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Silicon carbide for future intense luminosity nuclear physics investigations

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Summary. — Silicon carbide (SiC) is one of the compound semiconductor which has been considered as a potential alternative to Silicon for the fabrication of radiation hard particles detectors. Material, detectors implementation and possible application in the future INFN projects has been discussed.

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1. – Introduction

The excellent properties of 4H-Silicon Carbide (SiC) epitaxial layers today are appropriate for the construction of radiation detectors. To this purpose the most appealing properties of 4H-SiC material are the wide band gap and the high energy threshold for defect formation. It has been reported that SiC detectors can operate at temperature higher than 300^{o}C. Moreover, SiC based detectors are more resistant to the ionizing radiations than Si ones. Then, they can be used in high level radioactive ambient where the temperature and the radiation environment preclude the use of conventional microelectronic semiconductors [1-3]. In the last decade, SiC-based Schottky and p-n junction diodes were used for the detection of neutron, X and gamma rays, alpha particles and heavy ions [4, 5]. These detectors show high spectroscopic performances for X-ray detection at room and also at elevated temperature. A charge collection efficiency near 100% and good energy resolution were reported for α-particles of 5.48 MeV) energy [6]. Some studies based on the effects of neutron, protons and heavy ions irradiation on SiC diodes evidenced the high radiation hardness of these devices [7], that maintain their performances after irradiation at doses as high as 20 MGy [8]. Therefore, for all these characteristic the use of these detectors is particularly interesting for all those activities where high particles flux must be detected. Radiation hard 4H-SiC detectors can be used as an innovative and very promising detection system for next generation nuclear physics experiments at high beam luminosity. For nuclear community it is very important the fabrication of detectors operating with high fluxes (10^7 pps/m^2) and fluencies (10^{14} ions/cm^2) of heavy ions in order to determine the cross section of very rare nuclear phenomenas [9-11]. The study of nuclear matrix elements of Neutrinoless double beta decay (NUMEN [12]) is a concrete example of activity that could takes advantage of such technological goal.

Silicon carbide technology offers today an ideal response to such challenges, since it gives the opportunity to cope the excellent properties of silicon detectors (efficiency, linearity, resolution) [13, 14] with a much larger radiation hardness, thermal stability and insensitivity to visible light. This last property is extremely important for nuclear reactions studies in Plasmas [15-19] activities that can will be conducted in the future Laser infrastructures (ELI [20]).

2. – Material studies, processing and devices test

The device structures typically used for the fabrication of a semiconductor detector are junctions (Schottky or `p-n`) operating under reverse bias. The lowest concentration of impurities and defects is required, in order to avoid a reduction in the current pulse amplitude due to recombination of electron-hole pairs and scattering of charge carriers. The quality of thick 4H-SiC epitaxial layers is very high considering the achievements of the last decades in the growth of material. The epitaxial growth is performed in a hot-wall reactor by using trichlorosilane and ethylene as silicon and carbon precursors and hydrogen as gas carrier. Nitrogen is commonly used for n-type doping and Trimethylaluminium for p-type. Processes are performed in a low pressure regime at high temperatures (1630 ^{o}C). Figure 1 shown the good results in terms of defects density distribution obtained by LPE epitaxial technology [21] in Catania on the 100 μm 4H-SiC epitaxy on a six inch wafers, by using a growing rate of 60 μm/h.

Wafers were processed for the fabrication of large area segmented (1 cm^2) `p-n` junction devices. Process starts with a double layer epitaxy, a p$^+$ layer 0.3 μm thick with

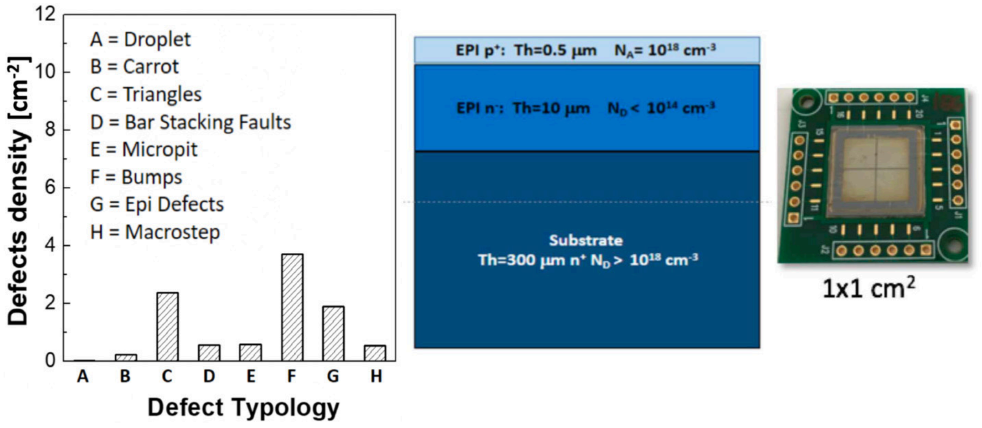

Fig. 1. – (left) Defects density distribution of 100 μm 4H-SiC epitaxies grown on a six inch wafers at 60 μm/h. (center) Epitaxial structure of devices. (right) Picture of the final prototype.

a doping concentration of 10^{18}-10^{19}/cm^3 was grown over the n-epilayer with a doping concentration of 5x10^{13}/cm^3. After this step, a first photolithography for the definition of the detector area by Inductive Coupled Plasma (ICP) etching was performed. Then, a second lithography was performed for the construction of the edge structures aimed at reducing the electrical field at the device borders. The process continues with the deposition of an isolation oxide and the opening of the contacts with a further photolithographic process and consequently annealed to form a good contact on the p+ region. Only on the periphery of the detector a thicker layer of Ti and Al was deposited for the bonding. Finally, the ohmic contact was formed by Ti/Ni/Au deposition. The devices were tested in order to study their performance by using a radioactive alpha source and a standard

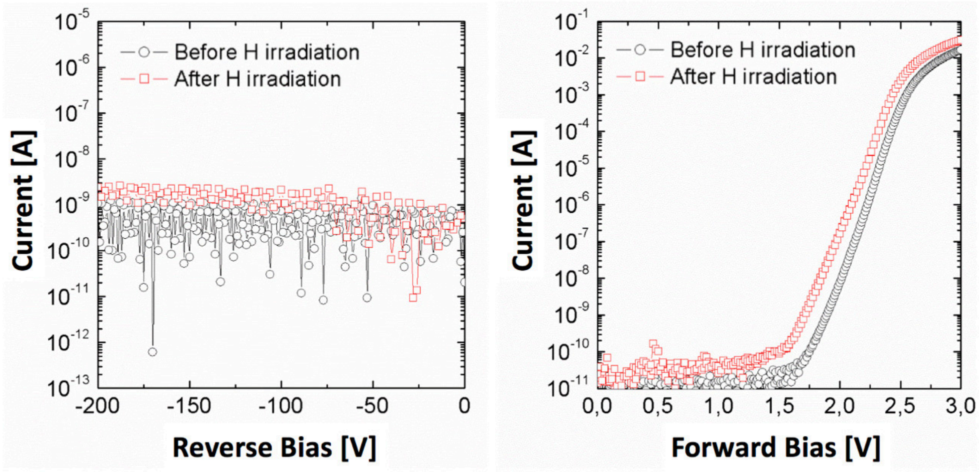

Fig. 2. – Reverse (a) and forward (b) current-voltage characteristic of p-n junction detector before and after 60 MeV proton irradiation at a dose of 2 KGy.

spectroscopic electronic chain [22]. They exhibit, for 5.34 MeV alphas from ^{241}Am, an energy resolution of the order of 17 keV (FWHM) [23]. Moreover, fast pre-amplifier signals, in terms of rise times, have been observed, compatible with the limits of the preamplifier velocity. In order to test the radiation hardness the devices were irradiated with 60 MeV H^+ up to a total dose of 2 kGy and the electrical characteristics measured before and after irradiation are shown in fig. 2. The reverse characteristics (fig. 2a) does not change significantly after irradiation and the leakage current measured up to -200 V remains low (10^{-9}–10^{-10} A), instead the forward I–V characteristic (fig. 2b) is slightly modified. In particular, after irradiation the I–V curve is shifted upwards, indicating a rise of the recombination current in the space-charge region. Similar effect was reported for p-n junction irradiated with 8 MeV H^+ [24] and with neutron [25], and it was associated with a decrease of the lifetime of non equilibrium carriers for deep level recombination in the space-charge region.

3. – Conclusion

A sequential process to perform the new device has been shown. The radiation hardness of the device has been tested through intense irradiations and as a result of the experiment a good energy resolution was measured. The work is in progress.

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