Lateral IBIC characterization of a GaAs Schottky diode

F.Fizzotti[1], A.Lo Giudice[2], C.Manfredotti[1,2,3], C.Paolini[1,2,3], E.Vittone[1,2,3], F. Nava[4], G.Egeni[5], V.Rigato[5]

1 Experimental Physics Dept. University of Torino, 2 INFM, UniTo, 3 INFN, sez. To, 4 Physics Dept., University of Modena and INFN sez. Bo., 5 INFN, Laboratori Nazionali di Legnaro

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 LNL by 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 (lifetime, diffusion length, drift length) and the evaluation of the uniformity of the charge collection efficiency. This latter 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.

As an example of the application of the IBIC technique, we report here the characterization of a Semi-Insulating (SI) n-GaAs Schottky barrier diode. The motivation of this research stems from the need to know the extension of the active region in GaAs Schottky diodes to be used as radiation detectors in high energy physics experiments or for medical applications as room temperature x/γ-ray detectors [1]. The aim of this lateral micro-IBIC analysis was to evaluate the dependence of the depletion layer region from the applied bias voltage in order to evaluate the best biasing conditions to maximize the detection volume and to reduce as much as possible charge trapping phenomena.

II. EXPERIMENTAL SET-UP

The detector studied in the present work was made on commercially available Semi Insulating Liquid Encapsulated Czochralsky (LEC) n-GaAs Schottky barrier diode, about 220 μm thick. Details on the device geometry and fabrication can be found in [2].

The detector was cleaved along the <110> direction to reduce the surface leakage, then it was edge-on mounted in order to perform measurements of the charge collection profile across the detector thickness.

The 2.4 MeV proton microbeam (2-4 μm size) was scanned over the cleaved surface from electrode to electrode (see Fig. 1). Fig. 2 shows the ion energy loss in GaAs as evaluated by the SRIM2000 code. The range of 2.4 MeV protons in GaAs is about 43 μm. Since the electron/hole generation occurs primarily at the Bragg's peak, i.e. at the end of the proton range, any recombination at the irradiated surface can be considered negligible. Under this hypothesis, the results we present here can be interpreted in a one-dimensional theory, i.e. considering the motion of carriers along the y direction which is parallel to the electric field and normal to the electrode surface (plane x-z).

III. RESULTS

Figure 3 shows IBIC maps obtained under different bias conditions. It is evident that active regions widen as the applied bias potential increases. Figure 4 shows the charge collection efficiency (CCE) profiles evaluated from the projection onto the horizontal axis of maps in Fig. 3. At

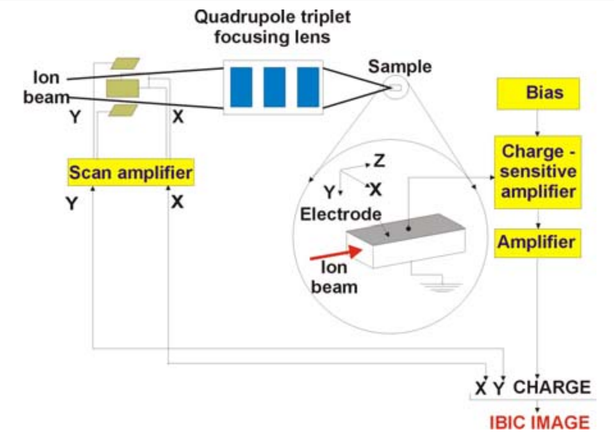

FIG. 1: lateral IBIC Set up

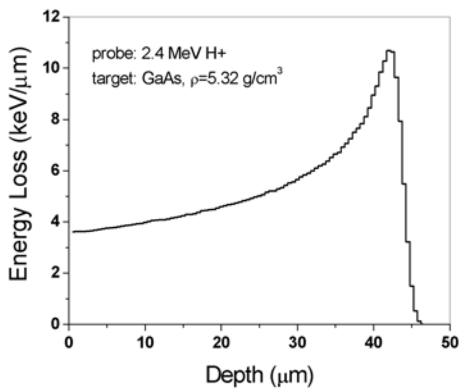

FIG. 2: Energy loss profile for 2.4 MeV H+ in GaAs

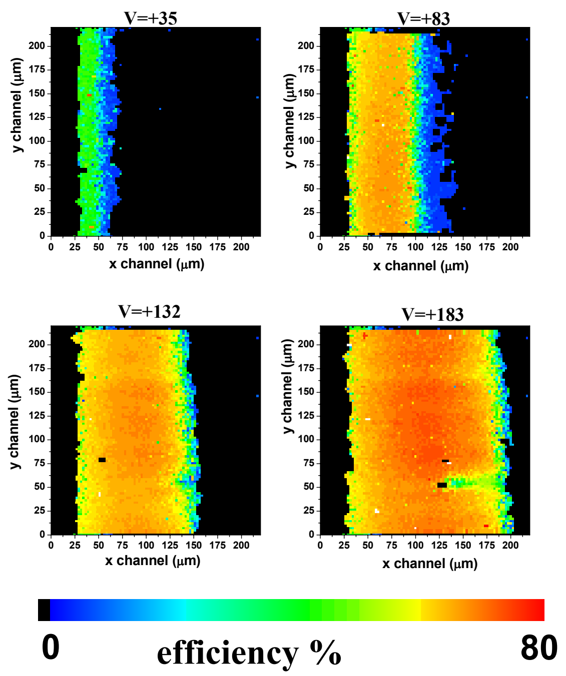

FIG. 3: Lateral IBIC map at different bias voltages

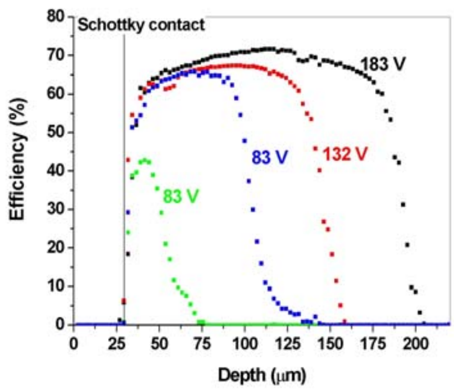

FIG. 4: Charge collection efficiency profiles obtained by the projection along the horizontal axis of the maps in Fig. 3.

high bias voltages, the CCE profiles in Fig. 4 show behaviors typical of regions where the electric field and carrier mobilities and lifetimes are constant.

In fact the CCE curves at bias voltages higher than 50 V can be well fitted by the function

$$CCE(y) = \frac{1}{W}\left\{ L_n\left(1 - e^{-\frac{W-y}{L_n}}\right) + L_p\left(1 - e^{-\frac{y}{L_p}}\right)\right\} \qquad (1)$$

where W is the depletion layer width, E is the electric field and $L_{n,p}=\mu_{n,p}\cdot\tau_{n,p}\cdot E$, are the hole (p) and electron (n) collection lengths., mobilities and lifetimes, respectively. Equation (1) can be easily derived from the Shockley-Ramo theorem [3]. It is worth noticing that the maximum of CCE occurs in the middle of the active region and its value is about 72%. These results lead us to conclude that the (mobility x lifetime) product is approximately the same for holes and electrons and that the collection length is about 70% of the width of the active region.

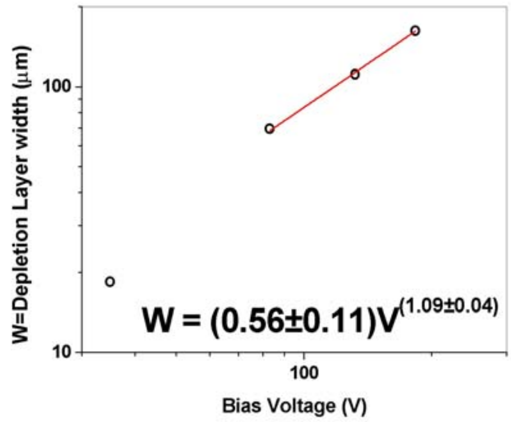

FIG. 5: Depletion layer width as a function of the applied bias voltage as evaluated from the CCE profiles in Fig. 4.

Figure 5 shows the depletion layer width W as a function of the applied bias voltage (for V_{bias}>50 V); W is defined as the half width at half maximum of the CCE profiles shown in figure 4. W linearly increases at a rate of about 0.6 μm/V.

This behaviour is in good agreement with OBIC (Optical Beam Induced Current) and SP (Surface Potential) measurements carried out by Castaldini et al. [4] and it is consistent with the interpretation of Mc. Gregor et al. [5]. At high bias voltage, the deep level capture cross section is enhanced by the electric field, resulting in the formation of a quasineutral region. This region estends from the Schottky contact to a transition region where the neutralisation estinguishes and a positive space charge distribution takes place.

The detector then behaves as a virtual condenser where the Schottky contact and the transition region act as charge plates separated by the quasineutral region of high electric field.

IV. ACKNOWLEDGEMENTS

This work was partially supported by INFN (National Institute of Nuclear Physics) and INFM (National Institute of Physics of Matter).

[1] E.Vittone et al. , Nucl. Instr. and Meth **B158** (1999) 470-475.
[2] M.Alietti et al., Nucl. Instr. and Meth **A355** (1995) 420-424.
[3] E.Vittone et al. , Nucl. Instr. and Meth. **B161** (2000) 446-451
[4] A.Castaldini et al. Phys. Rev. B, **56** (1997), 9201-9203
[5] D.S.McGregor et al. Semicond. And Semimet. **43** (1995) 383.