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# Diamond pixel modules

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A R T I C L E I N F O

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A B S T R A C T

With the commissioning of the LHC in 2010 and upgrades expected in 2015, ATLAS and CMS are planning to upgrade their innermost tracking layers with radiation hard technologies. Chemical Vapor Deposition diamond has been used extensively in beam conditions monitors as the innermost detectors in the highest radiation areas of BaBar, Belle, CDF and all LHC experiments. This material is now being considered as a sensor material for use very close to the interaction region where the most extreme radiation conditions exist. Recently the RD42 collaboration constructed, irradiated and tested polycrystalline and single-crystal chemical vapor deposition diamond sensors to the highest fluences expected at the super-LHC. We present beam test results of chemical vapor deposition diamond up to fluences of $1.8\times10^{16}$ protons/cm$^2$ illustrating that both polycrystalline and single-crystal chemical vapor deposition diamonds follow a single damage curve. We also present beam test results of irradiated complete diamond pixel modules.



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## 1. Introduction

Detectors and radiation monitors of future experiments will be situated in radiation environments several orders of magnitude harsher than those of any current detector. At present detectors for tracking close to the interaction region are based on the mature silicon technology which functions very well in relatively low radiation environments. Chemical Vapor Deposition (CVD) diamond has a number of properties which make it an attractive material for detector applications. Its large band-gap (5.5 eV) and large displacement energy (42 eV/atom) make it a material that should be inherently radiation tolerant with very low leakage currents. Chemical Vapor Deposition (CVD) diamond is being investigated by the RD42 Collaboration [1] for use very close to the interaction region where the most extreme radiation conditions will exist.

### 1.1. Principles of diamond detectors

In Fig. 1, we show the basic principle of using diamond as a particle detector [2]. A voltage is applied across a layer of diamond a few hundred microns thick. When a charged particle traverses the diamond, atoms in crystal lattice sites are ionized, promoting electrons into the conduction band and leaving holes in the valence band. On average, 3600 electron-hole pairs are created per 100 μm of diamond traversed by a minimum ionizing particle. These charges drift across the diamond in response to the applied electric field producing a signal that can be measured. Since there may be traps in CVD material we often use the charge collection distance (ccd) to characterize the material, which is the average distance the electron–hole pair travel apart before being trapped.

## 2. Radiation hardness studies with CVD diamond

Radiation tolerance is one of the strongest arguments for using any material in a high-energy physics experiment. The RD42 irradiation program consists of characterizing each sample prepared as a tracking detector (strip detector or pixel detector) in a test beam before and after each irradiation. The samples prepared as strip detectors were read-out with VA-2 electronics [3] for characterization in the test beam at CERN where as the samples prepared as pixel detectors were read-out with ATLAS FE-I3 pixel electronics [4]. All polycrystalline CVD (pCVD) and single-crystal CVD (scCVD) samples were prepared in this manner. Fig. 2 shows a photograph of four scCVD samples prepared as strip detectors and read-out with VA-2 electronics for characterization in the test beam at CERN. The irradiations described in this paper were performed using 24 GeV protons at the CERN PS facility. The detectors were irradiated at room temperature and in an un-biased state.

Fig. 3 shows the pulse height spectrum obtained from a recent pCVD diamond after being irradiated with $1.4 \times 10^{15}$ 24 GeV protons/cm$^2$. A clear Landau distribution is observed in the data with a mean observed charge of 7300e (or a ccd of 203 μm) and a most probable charge of 6000e. To set the scale, for use at the LHC as a pixel detector with ATLAS FE-I3 electronics it is estimated that a minimum charge of 2200e (1400e threshold plus 800e overdrive) corresponds to an efficiency of $>99\%$. Fig. 4 shows the pulse height spectrum obtained from a recent scCVD diamond before and after being irradiated with 1.5 $\times 10^{15}$ 24 GeV protons/cm$^2$. Clear Landau distributions are observed in the data with the mean ADC counts of 1393 before irradiation and 837 after irradiation.

In order to estimate the effects of radiation on CVD diamond detectors we have compared the collection distances for pCVD and scCVD samples before and after irradiation. The scCVD diamond is expected to be representative of the next generation

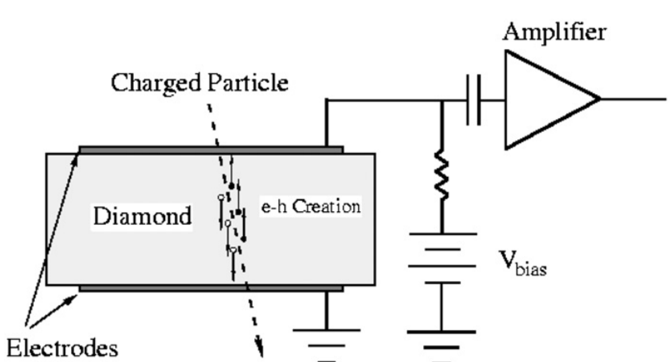


**Fig. 1.** A schematic view of a diamond detector.

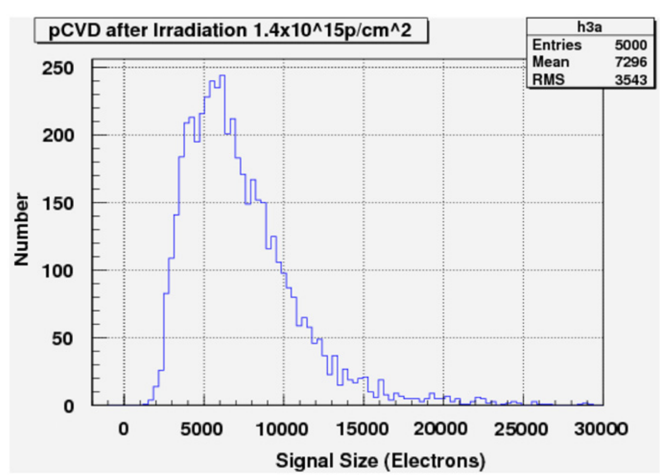


**Fig. 3.** The pulse height spectrum from an irradiated pCVD strip detector after irradiated with $1.4 \times 10^{15}$ 24 GeV protons/cm$^2$. A clear Landau distribution of pulse heights is observed. The observed mean charge is 7300e and the observed most probable charge is 6000*e*.

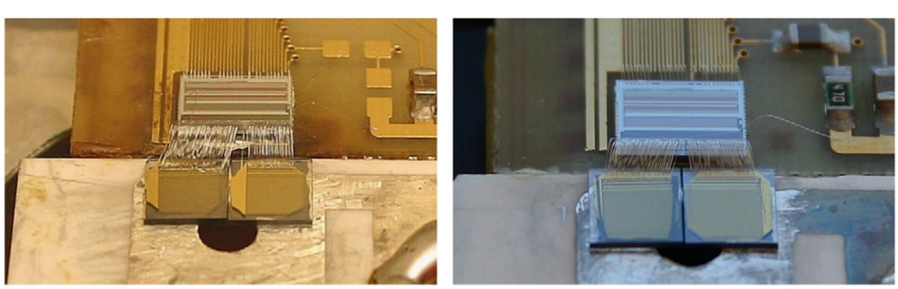

**Fig. 2.** Photographs of the four 5 mm × 5 mm scCVD samples fabricated into strip detectors and characterized in a 120 GeV pion beam at CERN.