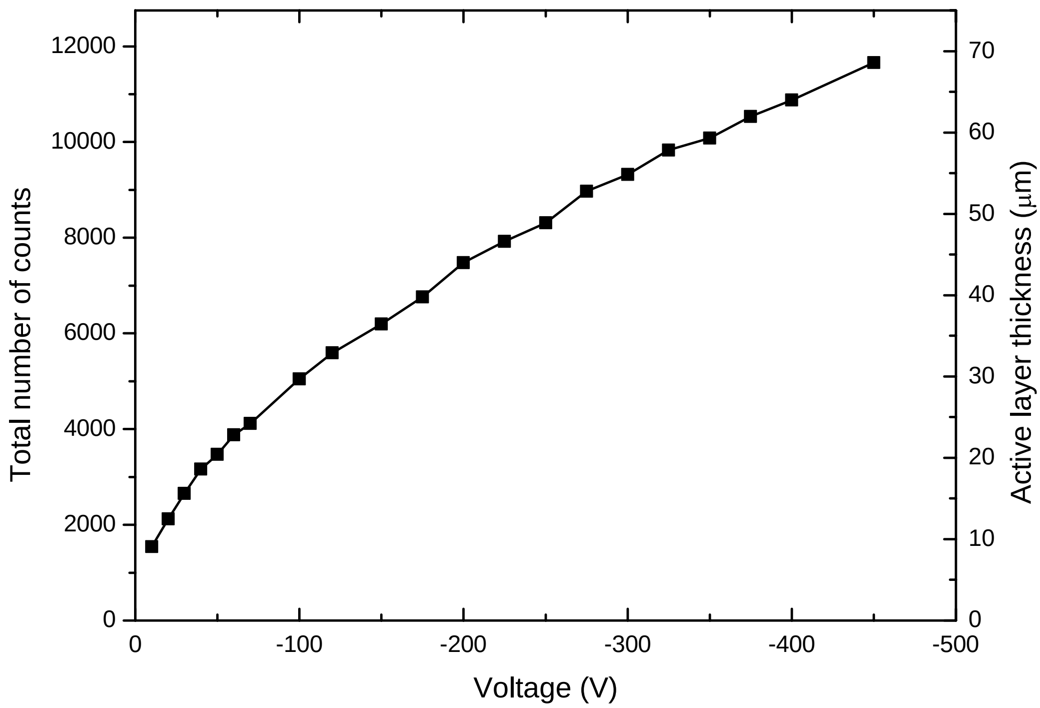

Fig.4. *Total number of count vs. bias voltage and corresponding active layer thickness.*

4. Conclusions

The Schottky barrier detector based on 4H-SiC high quality LPE layer was investigated. We estimated the thickness of the active layer of detector depending upon reverse bias voltage using three different methods: capacitance-voltage measurements, CCE of detected α-particles and detection efficiency of 59.5 keV γ-photons. We found out that the thickness of active layer is about 3 μm at 0 V and increases up to 70 μm at a reverse bias voltage of about -500 V. Results show that the free carrier concentration varies from 1.1×10^{14} cm^{-3} to 1.4×10^{14} cm^{-3}.

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