Temperature dependent IBIC study of 4H-SiC Schottky diodes

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INTRODUCTION

IBIC (Ion Beam Induced Charge Collection) technique using focussed ion beams is a well established technique to characterise semiconductor materials and devices [1]. It consists in the measure of the charge induced by free carriers generated by MeV ions beams. The carrier drift length (mobility x lifetime x electric field) and diffusion length (square root of diffusivity x lifetime) are the physical observables usually measured and mapped in IBIC experiments both in fully and partially depleted devices. These transport parameters are functions of the sample temperature. Several ion beam analysis facilities have been equipped with sample cooling/heating systems, in order to investigate the transport properties and to evaluate the performances of semiconductor devices in a wide temperature range. Fully depleted, wide band-gap radiation detectors, such as diamond and CdZnTe, have been successfully studied both at cryogenic and at high temperature.

At the LNL AN2000 microbeam facility, we have carried out a new temperature dependent IBIC experiment on partially depleted semiconductor devices aimed to evaluate the dependence of the minority carrier diffusion length (L) on temperature. The measurements were carried out by recording the Charge Collection Efficiency (CCE) as a function of applied bias voltage in the temperature range of 120-380 K of a partially depleted semiconductor device using an ion probe able to generate carriers well beyond the depletion region [2] .

EXPERIMENTAL

IBIC measurements were performed at the AN2000 microbeam facility of Legnaro National Laboratories (Italy) with a focused 1.5 MeV proton ion beam (spot size ≈ 5 µm). The proton flux was of the order of 100 aA.

The IBIC apparatus was upgraded with a cryogenic sample holder consisting in a commercial "Microstat Optistat CF-V" cryostat by Oxford Instruments which was adapted to the microbeam line analysis chamber to perform IBIC and ionoluminescence experiments at temperatures ranging from 77 K to 500 K. The sample was electrically insulated from the cryostat by a sapphire layer insuring good thermal conductivity and the temperature was measured by a platinum thermoresistance placed close to the sample. The signal acquisition was controlled by a LabView program, which allowed the simultaneous control of other experimental parameters such as sample temperature and bias voltage.

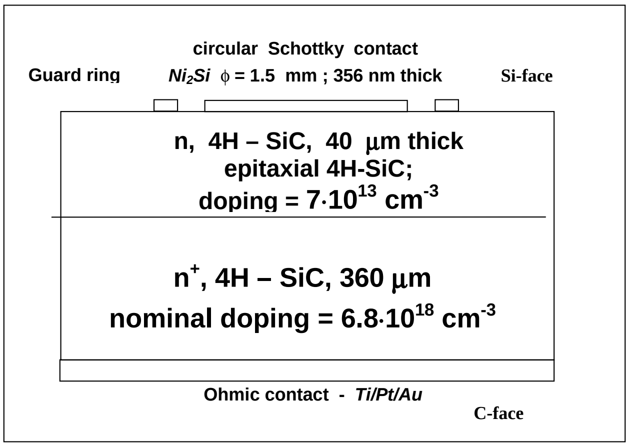

FIG. 1: Scheme of the 4H-SiC diode

The sample under investigation was a 4H-SiC Schottky diode; the epitaxial layer was grown at the Institut für Kristallzuchtung of Berlin (Germany) on commercial, low defect density, substrates from CREE Res. Inc [3]. A scheme of the diode is shown in Fig. 1.

RESULTS

Figure 2 shows IBIC maps and spectra obtained at two different bias voltages, which highlight inhomogeneities due to the presence of the bonding wire, silver paste for the electrical contact, surface scratches and material defects (comets, micropipes etc.), which are typical of 4H-SiC material. In order to avoid the collection of IBIC spectra from defective regions, we performed all the measurements in a small uniform region; moreover, the surroundings of the irradiated region were periodically monitored in order to check the absence of induced damage effects.

The 3D bar graph in Figure 3 shows the behavior of the peak value of CCE at different bias voltages and different temperatures.

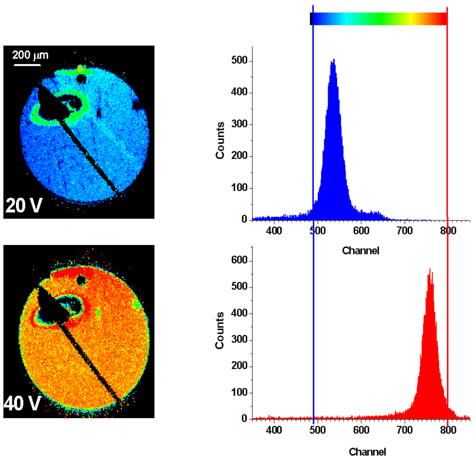

FIG. 2: IBIC maps and spectra at two different bias voltages

In order to interpret such data, we have adopted the formalism based on the Schockley-Ramo-Gunn theorem [4], which predicts that the induced charge at the electrode, i.e. the IBIC signal, is due to the motion of free carriers in the regions where electric field occurs, i.e. in the depletion layer. The width of such active region was determined by C-V measurement together with the energy loss profile of 1.5 MeV protons in 4H-SiC as evaluated by SRIM2003 simulation [5].

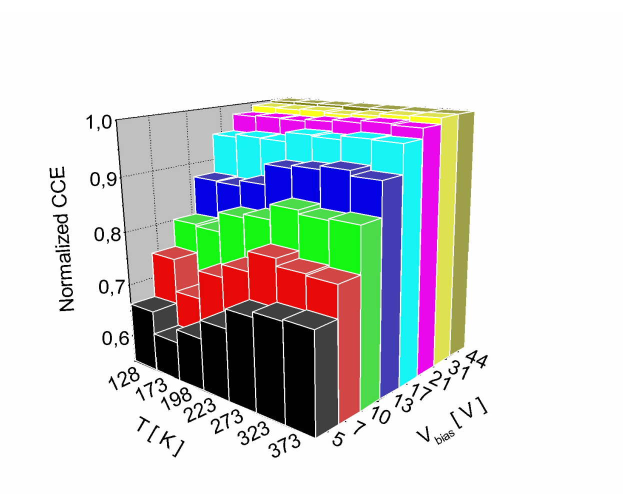

Fig. 3: 3D bar graph of CCE vs. sample temperature and bias voltage.

At low bias voltages, a fraction of carriers are generated within the neutral region. Minority carriers are injected into the active region by diffusion and hence contribute to the formation of the IBIC signal. In a one-dimensional model along the depth coordinate, the total charge Q induced at the sensing electrode by the motion of the carriers generated by ions of energy E is proportional to:

$$Q \propto \left[\int_0^w \left(\frac{dE}{dx}\right)\cdot dx\right] + \left[\int_w^d \left(\frac{dE}{dx}\right)\cdot \exp\left[-\frac{x-w}{L}\right]\cdot dx\right] \qquad (1)$$

where d is the epitaxial layer thickness, dE/dx is the proton energy loss and the exponential term is relevant to the probability of carriers generated within the neutral region to diffuse into the depleted layer (w thick).

Equation (1) was used to fit the CCE vs. V curve in the range 5V-45V for each sample temperature in order to evaluate the relevant hole diffusion lengths. Fig. 4 shows the result of the fitting procedure.

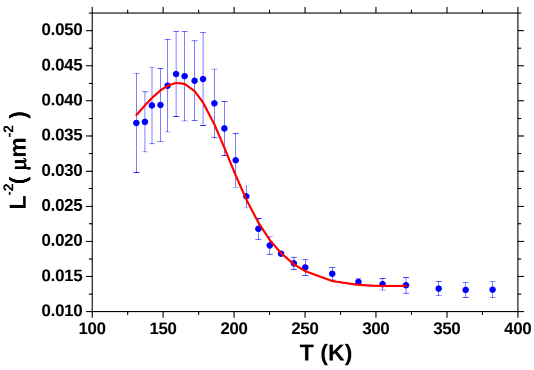

Fig. 4: Inverse of the square of hole diffusion length vs. T.

To interpret such a non monotonic trend we have adopted the Shockley-Read-Hall recombination model for fitting the temperature dependence of the diffusion length assuming one trap level E_t . The fitting procedure provides a value of E_t of about 0.16 eV which is in satisfactory agreement with the value found by Castaldini et al. [6] in similar 4H SiC Schottky diodes by deep level transient spectroscopy technique.

This experiment demonstrates that temperature dependent IBIC technique can strengthen the analytical capabilities of traditional spectroscopic techniques to detect energy levels of defects in semiconductors and to spatially resolve their distribution if combined with the raster scanning of a focused ion beam across the sample.

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