Investigation of 4H SiC Schottky diodes by Ion Beam Induced Charge (IBIC) technique

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I. INTRODUCTION

The ALCHIMIA (Analysis of Light and CHarge induced by Micro Ion beams) project is aimed to characterize semiconductor materials and devices by means of micro-ion beam analytical techniques. This activity is carried out at the LNL using the ion microbeam facility at the AN2000 accelerator. One of the most powerful analytical techniques developed during the ALCHIMIA project concerns the measurement of the charge induced by ion beams (IBIC) on semiconductor devices. Such a technique has been successfully applied on silicon, CdTe, diamond, GaAs nuclear detectors and allowed both the measurement of some electronic transport parameters (e.g. lifetime, diffusion length) and the evaluation of the uniformity of the charge collection efficiency. This measurement was carried out by scanning a focusing beam onto the surface of the device and by the simultaneous recording of the induced charge signal.

In this report we present an application of the IBIC technique aimed to evaluate some basic parameters of 4H-SiC Schottky diode. Silicon carbide is a very hard material, which can be used in devices that operate under severe conditions such as high power / high temperature, or in a high radiation environment [1]. New 4H -SiC Schottky diodes have been fabricated within the COFIN-MIUR collaboration, which involves the Universities of Milano, Modena, Bologna and Torino, aimed to develop highly efficient and radiation hard SiC x-ray and nuclear detectors [2].

The spectral response of two 4H-SiC Schottky diodes to helium ions with energies ranging from 1 to 5.48 MeV was analyzed in order to evaluate both the electron-hole pair generation energy (ε) of 4H SiC and to measure the hole diffusion length.

II. EXPERIMENTAL SET-UP

The Schottky diodes were fabricated on 4H-SiC epitaxial wafers purchased from CREE Research. Two samples (named A and B) have been analyzed with active layer thickness of 30 and 50 μm and with a doping concentration of (Nd-Na)=2.2×10^{15} cm^{-3} and 5×10^{14} cm^{-3}, respectively. The Schottky contact is circular with a diameter of 2 mm and has been formed on the silicon surface of the epitaxial layer by deposition of 100 nm of gold. The barrier height is 1.6 eV as measured by C-V characteristics. Details on the geometry and on detector fabrication are described in [1].

The IBIC measurements were performed with partially focused He++ beams with a spot size of about 100 μm and energies ranging from 1 to 2 MeV and from a ^{241}Am source. The beam current was kept below 0.1fA (i.e. below 600 ions/s) in order to reduce radiation damage.

III. RESULTS AND DISCUSSION

Figure 1 shows the penetration longitudinal straggling of He ions in SiC as evaluated by SRIM2000 code in the energy range of 1-5.5 MeV.

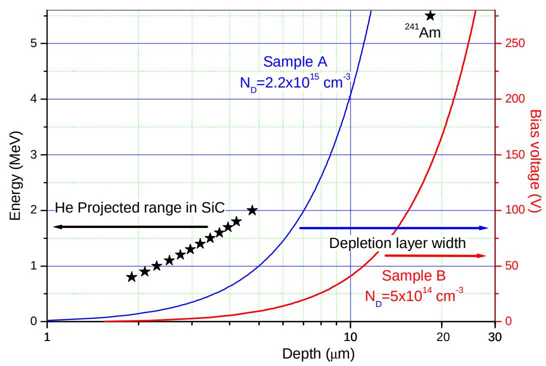

FIG. 2: Lateral straggling of SiC for He++ ions of different energies and depletion layer width as a function of the applied bias voltage.

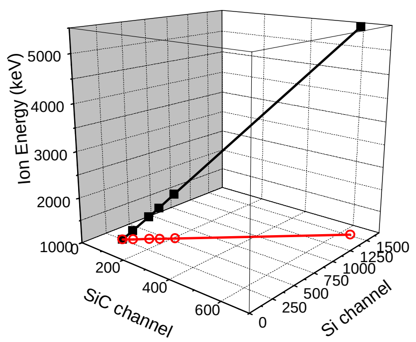

FIG. 2: Behavior of the peak channels vs. He++ ion energy for both Si and SiC diode.

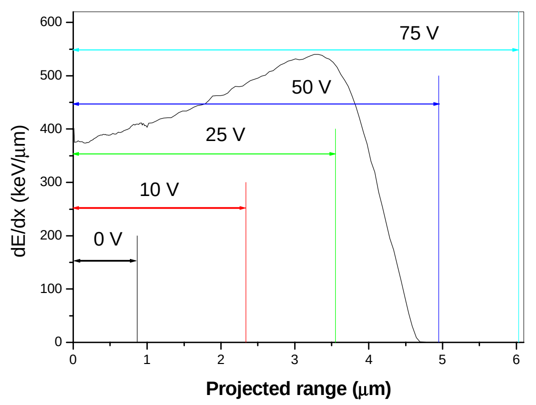

FIG. 3: Bragg ionization curve for 2 MeV He ions; the electrode (Au, 100 nm thick) has been subtracted; the total energy loss in SiC is about 1.93 MeV. Arrows indicates the different widths of the depletion layer at different applied bias voltages.

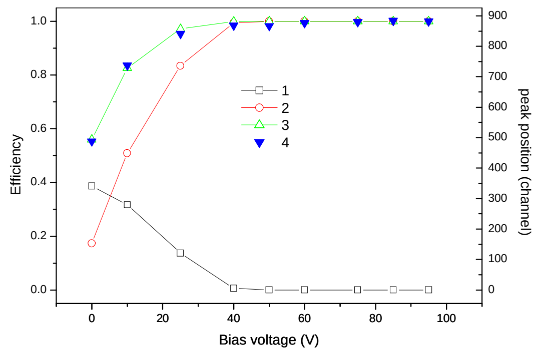

FIG. 4: Peak position of the SiC spectra versus the applied bias voltage and relevant theoretical evaluations of the charge collection efficiency. 1: contribution from neutral region; 2: contribution from depletion region; 3: theoretical charge collection efficiency; 4: experimental charge collection efficiency.

In the same figure, the width of the depletion layer as a function of the applied bias voltage is shown as evaluated from C-V measurements. It is clear that at a bias voltage of 150 V, the ionization profile falls within the depletion layer width of sample B. All the electron/hole pairs generated within the depletion layer width are collected at the electrode, i.e. at 150 V for the alpha particles with energies within 1-5.48 MeV, the charge collection efficiency can be considered equal to 100%. Figure 2 shows the spectral response of Si and SiC detectors to different He++ energies. The slope of the linear fit in the horizontal plane represents the ratio of the electron-hole pair generation energy in Si and SiC. Considering $\varepsilon_{Si} = 3.67$ eV at 300 K, we obtained a preliminary measurement of the electron-hole pair generation energy for 4H-SiC equal to $\varepsilon_{Si} = (7.75\pm0.03)$ eV.

By varying the applied bias voltage at a fixed energy, we have evaluated the diffusion length of minority carriers (holes) of the epitaxial active region. Figs. 3 and 4 show the 2 MeV He++ Bragg ionization curve and the experimental CCE as a function of the reverse bias voltage, respectively.

At bias voltages higher than 50 V, the charge collection efficiency is 100%. Such a threshold voltage corresponds to a depletion layer width equal to the ion penetration depth in SiC. Hence, all the electron/hole pairs generated within the depletion layer are collected at the electrodes.

If W is narrower than R, a fraction of the Bragg curve falls into the neutral region. Carriers generated there diffuse into the electric field region and give their contribution to the induced signal. The partial collection relevant to bias voltage lower than 50 V is due to the recombination of charge carriers in the neutral region. Since the number of carriers generated into the neutral region which reach the depletion layer decreases exponentially with the distance, the total measured charge pulse height can be calculated as follows

$$(1) \quad \eta = \frac{1}{E}\cdot\int_0^W \frac{dE}{dx}dx + \frac{1}{E}\cdot\int_W^R \frac{dE}{dx}\cdot\exp\left[-\frac{x-W}{L_p}\right]dx$$

Where W indicates the depletion region width, L_p is the hole diffusion length, dE/dx is the ionization energy loss of the ion per unit path length. E and R are the ion energy and range, respectively.

By fitting the experimental mean collection efficiency by means of equation (1), the free parameter L_p is evaluated: Lp = (8.4 ± 0.2) μm. The value of the hole life time, τ_p, have been inferred by those of L_p [$L_p = (D_p\tau_p)^{1/2}$] by combining with the Einstein relationship, $D_p = (kT/q)$, where μ_p is the ohmic hole mobility.

In Fig. 4 the drift and diffusion contributions to the total charge collection are reported. The drift contribution increases monotonically as the depletion layer widens, whereas the contribution of diffusion decreases up to zero when W>R.

The results reported here represent an example of the potentiality of the IBIC technique to characterise semiconductor materials and devices. The simple unidimensional model above described allows an evaluation of some basic transport parameters in semiconductors. The use of focused and low intense ion beams will increase the interest in this analytical approach as requested by the development of technologies involving micrometric sized structures.

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