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Study of physical and chemical inhomogeneities in semiconducting and insulating materials by a combined use of micro-PIXE and micro-IBIC

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Abstract

Micro-IBIC and micro-PIXE have been used on samples of CVD diamond, CdTe and Si, in order to find correlations between the chemical impurities distribution and the transport properties or collection properties of charge carriers. In CdTe and Si, which are relatively good nuclear detectors, chemical impurities contents are largely below PIXE sensitivity, but micro-IBIC is able to determine the electrical field distribution and the carrier trapping times. In CVD diamond, micro-PIXE maps have been measured for a series of impurities, including both light and heavy elements. These impurities are spread out in regions of low crystallographic order and at grain boundaries, leaving probably the true single crystal unaffected. They should be connected with the large trapping effects measured by micro-IBIC in the same regions.

1. Introduction

The aim of this work is the investigation of several devices through ion beam induced current (IBIC) and proton-induced X-ray emission (PIXE) techniques. IBIC maps are essentially, for our samples and experimental geometry, collection length maps: they are very important for a polycrystalline material like CVD diamond [1], in which it is more than reasonable to assume that grain boundaries severely limit the collection length, which for a pure crystalline material should be much larger than grain dimensions. Grain boundaries are not only highly defective regions, but also represent a very favourable path for diffusion of chemical impurities. Therefore, one could expect that grain boundaries are “decorated” by impurities which are either extracted from the substrate or by the chemical environment in which CVD diamond is deposited, and which can be detected by micro-PIXE. Of course, both micro-IBIC and micro-PIXE maps are “averaged” over the penetration depth of protons and, therefore, a good image of grain boundaries is possible only for a columnar structure of grains themselves aligned with proton trajectories. Fortunately, this is the case of CVD

diamond, which generally displays a columnar structure, even if not always regular.

A quite different problem concerns crystalline materials like CdTe and Si, for which there are no reasons to argue that collection length maps are not uniform. In the case of CdTe, problems related to polarization effects and to carrier injection at the contacts lead to the conclusion that the electrical field profile inside the detector, i.e. along the coordinate z for a planar (xy) arrangement of electrodes, is not uniform [2]. This conclusion is strongly supported by time-of-flight data and by direct measurement of the electrical field profile using Pockel effect [3]. In our case, the distribution of the electrical field can be obtained by scanning with a proton microbeam the cross section of CdTe “detector grade” samples and by mapping the measured collection efficiency. Of course, the distribution of the electrical field cannot be calculated directly, but by a fitting procedure, with the assumption that both μ and τ are constant for both carriers over the whole volume of the detector. A comparison with calculated profile of the electrical field could be very important in looking for possible nonuniformities of τ or, more likely, to its possible dependence on the electrical field.

In the case of Si, the electrical field profile can be easily obtained by diffusion process parameters and by the use of suitable codes for solving the relevant Poisson's equation.

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