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Study of 4H SiC Schottky diodes as nuclear detectors

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I. INTRODUCTION

Silicon carbide is a useful material for the fabrication of electronic devices for high power, high temperature and high frequency applications. Moreover, the wide band-gap, large saturation velocity, large breakdown voltage, high thermal conductivity, and radiation hardness make silicon carbide an attractive material also for the realization of ionizing radiation detection. The recent development of SiC high purity crystal growth and SiC epitaxy has allowed the realization of charge particle [1], neutron [2], and x-ray [3] detectors and dosimeters [4].

However, the realization of advanced device structures and improvements of the performances of such detectors impose severe constraints, which require suitable characterization techniques to check the electronic quality and the homogeneity of the material.

A brief summary of the activity carried out by the group of the Experimental Physics Department of the Torino University concerning the characterization of SiC nuclear detectors within the research projects listed below* is described in this work.

II. DESCRIPTION OF THE RESEARCH

Several 4H SiC Schottky diodes developed within the MIUR-COFIN2001 project in collaboration with Alenia Marconi Systems have been characterized.

The Schottky diodes were fabricated on 4H-SiC epitaxial layers purchased from CREE Research Inc. or from the Institute fűr Kristallsuchtung of Berlin (D), with donor concentrations ranging from 10^{14} to 10^{15} cm^{-3}. In both cases, high doped, commercial 4H-SiC substrates from CREE Research Inc. were used. The Schottky contact were fabricated by the deposition of Au or Ni thin layers on the Si surface, whereas the ohmic contact was realized on the back of the substrate (C-face) by a multilayer of Ti/Pt/Au.

The performances of SiC Shottky diodes as charge particle detectors were studied by measuring the collection efficiency of charges induced by MeV ions (H, He and Li) in order to evaluate the transport parameters of the materials within the drift-diffusion model.

Figure 1 shows the charge collection efficiency (CCE) curve as a function of bias voltage for a SiC detector irradiated with 1.5 MeV protons. The curves saturates when the depletion layer covers the complete Bragg's ionization curve. The study of the behavior of the CCE vs. the applied bias voltage allows also the evaluation of the diffusion lengths of minority carriers generated in the neutral region and injected into the depletion region. Figure 1 shows the contribution of the carriers generated into the depletion region (drift contribution) and of the carriers generated into the neutral region (diffusion contribution). The Schottky diodes we have analysed

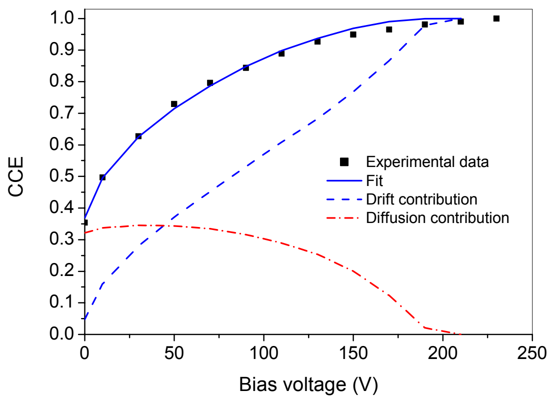

Fig. 1: Collection efficiency vs. bias voltage under 1.5 MeV irradiation

showed values of hole diffusion lengths ranging from 4 to 12 micrometers.

The complete collection of charge observed when the depleted region is wider than the incident ion extrapolated range, allowed us to evaluate the electron-hole pair generation energy ε_{eh}. These measurements were carried out at the National Laboratory of Legnaro (I) by measuring the charge pulse spectra induced by alpha particles with energies ranging from 1 to 5.48 MeV. Fig. 2 shows the peak position of the spectra obtained at different ion energies with our SiC diode and a reference Si detector. The ratio of the two slopes is equal to the ratio of ε_{eh} relevant to silicon and SiC; the value of ε_{eh} = (7.75±0.04) eV has been measured for SiC.

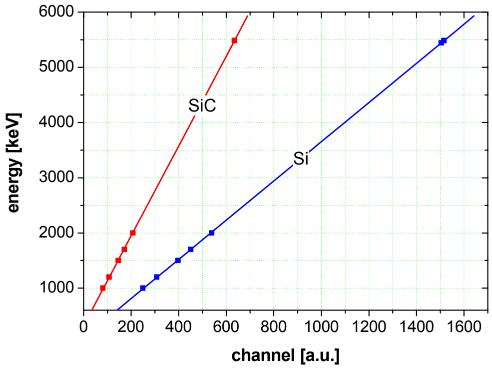

Fig. 2: Peak position of Si and SiC detectors at different alpha particle energies

The homogeneity of the response was evaluated by micro-IBIC (Ion Beam Induced Charge) and micro-XBIC (X-ray Beam Induced Current) techniques. These two microscopy techniques make use of scanning high-energy probes (MeV ions or keV photons) to image the transport properties of semiconductor materials and devices. IBIC consists of measuring the charge induced by the movement of free carriers generated by MeV ions. Similarly, XBIC consists of measuring the photocurrent induced by x-rays from a synchrotron light source. Both the ion and x-ray beams were focused onto the Schottky electrode into micrometric spots. Uniformity analysis of the detector performances were then carried out by imaging the charge collection efficiency or the photocurrent by deflecting the beam (IBIC case) or moving the sample perpendicularly to beam direction (XBIC case). As an example, Fig. 3 shows the XBIC map of a SiC diode. The gray scale, shown at the right hand side, indicates the photocurrent induced by 3 keV x-rays focused onto 1 micrometer spot. The border of the electrode is shown on the left hand side. Dark structures (aligned black points) are attributed to defects underneath the Schottky electrode which appears to an optical inspection perfectly smooth and without any defect.

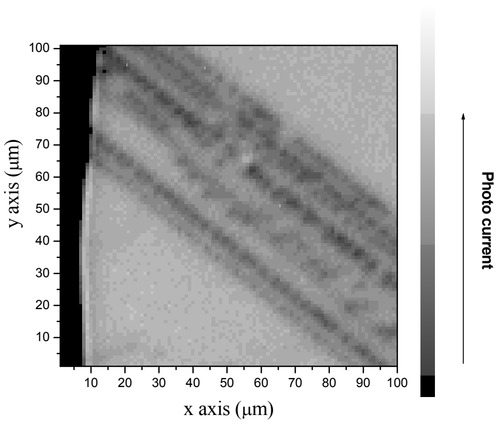

Fig.3 : Photocurrent map of a SiC diode irradiated with 3 keV photons

Finally, within the INFN-GAMMANEU project, we have tested a SiC Schottky diode as a neutron detector. The SiC diode detects neutrons via neutron-induced charged particles produced by the $^{6}Li(n,a)^{3}H$ reaction due to a 100 micrometer thick ^{6}LiF layer next to the diode surface. The detector was exposed to neutron irradiation from an AmBe source with an activity of about $6 \cdot 10^{11}$ Bq at the Joint Research Centre of Ispra (I). The neutron flux was equal to about $3.6 \cdot 10^{7}$ neutrons/s. Fig. 4 shows the charge pulse spectra collected from the Schottky electrode of the SiC diode irradiated by neutrons crossing the ^{6}LiF converter.

No radiation damage was detected after an irradiation of about 10^{9} neutron/cm^{2}.

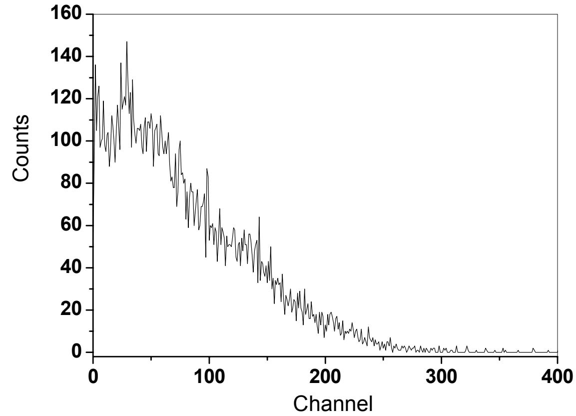

Fig.4 SiC Schottky diode neutron response

Active projects*:

- NATO Cooperative Science and Technology Sub-Programme Collaborative Linkage Grant: "Research of Charge Transport Properties in SiC by Nuclear Microbeam Techniques"; Coordinator: E.Vittone
- MIUR-COFIN2001 project: "Silicon Carbide Radiation Detectors for Room and High Temperature Spectrometry"; Coordinator: G.Bertuccio.
- INFN-GAMMANEU Experiment: "SiC neutron dosimeters". Coordinator C.Manfredotti

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