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Focused ion beam fabrication and IBIC characterization of a diamond detector with buried electrodes

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ABSTRACT

This paper reports on the fabrication and characterization of a high purity monocrystalline diamond detector with buried electrodes realized by the selective damage induced by a focused 6 MeV carbon ion beam scanned over a pattern defined at the micrometric scale. A suitable variable-thickness mask was deposited on the diamond surface in order to modulate the penetration depth of the ions and to shallow the damage profile toward the surface. After the irradiation, the sample was annealed at high temperature in order to promote the conversion to the graphitic phase of the end-of range regions which experienced an ion-induced damage exceeding the damage threshold, while recovering the sub-threshold damaged regions to the highly resistive diamond phase. This process provided conductive graphitic electrodes embedded in the insulating diamond matrix; the presence of the variable-thickness mask made the terminations of the channels emerging at the diamond surface and available to be connected to an external electronic circuit. In order to evaluate the quality of this novel microfabrication procedure based on direct ion writing, we performed frontal Ion Beam Induced Charge (IBIC) measurements by raster scanning focused MeV ion beams onto the diamond surface. Charge collection efficiency (CCE) maps were measured at different bias voltages. The interpretation of such maps was based on the Shockley–Ramo–Gunn formalism.

1. Introduction

Diamond has been systematically studied since 1940s to make solid state ionization chambers for ionization radiation detection. In fact, its extreme properties make this material appealing for many applications, ranging from high energy physics experiments to radiotherapy dosimetry, neutron spectroscopy and monitoring of the activity in corrosive nuclear waste solutions [1].

The advances in the CVD growth technology recently made available to the market “detector grade” diamond samples with superior features, from both a structural (high crystal perfection, low impurity density) and an electronic (high carrier mobilities and lifetimes) point of view [2]. However, the full exploitation of the potential of diamond as a material for ionizing radiation detectors requires the availability of techniques that allow the modification of the structural and electrical properties of single crystals at a micrometric scale.

In this paper we show that focused MeV ion beams can effectively contribute to both the fabrication and the characterization of a diamond detector with active regions defined with micrometer resolution.

For what concerns the fabrication, we have realized buried conductive electrodes by exploiting the phase transformation of selected regions irradiated with C ions from diamond to a graphitic phase. Such phase transition only occurs in regions where the damage density overcomes the so-called “graphitization threshold” (i.e. the vacancy density above which the damaged diamond structure permanently converts to graphite upon thermal annealing), thus resulting in the formation of well-defined graphitic layers at the end-of-range of the implanted ions [3,4]. The electrical contacts were realized with a novel technique based on the employment of variable-thickness metallic masks that allowed the modulation of the depth of the buried electrodes, thus allowing their electrical contacting with the surface at their endpoints [5,6].

For what concerns the characterization, we employed the IBIC technique to map the charge collection efficiency of the ion-microfabricated diamond detector. This technique allows a direct imaging of the active regions and a deep insight into the mechanisms occurring in induced-charge pulse formation [7].

2. Experimental

The sample used in this work is a synthetic single crystal diamond produced by ElementSix Ltd., with Chemical Vapor Deposition (CVD) process [2]. The crystal is $2.0 \times 2.0 \times 0.5\ mm^3$

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