Towards a Measurement of the Mean Number of Charge Carriers Created by a MIP in sCVD Diamond using the EUDET Telescope

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Abstract

We plan to measure precisely the charge created by ionisation when a high energy particle of precisely known energy crosses a single crystal diamond and from here the energy which is deposited in the material. In the literature the amount of charge carriers liberated by a minimum ionising particle (MIP) in diamond is assumed to be 36 electron-hole pairs per micrometer of traversed material. This document presents a first look at the data collected in December 2007 at the DESY test beam facility using the EUDET beam telescope.

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1 Introduction

The determination of the Charge Collection Distance (CCD) of diamond detectors has been the subject of discussions within our group. Inconsistencies have been found with the methods applied by other groups such as RD42 or the CMS group. Our method using a ^{90}Sr source provided a very consistent result when we investigated single crystal CVD (sCVD) diamonds with an expected charge collection efficiency of 100%. However, here we used electrons from the high energy tail of the β-spectrum. Consequently, the energy distribution and hence the energy loss inside the sensor are not precisely controlled.

To obtain a reference measurement of the energy deposited by a high energy particle of known energy in a single crystal diamond detector, we used the test beam at DESY providing a GeV electron beam and the EUDET beam telescope. This measurement allows us to determine the number of electron-hole pairs created per micrometer of traversed material. In order to avoid border effects due to metallization, we used the EUDET telescope of the test beam facility to control the fiducial region of the device under test (DUT). We collected data at different beam energies ranging between 1 GeV to 5 GeV. This work presents a fist look at the data collected with the test beam telescope and a beam energy of 3 GeV.

2 Principle and method of investigation

The determination of the CCD or the efficiency of charge collection of the DUT using a charge-sensitive preamplifier and ADC, depends on the knowledge of the following parameters:

1) The calibration factor, k, of the preamplifier and ADC combination. The calibration factor includes the entire read out electronics. For the highest accuracy one should either correct for the specific capacitance of a DUT at the input of the preamplifier, or calibrate while the DUT is connected to the preamplifier.
2) The amount of energy deposited, E_{dep}, in the DUT by a particle. A radioactive source emitting beta particles, as for instance a ^{90}Sr source, is not perfectly suitable due to the a priori unknown energy spectrum of the particles generating trigger signals. E_{dep} depends on the material. Ref. [1] calculates the deposited energy in a 500 μm thick diamond detector to be a factor 1.08 higher than a MIP energy deposition. The calculation assumes a lower cutoff of the ^{90}Sr spectrum at 0.5 MeV and a MIP-like energy deposition for E_{beta} > 1.2 MeV (Ref. [1]).
3) The thickness of the DUT, d.
4) The ionisation energy, ε, needed to create an electron-hole pair in the DUT. In Ref. [2] values for ε of 13.1 eV and 3.63 eV are given for diamond detectors and for silicon respectively. These values are slightly temperature dependent.
5) The latter three parameters are often combined in a constant factor $Q_{expected,\ diamond}$ = 36 eh-pairs per μm, which gives the mean number of expected charge carriers created by a MIP per μm of traversed material. This value is taken from [1] and is commonly accepted by the relevant groups (RD42, GSI and others). However, Zhao's [1] experimental result was 38 ± 4 eh-pairs per μm, and his calculation of the restricted energy loss in 500 μm lead to 36.3 eh-pairs per μm, using $\varepsilon_{diamond}$ = 13 eV.
6) The determination of the signal in terms of ADC channels from a spectrum measured using a charge sensitive ADC. What we usually determine is the Most Probable Value (MPV) of the Landau part of the spectrum from a fit with a Landau function convoluted with a Gaussian. This procedure is not in accordance with various other groups and ignores the definition of the signal expectation as defined in Ref. [1],which uses the average value of the signal. Nevertheless our results are consistent with the

sCVD data from our measurements using a ^{90}Sr source in our laboratory. We would not recommend to use the average value due to possible fluctuations in the Landau tail of the spectrum.

2.1 The experimental set-up

To measure experimentally with high accuracy the $Q_{expected,\ diamond}$ we used the EUDET infrastructure at DESY which offers a high energy electron beam of known energy and with single particle trigger. We develop a new standard procedure based on the expected MPV of the signal in diamond detectors. This measurement has the potential of leading to a future reference also for other groups. We used a non-irradiated sample of sCVD material produced by GSI (So14-10). The sample is about 320 μm thick and the sensitive area is defined by a circular metallization of 3 mm diameter. We assume 100% charge collection efficiency, which is known to be true for sCVD diamond on the 1% level, as confirmed by various experiments.

2.2 Calibration of the experimental set-up

We performed a calibration of the read-out chain using an ^{241}Am radioactive photon source, the sCVD diamond, and a silicon sensor. A direct energy to ADC channel conversion was obtained. An independent calibration has also been performed using a charge injection capacitor.

2.3 Correction factor for high beam energy

The energy of the particle beam at DESY is in the range of a few GeV. We need to calculate a correction factor for this beam energy, which is significantly higher than for a MIP energy. A GEANT4 simulation has been set up for that purpose.

3 Data analysis

We used the EUDET test beam telescope in order to define a fiducial area in the centre of the DUT to avoid any edge effects. The data has been reconstructed using the tracking software tool EUTelescope described in Ref. [3]. The analysis comprises several steps, each step being implemented into a separate Marlin processor. Firstly a conversion from the original RAW data format used by the DAQ software to the LCIO format was done. In the next step of the analysis procedure clusters were searched for and cuts were applied on the signal-to-noise ratios of seed pixels and clusters. After the cluster centers were evaluated, the hit positions in the global telescope frame of reference were calculated. The obtained hits were then fitted with a straight line and the particle track was reconstructed. Before tracks were reconstructed, the telescope sensors were aligned as described in Ref. [3]. The x and y coordinates of the electron impact positions on the DUT surface are shown in figure 1 for events containing only one reconstructed track. Blue points in this figure represent an ADC response of more than 1200 channels and black points are for less than 1200 ADC channels. The correlation between the ADC data and the telescope data allows to define the fiducial area as it is indicated by the white circle. The circle represents the edge of our detector. Selecting only events inside the circle we obtained the CCD spectrum represented in figure 2. Superimposed is a fit with a Gaussian distribution for the pedestals and a Landau distribution convoluted with a Gaussian for the signal part of the spectrum. In the near future we will proceed to analyse such spectra and extract the mean number of charge carriers created by a MIP.

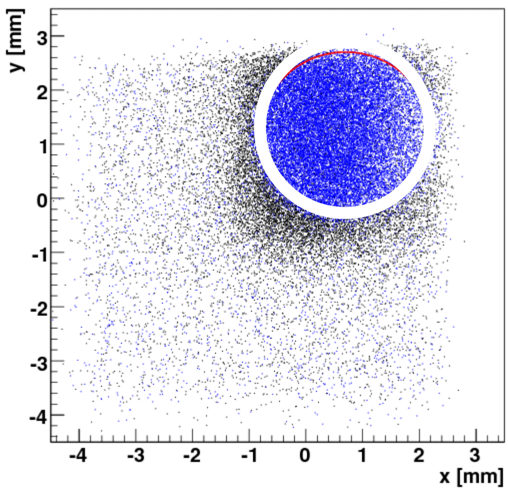

Figure 1: Coordinates of the impact point of the electrons on the DUT surface.

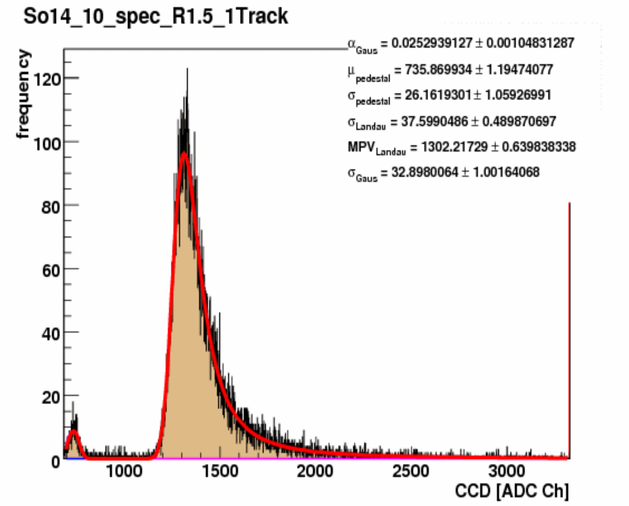

Figure 2: Signal spectrum in a sCVD diamond sensor.

4 Conclusion

We have collected data at the DESY test beam facility at different beam energies using the test beam telescope. We have started to analyse our data, however further work is needed in order to extract the mean number of expected charge carriers produced by a MIP in sCVD diamond.

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