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Influence of temperature on the response of high-quality polycrystalline diamond detectors

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Abstract

We investigated the charge collection properties of a polycrystalline CVD diamond detector in a temperature range from −10 to 80 °C, by means of a ^{90}Sr minimum ionizing β radiation source. The sample is a state-of-the-art diamond sensor yielding a maximum charge collection distance of 260 μm at room temperature and 1 V/μm applied field, when set in the so called pumped state, i.e., after passivating the deep traps with a pre-irradiation with β particles. We observed a decreasing charge collection distance with increasing temperature, which is a trend opposite to that reported recently by other research groups. We ascribe this discrepancy to the higher quality of our detector, in terms of a lower concentration of defects and grain boundaries. Conversely, we observe a less dramatic temperature dependence which we tentatively explain assuming a combined effect of variation with temperature of the thermal velocity and of the capture cross-section, according to a well known model of multi-phonon non-radiative processes.

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Keywords: Diamond detectors; Chemical vapour deposition; Trapping and recombination processes; Priming

1. Introduction

Polycrystalline Chemical Vapor Deposited (pCVD) Diamond and Single Crystal Chemical Vapor Deposited (scCVD) Diamond are presently studied as base materials for tracking devices close to the interaction region of high energy experiments as ATLAS, BaBar, CDF [1–5]. The main advantage of diamond is the superior radiation tolerance with respect to silicon. pCVD diamond yields a mean value of electron collected charge of about 3000e$^-$ after a proton irradiation as high as 1.8×10^{16}/cm^2 and an applied field of 1 V/μm [4] which compares with about the same collected charge obtained with oxygenated Si at a fluence of 6×10^{15}/cm^2 with an applied field as high as 5 V/μm [6,7]. Continuous progresses in terms of Charge Collection Distance (CCD) of pCVD diamond have been recorded in the past years (the present state-of-the-art value is 300 μm) whilst a comparison between pCVD and scCVD is envisaged in the short term. Diamond-based devices are beam-tested by the RD42 CERN Collaboration and other research groups, along with the improvements of the manufacturer (Element Six), while major issues regarding the properties of the materials are addressed. Instabilities as erratic currents [2], priming effects [8], trapping/recombination mechanisms [9], uniformity [10] and reproducibility are investigated.

In this work we present recent results in the study of charge collection properties of a pCVD diamond sensor, by means of an investigation of the dependence of CCD on temperature, performed with a β minimum ionizing particle source and a charge collection set up operating

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in a range of temperatures from −10 to 80 °C. The results assess a substantial independence of the state-of-the-art diamond material from trapping mechanisms involving grain boundaries that have been observed in the past years.

2. Experimental details

2.1. Sample

Part # 3 of sample CDS92 of the RD42 CERN Collaboration was characterized in this work by means of CCD vs. temperature measurements. The CDS92 diamond pCVD layer was grown by De Beers Industrial Diamonds (or Element Six) in the year 2000. Ohmic Al contacts were coated on both sides of the diamond parts at Ohio State University (OSU). A work on the trapping/recombination mechanisms involving a twin sample (CDS92 # P4) was presented recently by some of the authors [9,11]. The high quality of these samples, yielding a CCD of about 250 μm in the *pumped state* was correlated there to a decrease in the concentration of the recombination centers, achieved by the manufacturer in recent years.

2.2. Radiation sources

Two ^{90}Sr sources of β radiation were used in this work: a 10 mCi source was used to *pump* the sample, i.e., to fill the deep (thermally inactive) trapping centers. This results in an increase of charge collection efficiency (a well-known *pumping effect*.) A second 0.1 mCi source was employed in the CCD measurements. The rate of events during the measurements was about 30 Hz which was adequate to the CCD measurement setup. To reset the sample in the opposite state we *depumped* it with a tungsten lamp. Both the depumped and pumped state were identified by the minimum and maximum CCD, respectively, obtained at room temperature (see Table 1).

2.3. Charge collection setup

The charge collection of the samples has been measured by use of a system designed by one of the authors at NIKHEF, Amsterdam (a thorough description can be found on the web [12]). It consists of a characterization box connected to a DAQ box, interfaced to a PC via an ADC board. The sample under test is mounted in the characterization box and the source is placed above it, the radiation is directed to the diamond detector via a 1 mm collimator.

The first stage of the preamp circuit, in the characterization box, is formed by a Amptek A250 integrating amplifier with a n-channel FET mounted onto the PC250 board. Subsequently the signal is shaped while its baseline is stabilized on the second stage of the preamp circuit that is mounted on a Amptek A275 board. The trigger signal is generated by a 3 mm wide and 3 mm long cylinder of scintillator plastic, sitting below the sample, coupled via a 22 mm-long light guide to a Hamamatsu H5783 photomultiplier. Because of the small scintillator dimensions in combination with the short light guide a high efficiency is obtained in combination with a negligible dark count rate (one-two percent of the total pulse height spectrum in the present work as shown in Fig. 1). The values of the bias voltage circuit are optimised for bias currents up to a few nA. The current was monitored by measuring the voltage across a 100 MΩ resistor in series with the sample, in the bias circuit. The current rised up to the nA range at the highest temperature (80 °C). The pulse height spectrum was sampled by a 12-bit ADC of a NI PCI 6024E board in a PC connected to the DAQ box. The series noise contribution to the electron noise charge of the system has been measured to be $ENC = 208e^- + 4.6e^-/pF$. The constant term depends on the input capacitance of the amplifier (Amptek250 plus external fet). The second term is proportional to the detector capacitance (∼1 pF). Parallel noise, proportional to leakage current times integration time (2 μs) adds up to give an effective *ENC* of about 350e$^-$ at 1 nA. The gain calibration has been performed both with a 2.4 pF test capacitor and with a 300 μm thick Si detector

Table 1
Mean and most probable values of the pulse height spectrum in the depumped and pumped state

	Most probable Value [e$^-$]	Mean value [e$^-$]	T [°C]
Depumped	4950 ± 25	6950 ± 25	20 ± 0.1
Pumped	7010 ± 25	9290 ± 25	19 ± 0.5
Then after 4 h at 80 °C	6970 ± 25	9250 ± 25	20 ± 1

The CCD is obtained by dividing the values given in electron charge by 36, which is the number of e–h couples generated per μm by minimum ionizing particles in diamond. The fit error is also indicated. The pumped state is preserved after a 4 h annealing at 80°, a period of time which is longer than any measurement performed in this work.

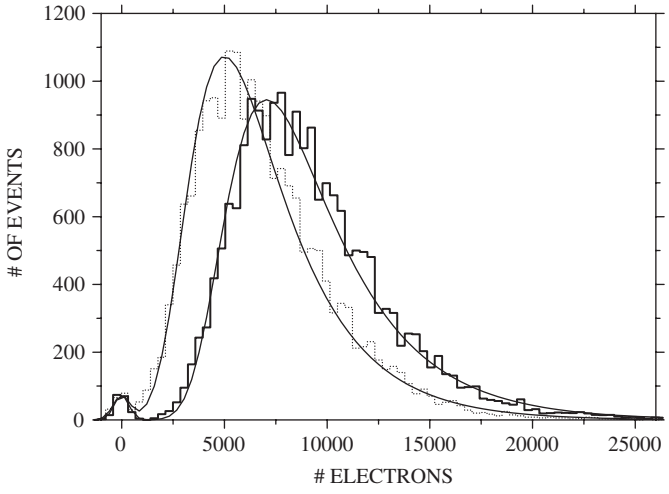

Fig. 1. Pulse height spectrum of the sample in the depumped state (dotted hystogram) and in the pumped state (solid hystogram) together with the best fit to a Landau distribution convoluted with a Gaussian noise distribution [13].