Application of Silicon Carbide detectors in future nuclear physics experiments

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Many future nuclear physics experiments foresee the study of very rare nuclear phenomena, whose cross sections are much lower than those studied in the past. A high beam intensity is required to carry out this kind of experiments, in order to produce the desired events with reasonable statistics within the available beam time. Semiconductor detectors are required for many of these applications, thanks to their high resolution and excellent fragment identification capabilities. However, despite their favourable characteristics, state of the art silicon detectors have serious limitations in terms of radiation damage [1], and may not be suitable for the experiments that require a high fluence. In these applications, silicon carbide (SiC) is an attractive alternative to silicon. SiC is a wide band-gap semiconductor that combines the excellent features of silicon detectors (resolution, linearity, efficiency, compactness) with a much higher radiation hardness [2]. SiC detectors also feature good temperature stability and insensitivity to visible light, and these characteristics allow for their application in those experiments that require the use of semiconductor detectors in a hot plasma environment [3], where high intensity visible light and high temperature can negatively affect the performance of silicon detectors.

Thanks to many technological improvements, the last decades have seen a renewed interest in silicon carbide as a promising alternative to silicon. However, there are no commercially available SiC detectors having the characteristics required by experiments such as NUMEN [4] or FAZIA [5] (e.g. thickness above $100\,\mu$m, active area of $1\,\mathrm{cm}^2$ or more). The INFN has therefore supported many R&D activities in the field of SiC production technology in the last few years: in this framework, the SiCILIA collaboration (Silicon Carbide detectors for Intense Luminosity Investigations and Applications) [6] has started. During the last year, some SiC detector prototypes have been produced and characterized within the collaboration activities [7]. The ultimate goal is to build the first SiC-based $\Delta E - E$ telescope array: in a recent work [8], three different configurations of $\Delta E - E$ telescopes have been assembled for the first time exploiting the newly produced SiC detectors. The telescopes have been tested under beam inside the CICLOPE scattering chamber at LNS, giving promising results in terms of nuclear fragment identification exploiting both $\Delta E - E$ and Pulse Shape Discrimination (PSD) techniques. Since the design and production of innovative SiC prototypes is still going on, driven by the interesting results that have been obtained so far, there is much room for new studies and further development.

The aim of this PhD project is a comprehensive study of silicon carbide detectors, mainly focusing on their nuclear fragment identification capability exploiting both $\Delta E - E$ and PSD techniques, and their use in nuclear physics experiments. The collaboration has already presented two experiment proposals to the LNS PAC meeting in December 2018, in order to test the PSD performance and to investigate the radiation hardness of the new generation SiC detectors produced within the SiCILIA project. The proposed PSD performance study is quite similar to the one carried out on silicon detectors in Ref. [9]: it includes the study of the PSD identification capability as a function of the applied bias voltage exploiting both the charge signal and the current signal, and a precise determination of the energy threshold for identification through PSD.

As an example, the FAZIA project [5] would greatly benefit from a thorough investigation of the performance of SiC based $\Delta E - E$ telescopes, with focus on their behaviour under high fluence of heavy ions. FAZIA is a state of the art apparatus for ion identification that exploits both $\Delta E - E$ and PSD techniques. The apparatus is aimed at the investigation of the nuclear Equation of State (EoS) far from standard conditions of nuclear temperature and density [10], focusing mainly on the Symmetry Energy term of the potential. These studies demand the accurate determination of the atomic and mass number of the fragments produced in heavy ion reactions at medium-low beam energy (Fermi energies). FAZIA presently employs highly optimized silicon detectors giving excellent performances. However, as pointed out in Ref.[1], silicon detectors have serious limitations in terms of radiation damage: in particular, at forward polar angles, close to the beam axis, where most of scattered ions and reaction products are focused, the fluence is so high that Si detectors would last only hours or days before becoming unusable. A SiC-based $\Delta E - E$ telescope array could be employed to extend the FAZIA apparatus towards small polar angles. The extension would be beneficial both at the Fermi energies and at the lower energies typical of the Radioactive Ion Beams (RIBs) facilities.

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