IBIC Characterization of Single Crystal Synthetic Diamond Detectors

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INTRODUCTION

In the recent literature significant improvements have been reported on the electronic quality and on the detection capability of single crystal (SC) synthetic diamond grown by chemical vapor deposition (CVD), both by commercial providers and by academic research groups. High detection efficiency and good energy resolution were reported, for example, when testing such materials as nuclear detectors with particles and fast neutrons.

IBIC (Ion Beam Induced Charge) is a very suitable technique for the characterization of transport properties in wide band gap semiconductors used as detectors [1]. In this report we present results obtained in the characterization of single-crystal (SC) diamond detectors by means of IBIC technique.

EXPERIMENTAL

SC-diamond detectors were fabricated at the laboratories of Rome "Tor Vergata" University [2]. HPHT (High Pressure, High Temperature) Ib single crystal diamonds (400 μm thick) were used as substrate. A boron-doped diamond buffer layer with 5 Ω cm resistivity was deposited onto HPHT substrates, followed by an intrinsic diamond film. The detectors were then realized using the conductive B-doped layer as a backing contact, while a 2.5 mm diameter Al contact was evaporated on the intrinsic diamond (see figure 1).

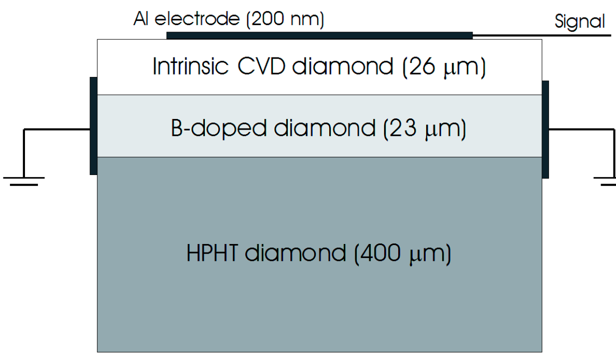

FIG. 1. *Scheme of the device configuration.*

In order to evaluate the efficiency and the charge collection profile of these detectors, a lateral IBIC analysis was performed using a 2.4 MeV proton microbeam, at the AN2000 microbeam line of the Italian National Laboratories of Legnaro (Italy). The proton beam was focussed to a spot size of about 3 μm and scanned over the cleaved cross section of the diamond detector. IBIC images were collected over a (250×100) μm^2 area.

RESULTS

In figure 2 a typical IBIC efficiency map of the sample cross section is shown. A bias voltage of +40 V was applied to the front electrode, which is positioned in the upper part of the map. The efficiency is encoded in the gray scale, the white color corresponding to complete (i.e. 100%) charge collection. The extension of the active area corresponds to the width of the homoepitaxial layer (intrinsic diamond).

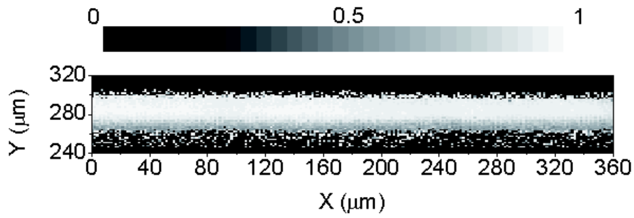

FIG. 2. *Typical CCE lateral map collected at 40 V bias voltage; the front electrode is in the upper part.*

Charge collection efficiency (CCE) profiles in the depth direction were extracted from maps collected at increasing bias voltage, as shown in figure 3.

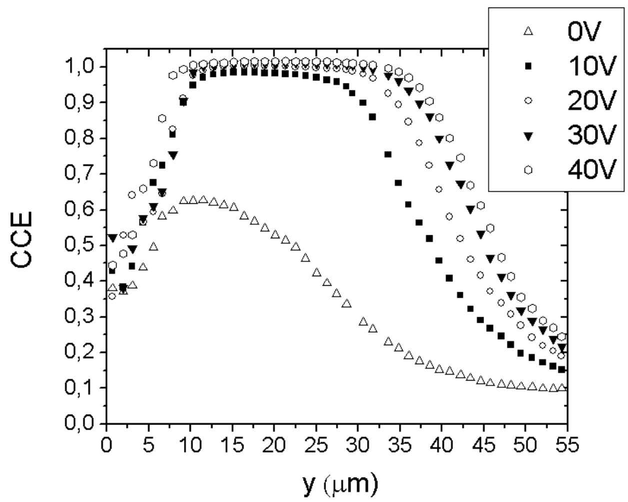

FIG. 3. *Charge collection efficiency (CCE) profiles in the depth direction collected at increasing bias voltage (Al electrode on the left).*

It is clearly visible from the profiles that regions with 100% CCE are visible when a bias voltage of ≥10 V is applied. The extension of such regions approaches the thickness of the homoepitaxial layer at ≥30 V bias voltage.

The profiles exhibit a sharp increase in CCE at the boundary with the front electrode (left side of the plot), while a broader edge is observed at the interface with the boron-doped back electrode. This is attributed to the diffusion of boron from the back electrode during the growth stages, which limits the collection efficiency of the nearby regions. Confirmation of this interpretation comes from lateral cathodoluminescence (CL) mapping (not reported here), which exhibits boron-related luminescence features. Moreover the CCE decreases gradually with increasing generation depth, since a small fraction of the charges generated deeply in the boron doped region diffuses towards the active region.

A typical CCE spectrum relevant to the active area at 40 V bias voltage is shown in figure 4, where the pulse height is expressed in arbitrary units. The high quality of the detector response can be appreciated, since the sharp peak in the spectrum corresponds to 100% efficiency in the charge collection.

CONCLUSIONS

Lateral IBIC mapping with micrometer-sized ion probes proved to be a powerful tool to directly investigate the spatial distribution of relevant charge transport parameters of detector devices. In particular, the CCE profiles in the depth direction of homoepitaxial diamond detectors grown on heavily-doped back electrodes were measured for the first time, allowing a direct evaluation of the extension of the active area and a local estimation of the CCE with micrometer spatial resolution. The influence of boron diffusion from the back electrode on the CCE can be easily evaluated from such profiles.

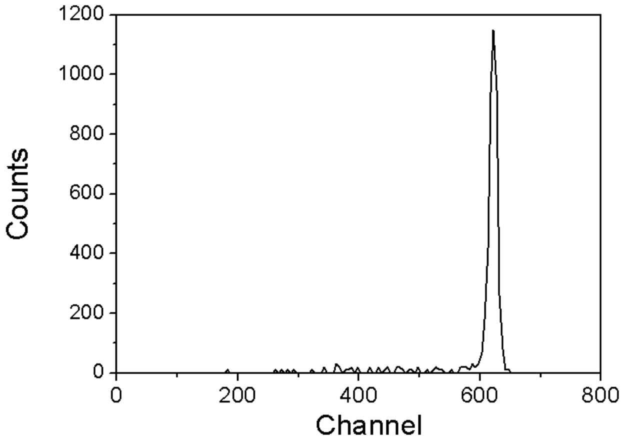

FIG. 4. *Typical CCE spectrum collected from the active region.*

ACKNOWLEDGMENTS

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[1] M.B.H. Breese et al., Nucl. Instr. and Meth., B264 (2007) 345.
[2] M. Marinelli et al., Appl. Phys. Lett., 89 (2006) 143509.