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Diamond sensors for future high energy experiments

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ABSTRACT

With the planned upgrade of the LHC to High-Luminosity-LHC [1], the general purpose experiments ATLAS and CMS are planning to upgrade their innermost tracking layers with more radiation tolerant technologies. Chemical Vapor Deposition CVD diamond is one such technology. CVD diamond sensors are an established technology as beam condition monitors in the highest radiation areas of all LHC experiments. The RD42-collaboration at CERN is leading the effort to use CVD diamond as a material for tracking detectors operating in extreme radiation environments. An overview of the latest developments from RD42 is presented including the present status of diamond sensor production, a study of pulse height dependencies on incident particle flux and the development of 3D diamond sensors.

1. Introduction

With the planned upgrades of the Large Hadron Collider (LHC) to High Luminosity (HL-LHC) [1] and the next generation of particle physics experiments in development, new energy and luminosity regimes will be reached. The expected fluence for the inner most layer of the tracking detector at HL-LHC is $\Phi_{1\ \mathrm{MeVn_{eq}}} = 2 \times 10^{16}\ \mathrm{n_{eq}/cm^2}$ [2] and the flux is expected to be up to 1.5 GHz $/\mathrm{cm}^2$ [3, scaled to the expected instantaneous luminosity]. For these harsh radiation environments new technologies for tracking detectors are most likely required. With its large band-gap ($E_{gap} = 5.5$ eV at $T = 302$ K) and its high binding energy, diamond has ideal material properties to work as a particle detector in these environments. Chemical Vapor Deposition (CVD) diamonds have been shown to be at least three times more radiation tolerant [4], to have at least a two times faster charge collection [5], and to be four times more thermally conductive [6] than corresponding silicon detectors. Low leakage currents, low dielectric constant and the ability to work at room temperature are also appealing properties for tracking detectors.

The RD42-collaboration, based at CERN, is investigating the capability of diamond detectors in the field of high energy physics. The signal response of response of single-crystal CVD (scCVD) and polycrystalline CVD (pCVD) diamonds irradiated up to 1.8×10^{16} protons/cm^2 [7] has been measured, indicating that diamond-based detectors are good candidates for tracking detectors close to the interaction point. In order to increase the radiation hardness even further RD42 recently started to evaluate diamond detectors based on the new 3D geometry. As part of the mission, RD42 has been working with diamond manufacturers for two decades to improve the quality of artificially grown diamonds based on the (CVD) technique to make them suitable for use as charged particle sensors. For a long time only a single manufacturer [8] was capable of producing detector grade diamonds. In the last years two new producers, II-VI Incorporated [9] and IIa Technologies [10], have entered the market.

When comparing qualities of diamond sensors the figure of merit is the Charge Collection Distance (CCD), which is defined as the average distance an e/h-pair separates under the influence of an electric field [11]. In order to maximize the amount of collected charge and obtain the best possible signal, the CCD should be as high as possible. For a non-irradiated scCVD diamond full charge collection is expected, which means that the CCD is equal to the thickness of the diamond. For pCVD diamonds the CCD is expected to be lower than the thickness due to charge trapping.

The company II-VI Incorporated [9] has been producing laser windows based on pCVD diamonds for several years, and recently started to grow detector grade diamond material as well. In this time the quality of their pCVD diamonds has improved. They have delivered final finished parts (~ 100 parts of various sizes) to the particle physics experiments Compact Muon Solenoid (CMS) and A Toroidal LHC ApparatuS (ATLAS). The majority of their final finished diamond sensor parts now reach a CCD of 275–300 μm. In Fig. 1 the CCD of four preselected diamonds is shown as a function of bias voltage. All samples reach a CCD of above 300 μm at a bias voltage of 800 V, corresponding to an electric field of 1.5 V/μm.

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