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Silicon carbide detectors study for NUMEN project

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Abstract

In this contribution, we will illustrate the main results of the R&D activities related to the Silicon Carbide detectors associated with NUMEN project.

1 NUMEN Physics

The NUMEN project[1-4] proposes an innovative technique to access the nuclear matrix elements entering the expression of the half-life of the double beta decay by relevant cross sections measurements of heavy-ion induced double charge exchange (DCE) reactions, $(^{18}O,^{18}Ne)$, $(^{20}Ne,^{20}O)$ and $(^{12}C,^{12}Be)$. DCE reactions will be investigated at the INFN-LNS laboratory with incident energies ranging from 10 to 60 MeV/A. A key aspect of the project is the use of the MAGNEX [5-6] large acceptance magnetic spectrometer to detect the ejectiles produced in the nuclear collisions[7]. With the present set-up it is difficult to suitably extend this research to the hot cases, where $\beta\beta$ decay studies are and will be concentrated. The present limitations concern mainly the low beam current from the L.N.S. superconducting cyclotron CS accelerator and the low counting rate tolerated (< 5 kHz)[8-9] by the MAGNEX Focal Plane Detector (FPD) . In the view of a systematic study of the many hot cases of $\beta\beta$ decays, an upgraded set-up, able to work with at least two orders of magnitude more current than the present, is thus mandatory. This goal can be achieved by a substantial change in the technologies used in the beam extraction and transport and in the detection of the ejectiles. For the spectrometer, the main foreseen upgrade is the substitution of the present FPD. In particular the existing wall of stopping detectors based on 50 x 70 mm^2, 0.5 mm thick silicon pad detectors needs to be upgraded in view of the higher detection rate. Many requirements must be taken into account for the design of the new stopping wall telescopes for particle identification. The most relevant aspects are: a) energy resolution better than 1% to maintain the performances in the particle identification reached with the present set-up of the FPD (mass resolution 1/160) [10]; b) unambiguous and fast particle identification procedure; c) time resolution better than $1\div2$ ns in order to guarantee an accurate measurement of the drift time in the gas chamber used to reconstruct the vertical track of the ejectiles; d) a high granularity(modules of 1 cm^2) is required in order to limit double-hit events probability below 10% in the whole FPD; e) the thickness of the telescope must be chosen in order to permit the detection of the ejectiles in the wide dynamical range of incident energies (from 10 up to 60 MeV/A). In this context, the choice of solid state detectors, such as SiC, is the most appropriate.

2 Silicon carbide

Radiation damage can affect various properties of a detector. Phenomena connected with the alteration of these properties are the increase of the leakage current, the decrease of charge collection efficiency (CCE) and the removal of free carriers from the conductive regions of the device. Radiation hardness is the inertness of these device parameters to high doses of particle irradiation [11]. SiC, due to its wide gap and strength of its chemical bonds, has been seriously considered as a valid alternative to Si for the production of radiation hard ionizing particle detectors. The leakage current of a p-n junction consists of diffusion current from the quasi-neutral areas and generation current from depletion area [12]. The second term depends essentially on the temperature T and on the energy gap E_g. Increasing the E_g from 1.1 eV (Si) to 3.2 eV (4H-SiC) determines a reduction of the diffusion term of the leakage current of about 17 orders of magnitude at room temperature($\sim 300K$). Silicon Carbide technology offers then an ideal response to such challenges, since it gives the opportunity to cope the excellent properties of silicon detectors (resolution, efficiency, linearity compactness) with a much bigger radiation hardness (up to five orders of magnitude for heavy ions), thermal stability and insensitivity to visible light. R&D activity is mandatory to develop innovative processes, which allows a massive production of thick (>100 μm) and large area (about 1 cm^2) SiC detectors. Following these indications we started the research work with a Monte Carlo simulation with the aim to study ΔE - E configuration (with respective thicknesses 100μm and 1000μm) from the point of view of defects dislocation generated by an^{18}O at 25 MeV/A. For this work we used the SRIM [13] software; it is a collection of packages which calculate many features of the transport of ions in matter. The following figure 1.a shows the number of simulated vacancies as function of protons (at 25 MeV and 1 GeV) and ^{18}O (25 MeV/A) ions fluency. One can notice that the number defects create in the same stage (ΔE or E) from protons beam at 25 MeV/A is about two orders of magnitude smaller then the corresponding number coming from heavy oxygen ions of 25 MeV/A. In Figure1.b, we show the results of such calculation, we can be notice as several order of magnitude of leakage current increased are expected at high doses irradiation/fluency. Such increase could be acceptable for SiC detectors, they have a leakage current five order of magnitude less than Silicon detectors.(Where the maximum of acceptable fluency is about 10^9 heavy ions/cm^3).

We have studied, moreover, the effects of the irradiation comparing SiC and Si detectors. These detectors were irradiated with C^+ ions at 740 MeV and at different doses. For the experiment we used a standard Si detector of 1 cm^2 of active area and 300 μm thickness and SiC detector which was built growing a 4H-SiC n-type epitaxial layers with a carrier concentration of $1.0 \cdot 10^{-14} cm^{-3}$ and a thickness of 80 μm on a highly doped n-type ($\sim 7.0 \cdot 10^{-18} cm^{-3}$) substrate. The following Table 1 shows the results of the electrical static characterization before and after the irradiation. Can be observe as Si detectors are acceptable to work at the irradiation 94kGy dose; while SiC are able to survive at 218 kGy dose.

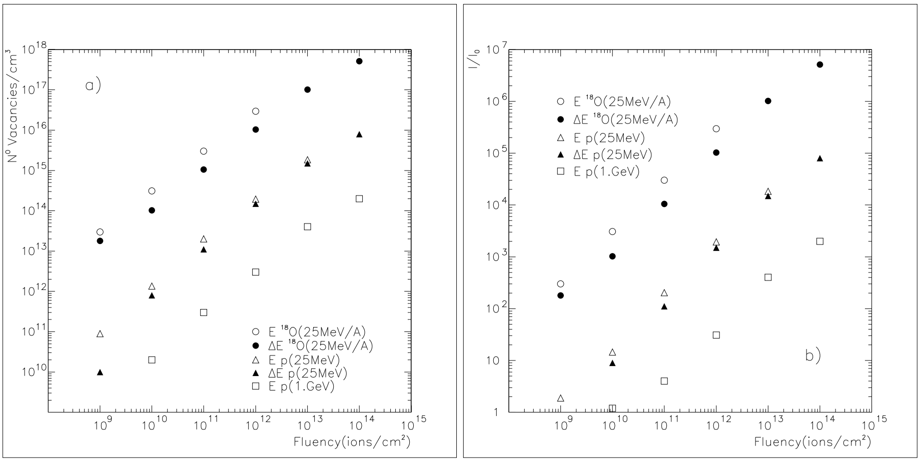

Figure 1: The figure 1.a shows the comparison of Number of silicon vacancies%Fluency on ΔE and E in SiC stages; while the figure 1.b shows the comparison of Increment of current leakage%Fluency in SiC for thickness of ΔE and E. In both figures the solid symbols indicate the first stage of the detector (with a thickness of 100μm), while the empty symbols the second stage (with a thickness of 1000μm). The following energies has been simulated: oxygen ions at 25 MeV/A (circle), protons ions at 25 MeV/A(triangle) and protons ions at 1 GeV/A(square).

Table 1: Comparison, with several doses, between SiC and Si detectors

	SiC reverse current[A/cm^3]			**Si reverse current[A/cm^3]**		
Voltage[V]	**SiCFresh**	**94kGy**	**218kGy**	**SiFresh**	**94kGy**	**21kGy**
-190	1.9 10^{-6}	8.6 10^{-6}	4.5 10^{-4}	8.3 10^{-5}	3.9 10^{-4}	8.3 10^{-5}
-150	8.0 10^{-7}	5.4 10^{-6}	2.9 10^{-4}	6.5 10^{-6}	3.2 10^{-4}	8.3 10^{-5}
-110	3.4 10^{-7}	3.2 10^{-6}	1.4 10^{-4}	4.8 10^{-6}	2.5 10^{-4}	8.3 10^{-5}
-70	1.4 10^{-7}	1.8 10^{-6}	3.5 10^{-5}	2.6 10^{-6}	7.8 10^{-5}	3.0 10^{-5}
-30	7.0 10^{-8}	6.1 10^{-7}	3.9 10^{-7}	7.9 10^{-7}	6.1 10^{-5}	2.2 10^{-5}
-10	4.7 10^{-8}	2.8 10^{-7}	5.1 10^{-8}	1.9 10^{-7}	3.5 10^{-5}	1.7 10^{-5}

3 Conclusions

Silicon Carbide is one of the promising radiation hard materials. Our goal is to realize a two stages detector increasing, beyond the state of the art, thickness and active area. The results of our simulations and test demonstrate that SiC is a good compromise between several detectors materials. Due to its wide band-gap it has a very low leakage current, good radiation resistance and reasonable sensing capability for charges created during the ionization processes.

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