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CHARACTERIZATION AND SIMULATION OF SILICON CARBIDE DEVICES IN THE SAMOTHRACE ECOSYSTEM*

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We present studies on two Silicon Carbide (SiC) detectors for applications as dosimeters, micro-dosimeters, and beam-tagging devices, including detailed detector characterization, optimization of the associated electronics, and a performance comparison with conventional silicon-based detectors. Furthermore, preliminary device-level simulations carried out with Sentaurus are discussed to support the experimental results. The combined experimental and simulation studies demonstrate the potential of SiC as a promising alternative to silicon for radiation detection, particularly in environments where high radiation tolerance and fast response are required. Within this framework, the SAMOTHRACE ecosystem, in collaboration with CHIMERA, is working toward the development of a 10 μm thick SiC detector for dosimetry and micro-dosimetry, as well as a 100 μm thick device for beam-tagging applications.

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1. Introduction

Research on Silicon Carbide (SiC) has grown significantly in recent years, driven by the unique properties that make it highly suitable for a wide range of applications. Today, SiC is employed in fields as diverse as medicine, aerospace, renewable energy, and nuclear research, among many others [1–6]. Advances in epitaxial growth techniques have further enabled the fabrication of high-quality SiC devices, expanding both their potential and reliability in demanding environments [7]. As a wide-bandgap semiconductor, SiC is particularly well suited for radiation detection, where high radiation tolerance and thermal stability are crucial. Its ability to maintain stable performance at elevated temperatures allows the associated electronics to be placed close to the detector, thereby reducing noise. Among the different types of SiC detectors, 4H-SiC is preferred for detection as it exhibits a wider band gap. The key properties of 4H-SiC, diamond, and silicon are summarized in Table 1. While the choice of detector material depends on the specific requirements of each experiment, SiC offers a balanced compromise between the superior performance of diamond and the widespread availability of silicon. Radioactive ion beams are gaining increasing importance across multiple fields. In cancer treatment, isotopes such as ^{11}C offer a unique advantage by combining hadron therapy with real-time imaging, thereby improving both precision and therapeutic effectiveness [8]. In nuclear physics, high-intensity radioactive ion beams [9, 10] are driving new research directions, though their use presents significant challenges at higher intensities. To meet these challenges, advanced diagnostics and tagging sys-

Table 1. Main characteristics of three materials for radiation detection [11].

Property	D	Si	4H-SiC
Bandgap [eV]	5.5	1.12	3.27
Relative dielectric constant	5.7	11.9	9.7
Breakdown field [MV cm^{-1}]	10	0.3	3.0
Density [g cm^{-3}]	3.5	2.3	3.2
Atomic number Z	6	14	14–6
e–h creation energy [eV]	13	3.6	7.78
Saturated electron velocity [10^7 cm s^{-1}] at 300 K	2.2	1.0	2
Electron mobility [cm^2 V^{-1} s^{-1}] at 300 K	1800	1300	800
Hole mobility [cm^2 V^{-1} s^{-1}] at 300 K	1200	460	115
Threshold displacement energy [eV]	40–50	13–20	22–35
Minimum ionizing energy loss [MeV cm^{-1}]	4.7	2.7	4.4

tems are under development, with SiC devices emerging as a key technology. This project focuses on the characterization and optimization of SiC detectors fabricated in two thickness configurations: 10 μm for dosimetry and micro-dosimetry, and 100 μm for beam tagging.

2. Data analysis and results

2.1. Characterization of SiC with alpha source

Two SiC devices, each with a surface area of 1 cm^2 and divided into four pads, have been characterized. They differ in thickness: one is 10 μm thick, designed as a dosimeter and micro-dosimeter, while the other is 100 μm thick planned to be used as beam tagging. The first characterized detector was the 10 μm thick SiC device, tested at the INFN-LNS laboratory using a ^{148}Gd α source. The readout chain consisted of a NeT Instruments preamplifier connected to a CAEN DT5725 digitizer (250 MHz). Energy-rise time correlation plots highlighted the presence of edge effects, which were suppressed through the use of a collimator. A detailed discussion of the data analysis is reported in [12, 13]. Edge effects were also observed in the 100 μm thick SiC detector, which is likewise segmented into four pads. In this case, the experimental setup employed a Mesytec MPR preamplifier [14] in combination with a CAEN DT5742 digitizer (1 GHz). The detector was characterized with a ^{239}Pu–^{241}Am–^{244}Cm mixed α source. Analysis of the energy spectra provided an initial energy resolution of approximately 1%, as reported in [15]. Concurrently, the energy *versus* rise time plot indicated a subset of events attributed to edge effects, consistent with the observations in [16, 17]. It is worth noting that additional simulations are in progress to investigate the inter-pad region and to clarify the origin of edge effects, which may arise either from residual glue at the corners or from weak electric fields at the detector boundaries.

2.2. Optimization of the electronic

A key aspect in the characterization and optimization of the two SiC devices is the improvement of energy resolution. As a first step, measurements were carried out using a conventional triple α source together with standard electronics, consisting of a Mesytec preamplifier (MPR-16) and a CAEN DT5742 digitizer. This configuration provided an energy resolution of about 50 keV, as reported in [15]. Preliminary tests with a more advanced electronic chain, based on the ASIC-FARCOS preamplifier [18, 19], already showed significant progress, achieving resolutions of the order of 30 keV. Furthermore, in collaboration with Politecnico di Milano [20], a dedicated front-end electronic system is under development, specifically tailored to these devices with the aim of achieving even higher-energy resolution (less than 0.7%) and good time resolution at elevated rates up to 10^6 particles/s.

2.3. Comparison with Silicon detector

To enable a first comparison with conventional electronics, a benchmark test was carried out using a Silicon detector (Si) with comparable capacitance (area of 1.77 cm^2 and thickness of 99.7 μm). A detailed analysis is provided in [21, 22]. In this test, the same electronic setup was employed for both detectors, allowing the intrinsic differences between the materials to be directly assessed. The electronics consisted of a Mesytec MPR 16 preamplifier, an ORTEC 542 amplifier, and a Multi Channel Analyzer (MCA). As shown in Fig. 1, the two devices exhibited a comparable energy resolution. In the picture, the extracted FWHM of the Gaussian fit is also reported.

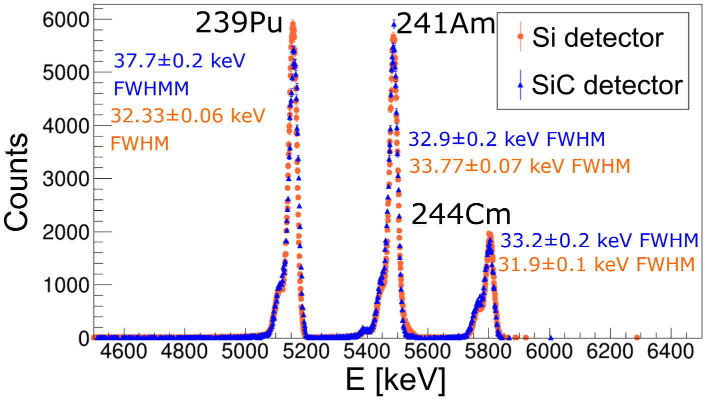

Fig. 1. Comparison of the Si and 100 μm SiC detector using the same electronic chain [21].

2.4. Timing performances

Another part of this work focuses on optimizing the detector's timing performance toward a 100 ps resolution. A novel technique was applied, exploiting the inter-pad region and analyzing coincidence events between adjacent pads. Tests were performed with 1 MeV proton beam, 2 MeV α beam, and two α sources. The resulting data enabled the extraction and extrapolation of the timing performance of individual SiC pads to higher energies, relevant for future experiments. Further details are reported in [21].

3. Simulations

A key aspect of detector development involves simulating device performance using tools such as Geant4 and Synopsys Sentaurus. An initial Geant4 simulation was performed to model the response of a 100 μm SiC detector exposed to a neutron beam, with a CH$_2$ converter placed in front of the sensor. Neutron interactions in the converter produce protons subsequently detected by the SiC. Further details are reported in [12, 13]. The simulated and experimental spectra exhibit good agreement, supporting the reliability of the setup and analysis, though additional refinement is required to optimize the simulation parameters and improve model accuracy. Complementary simulations with the Sentaurus TCAD toolkit [23] were carried out to replicate the detector structure and evaluate its response under applied bias conditions. These simulations reproduce the device's doping profile and model its internal electric field, providing deeper insight into its electrical behavior and overall response. Doping parameters were adopted from a previous study on a device with similar characteristics [24].

4. Conclusions and perspectives

Two detectors, 10 μm and 100 μm thick, are being developed through the collaboration between the SAMOTHRACE (Sicilian Micro and Nano Technology Research and Innovation Center) ecosystem [25] and the CHIMERA Collaboration [26]. The preliminary results show an improved energy resolution thanks to a more advanced electronic readout. A new method for assessing timing performance has been tested, and the front-end electronics under development at Politecnico di Milano are expected to enhance it further. Ongoing work includes analyzing data from beam tests at INFN-Labec (Florence) which involved beam tests using the new front-end electronics and from a reaction ^{12}C+^{12}C at 90 MeV performed at HIL (Warsaw) to study time resolution *versus* fragment energy. Parallel efforts aim to refine Geant4 and Synopsys Sentaurus simulations to enhance the modeling and optimization of device performance. These advancements are expected to yield deeper insights into device behavior and inform further design improvements.

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