SiC NUCLEAR RADIATION DETECTORS FOR DETECTION OF HEAVY ION

L. Hrubčín[1,2], B. Zat'ko[1], Yu.B. Gurov[2,3], P. Boháček[1], S.V. Rozov[2], V.A. Skuratov[2]

Corresponding author: ladislav.hrubcin@savba.sk

[1]Institute of Electrical Engineering, Slovak Academy of Sciences, Dúbravská cesta 9, SK-814 04 Bratislava, Slovak Republic
[2]Joint Institute for Nuclear Research, Joliot-Curie 6, Russian Federation 141980 Dubna, Moscow Region, Russia
[3]INational Research Nuclear University (MEPhl), Kashirskoe shosse 31, 115409 Moscow, Russia

INTRODUCTION

Detectors based on 4H-SiC (Silicon Carbide) are very perspective due to:

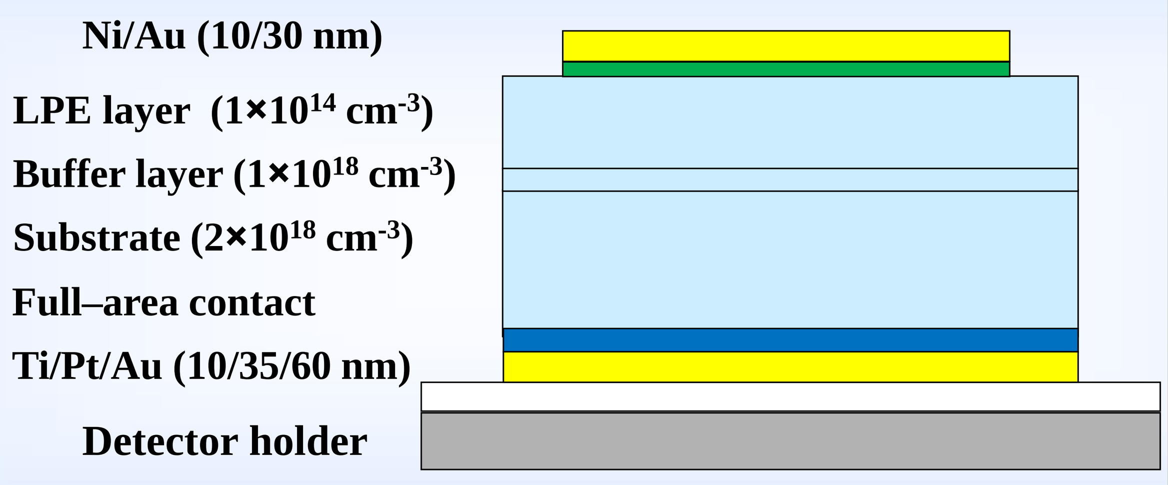
- good radiation hardness
- good spectroscopic resolution
- operation at increased temperature up to 300°C
- band gap energy (3.26 eV)
- high breakdown voltage (4×10^6 V/cm)
- electron mobility (about 900 $cm^2V^{-1}s^{-1}$)
- high electron saturation drift velocity (2×10^7 $cm s^{-1}$)

DETECTOR MATERIAL

Base material parameters:

- **20, 50** or **70** µm thick nitrogen-doped 4H-SiC layer grown by LPE
- Doping concentration about 1×10^{14} cm^{-3}
- 4H-SiC n^{++} substrate (350 µm thick)
- 0.5 µm buffer layer n^+-SiC with concentration 1×10^{18} cm^{-3}

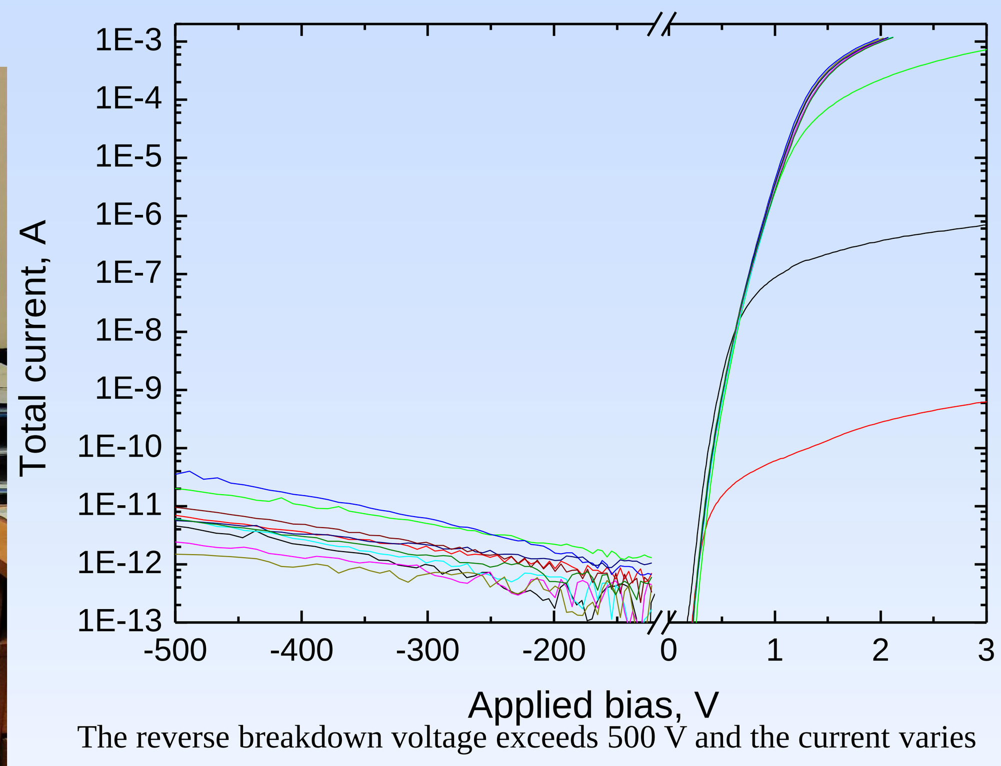
CROSS-SECTION OF DETECTOR



PHOTOGRAPHS OF DETECTOR

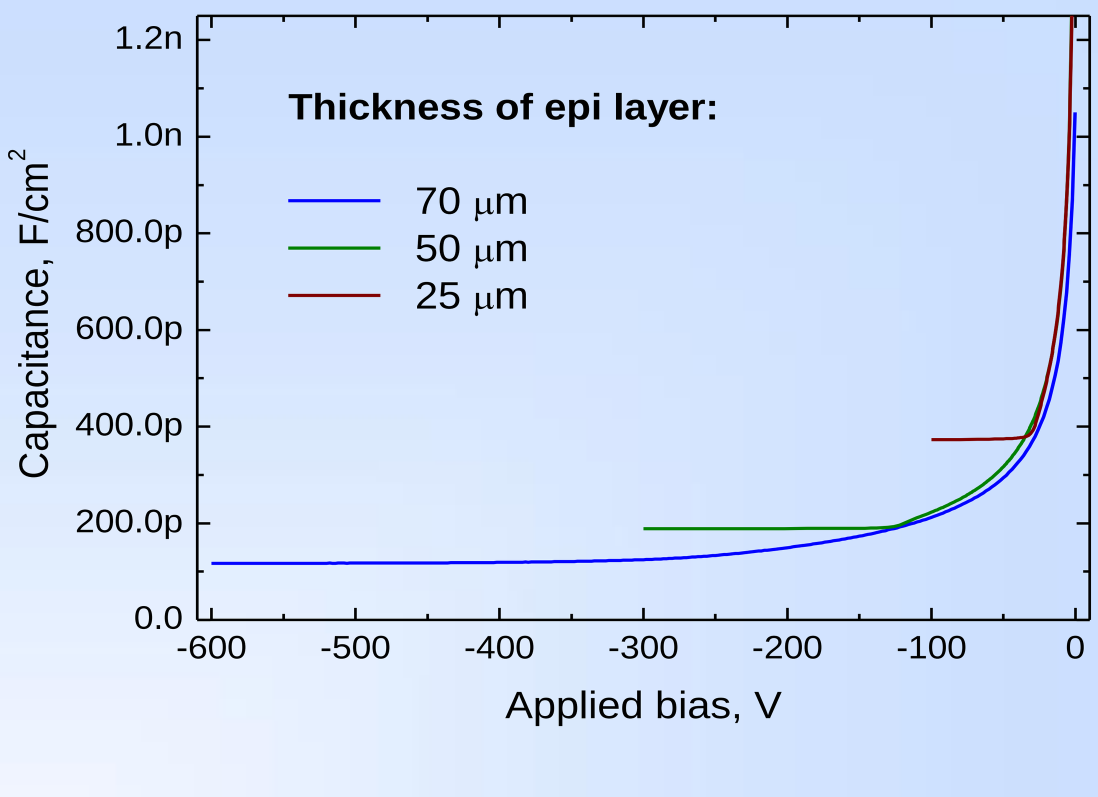
KEITHLEY MEASURING SYSTEM for I-V and C-V characteristics up to 3 kV

CURRENT - VOLTAGE MEASUREMENTS

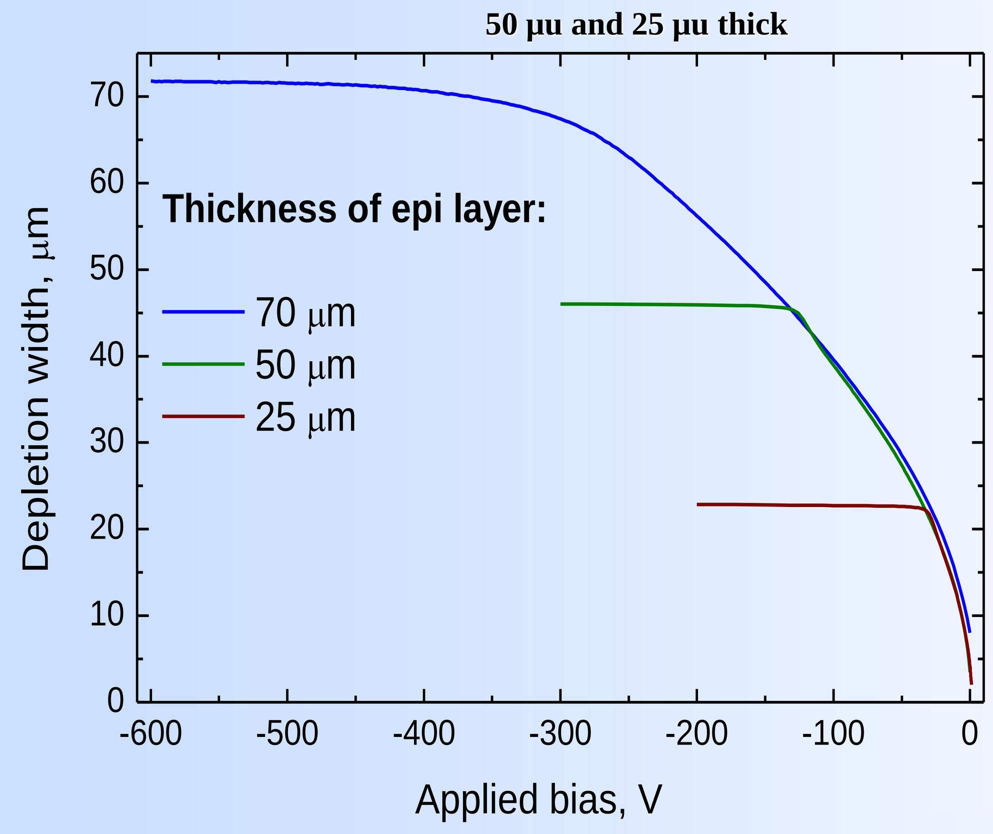


The reverse breakdown voltage exceeds 500 V and the current varies from 2 pA up to 30 pA at -500 V. The forward I-V characteristics we used for Schottky barrier height and ideality factor estimation (1.25 eV and 1.59).

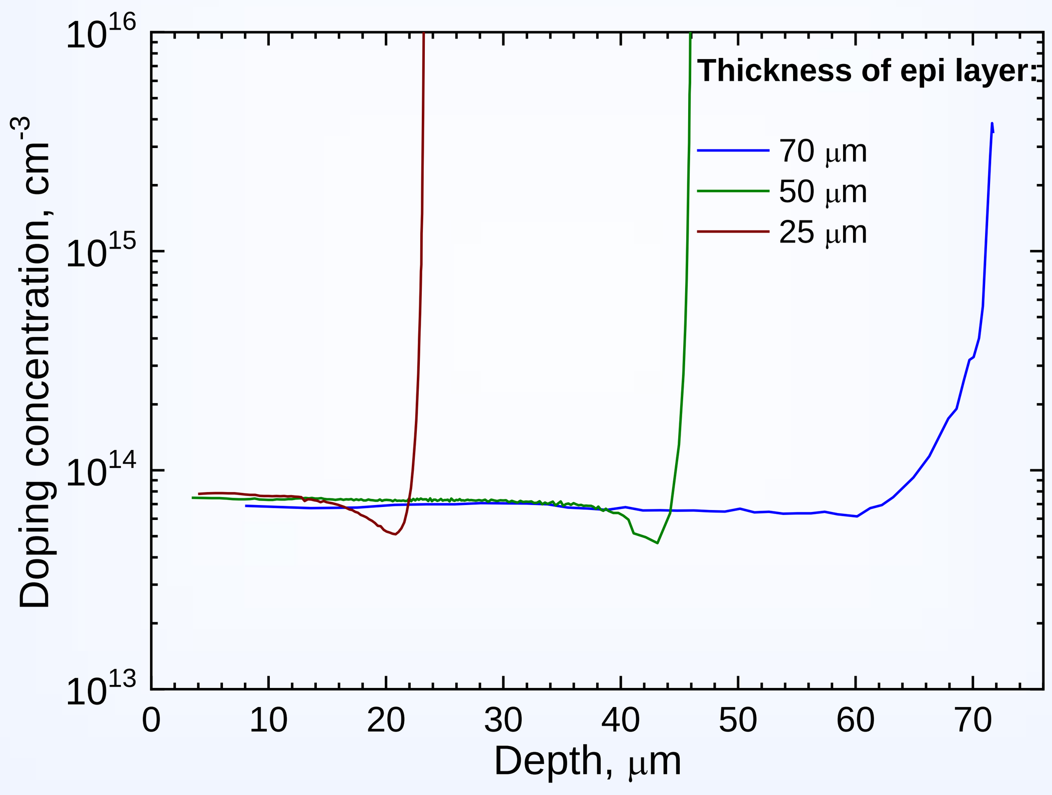
CAPACITY - VOLTAGE MEASUREMENTS



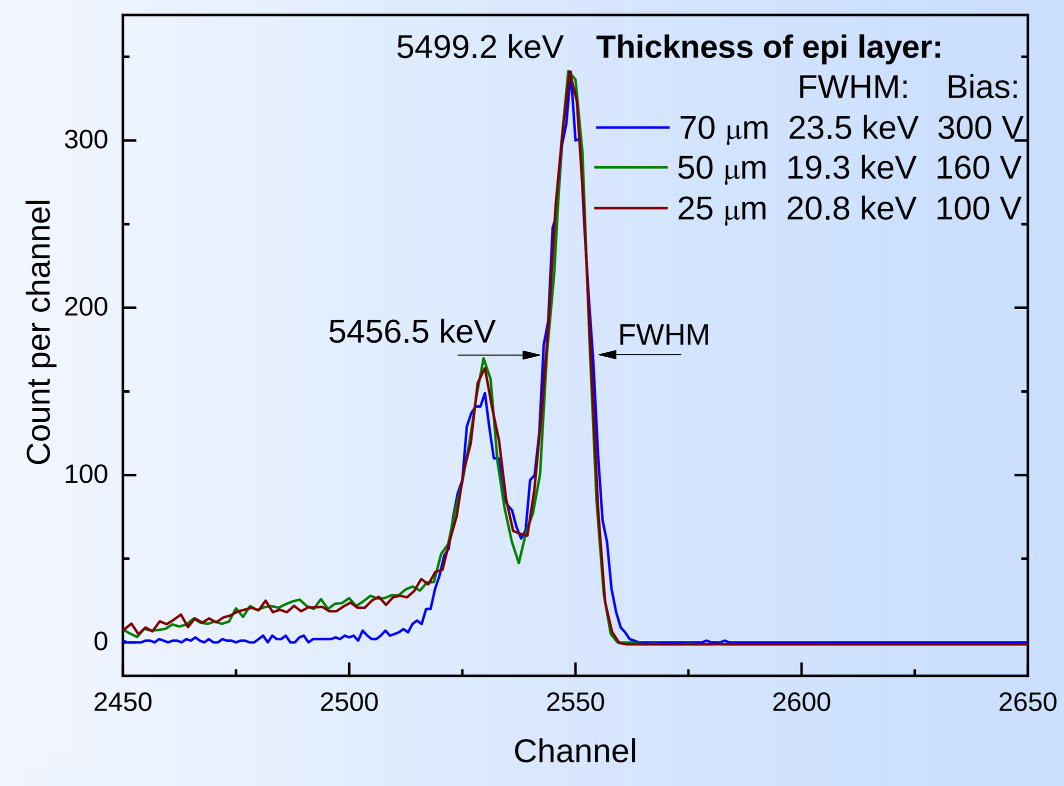
DEPLETION WIDTH for SiC detector with LPE layer 70 µu, 50 µu and 25 µu thick



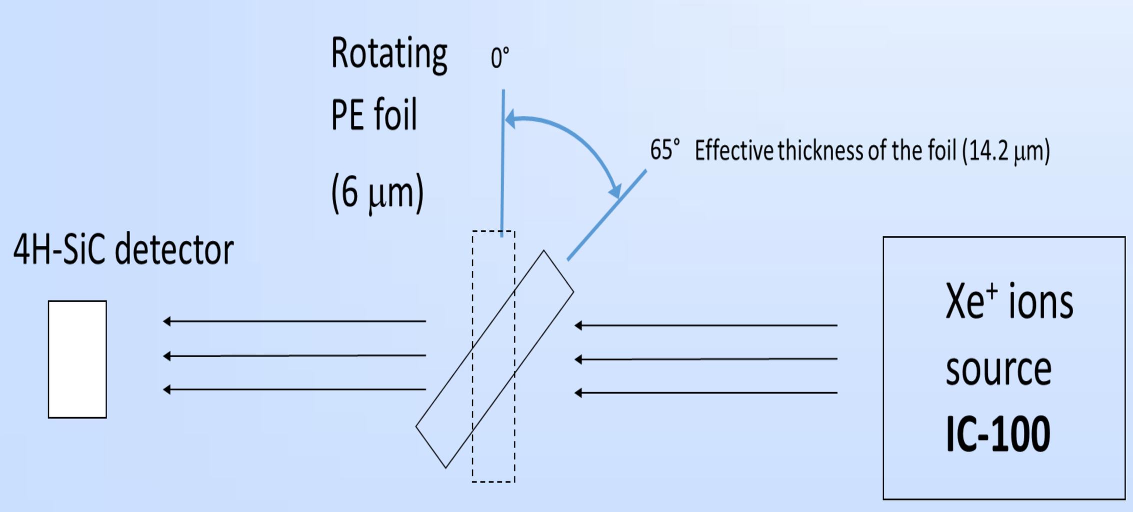
DOPING CONCENTRATION PROFILE



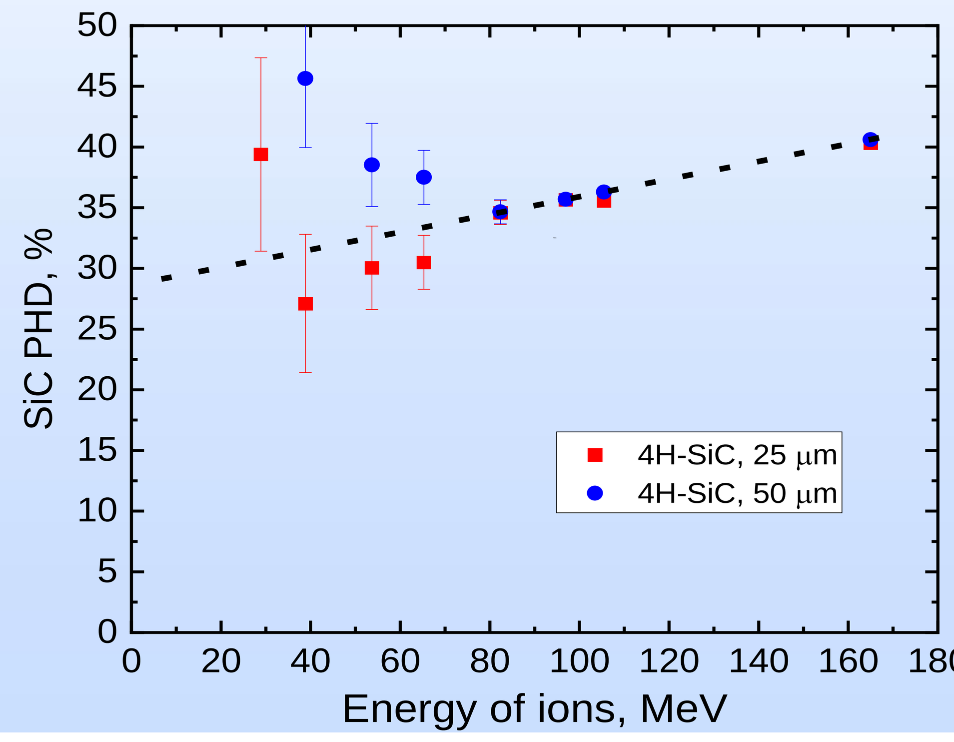
ALPHA PARTICLE MEASUREMENTS



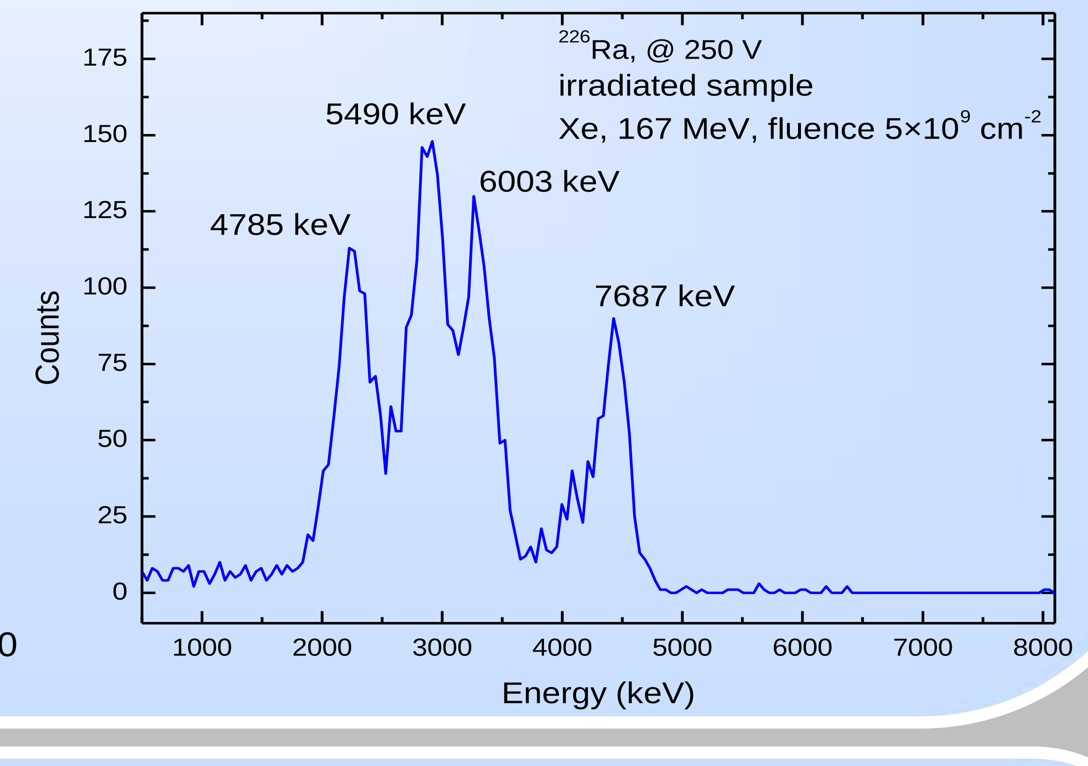
EXPERIMENTAL CONFIGURATION for irradiation of detectors and PHD measurements



PHD MEASURED WITH SiC DETECTORS



SiC DETECTOR IRRADIATED by Xe ions, fluency 5×10^9 cm^{-2}



SUMMARY

- **We fabricated semiconductor detectors based on 4H-SiC epitaxial layer.**
- **Active layer consists of 25, 50 or 70 µm 4H-SiC LPE with a net concentration of about 1×10^{14} cm^{-3}.**
- **The detector size was defined by a circular Schottky contact with the diameters of 3.0 mm.**
- **Used Schottky contact had thickness of 40 nm to minimalize the influence on alpha particles energy.**
- **I-V and C-V measurements were done using KEITHLEY measuring complex consisted of 4200A-SCS Analyzer, 4200A-CVIV Multi-Switch and 2657A Power System.**
- **The doping profile corresponds to value declared by the producer of epitaxial layer.**
- **The sources of alpha particles for detector testing were ^{238}Pu and ^{226}Ra.**
- **4H-SiC detectors were irradiated by 167 MeV Xe ions at the IC-100 cyclotron (JINR Dubna) with fluency from 5×10^9 cm^{-2} to 1×10^{11} cm^{-2}.**
- **For comparision we used SiC and silicon (Si) detector in case of high energy ions irradiation. SiC detector is applicable almost to 100× higher ions dose.**
- **SiC detectors were used for Pulse Height Deficit (PHD) measuring.**

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Полупроводники с шириной запрещеной зоны больше, чем у кремния

Si - 1,12 эВ;
InP - 1,34 эВ; **GaAs** - 1,43 эВ;
CdTe - 1,44 эВ; **CdZnTe** - 1,57 эВ; **HgJ_2** - 2,13 эВ; **GaP** - 2,26 эВ;
4H-SiC - 3,27 эВ; **GaN** - 3,39 эВ;
Алмаз (С) - 5,5 эВ.
возможность применить планарную технологию при изготовлении детекторов

Эпитаксиальные слой 4H-SiC на SiC пластине коммерчески доступны (L.P.E. spa, Catania, Italy; CREE Research Inc., Durham, USA, …)

Параметр	Si	4H-SiC
Ширина запрещенной зоны (эВ)	1,12	3,27
Энергия на образование e-h (эВ)	3,63	7,78
Время жизни неосновных носителей заряда [мкс]	> 1000	> 1*

* Из-за большой плотности дислокаций (~ 10^2 см$^{-2}$).

Таб.: Физические свойства кремния и карбида кремния.

Достоинствами 4H-SiC детекторов являются:
- **высокая радиационная стойкость;**
- **возможность их эксплуатации при повышенных температурах ~ 300^{0}C;**
- **химическая инертность;**
- **механическая прочность.**

Перспективные применения:
- **детекторы для контроля работы ядерных реакторов;**
- **диагностика горячей плазмы.**

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[1]*Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovakia;*
[2]*Joint Institute for Nuclear Research, Dubna, Russia;*
[3]*National Research Nuclear University (MEPhl), Moscow, Russia*

[a)]Corresponding author: ladislav.hrubcin@savba.sk

In the last decade, silicon carbide (SiC) has obtained increasing interest in the field of radiation detectors due to achievement of a high purity level in the crystal structure and considerable thickness (> 100 µm) in the epitaxial layer. SiC is very perspective material for fabrication radiation-tolerant electronics, high-temperature electronics as well as for nuclear radiation detectors of ionizing radiation for working in harsh environments. SiC is mostly investigated for its physical properties, e.g.: the band gap energy of the polytype 4H-SiC is 3.26 eV, the mean energy of electron-hole pair creation is 7.78 eV, the electron saturation drift velocity is 2x10^7 cm/s and the breakdown voltage is 2x10^6 V/cm at room temperature. Detectors based on high quality epitaxial layer of 4H-SiC show a high radiation hardness, good spectroscopic resolution and can operated at room and also at elevated temperatures (~300°C) [1,2].

Our detector structures [3] were prepared on a 25 µm or 50 µm thick nitrogen-doped 4HSiC layer (donor doping ~ l x 10^{14} cm^{-3}) grown by the liquid phase epitaxy on a 4" SiC wafer (donor doping ~ 2 x 10^{18} cm^{-3}, thickness 350 µm). Circular Schottky contact (diameter 3.0 mm) to 4H-SiC layer (Ni/Au with thicknesses 10/30 nm) was formed through a contact metal mask, while full area contact (Ti/Pt/Au with thicknesses 10/30/90 nm) was evaporated on the other side (substrate).

Electrical characteristic of prepared SiC detectors were measured using Keithley measuring complex, which consisted of 4200A-SCS Parameter Analyzer, 2657A High Power System and CVIV Multi-Switch. Current-voltage and capacity-voltage (C-V) measurements were performed up to 300 V. The reverse breakdown voltage exceeded 300 V and the reverse current was below 10 pA. From C-V measurements the depletion thickness and doping concentration profile were calculated. Spectroscopic parameters were measured with alpha sources ^{226}Ra and ^{238}Pu and FWHM of SiC detectors varied round of 20 keV for 5.5 MeV α-particles energy.

SiC detectors were used in experiments at the IC-100 cyclotron of the Joint Institute for Nuclear Research in Dubna. We studied the effect, which is known in the literature as Pulse Height Defect [4], as well as the degradation of these detectors under impact of the high-energetic beam of heavy ions of Xenon. Prepared SiC detectors shown good energy resolution and high radiation resistance and can be used for long-term monitoring of heavy ion beams.

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