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Status of the R&D activity on diamond particle detectors

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The RD42 Collaboration

Abstract

Chemical Vapor Deposited (CVD) polycrystalline diamond has been proposed as a radiation-hard alternative to silicon in the extreme radiation levels occurring close to the interaction region of the Large Hadron Collider. Due to an intense research effort, reliable high-quality polycrystalline CVD diamond detectors, with up to 270 μm charge collection distance and good spatial uniformity, are now available. The most recent progress on the diamond quality, on the development of diamond trackers and on radiation hardness studies are presented and discussed.

1. Introduction

A large effort is presently spent by the scientific community in the development of semiconductor-based particle detectors to be operative in extremely severe radiation environments. The study is mainly focussed on microstrip and pixel position-sensitive detectors to be applied in the forward tracker region of high-energy physics experiments at the Large Hadron Collider (LHC), where a luminosity of $\sim 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$ will give rise to hadron fluences up to $\sim 10^{15}\ \mathrm{cm^{-2}}$ after 10 years operation [1]. A possible further increase of the luminosity up to $\sim 10^{35}\ \mathrm{cm^{-2}\ s^{-1}}$ (SuperLHC) [2] would raise the hadron fluence after 5 years operation up to $\sim 10^{16}\ \mathrm{cm^{-2}}$ at the innermost radius. The development of novel, radiation-hard, position-sensitive detectors which can operate in such a hostile radiation environment is mandatory, as standard silicon detectors, due to their limited radiation hardness [3], would not survive. The exceptionally high radiation hardness of diamond makes this material a potential alternative to silicon for particle detection. A low read-out noise, due to the low leakage current and a low dielectric constant, a fast signal collection time, due to high electron and hole mobilities and high saturation velocity and the possibility of room temperature operation are other significant strengths of diamond for this application. For these reasons, the CERN RD42 Collaboration [4] started a research program to investigate the efficiency of position-sensitive diamond particle detectors: due to the potential low-cost and large-scale production of synthetic material, this research activity has been mainly focussed on Chemical Vapor Deposited (CVD) polycrystalline diamond. CVD diamond films are commercially available with typical diameters up to 5–6″ and thickness in the range 100 μm–1 mm; this material mainly consists of diamond microcrystals (typical linear size 1–100 μm) growing columnarly from the substrate. The performance of CVD polycrystalline diamond devices is strongly dependent on the microscopic quality of the films, and it is usually degraded by the presence of native defects (like nitrogen-related complexes, graphitic remnants, dislocations, etc.) incorporated in the material bulk during the growth process, mainly at grain boundaries. Native defects can significantly reduce the mobility weighted charge carrier lifetime τ through trapping and recombination: this effect can lead to a charge collection distance $d = \mu E \tau$ smaller than the sensor thickness (with μ the summed electron and hole mobility and E the electric field). This can result in significantly lower pulse heights than in silicon detectors: the charge collection distance is therefore the most important figure of merit for CVD diamond sensors. In order to significantly improve the charge collection distance of these devices, the RD42 Collaboration has recently undergone a research program with the main CVD diamond manufacturers to produce a