In Beam CVD-Diamond Detectors for Heavy Ions

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1. Introduction

Diamond is a wide band-gap semiconductor [1]. Radiation hardness and fast signal collection are special features of this material. This makes it ideal for in beam detectors. We produced small test detectors of 10 x 10 mm^2 from different substrate material qualities (20, 50, 100 μm from IAF Fraunhofer Institute Freiburg and thicknesses 100 μm non polished and 500 μm from element-six CERN Standard) with Al-strips of 4×2 mm in x and y each. The aim of the measurement was to test the radiaton hardness and to appraise the charge collection and the efficiency of such devices.

2. Setup

The experiment was performed using an ^{16}O beam of E_{kin} = 117 MeV from the Tandem accelerator Munich. A Si diode was mounted behind each detector. The beam is passing the detector and is stopped in the diode which provides a trigger signal and a residual energy measurement.

3. Measurements

First the dependence of leakage current on the applied voltage was measured. The current is constant up to 5 V/μm at 5 nA/cm^2 and increased by a factor of 10 between 5 - 7 V/μm. We operated the detector at 3 V/μm.

3.1 Detector Efficiency

The detector efficiency was determined for a 50 μm thick diamond detector. Fig. 1 shows the total energy measured in the frontstrips of the diamond detector compared to the residual energy from the diode, which also provided the trigger. Using an energy threshold of $E > 0.2 \cdot \langle E_{Dia} \rangle$ we still see a signal for about 98 % of all the particles.

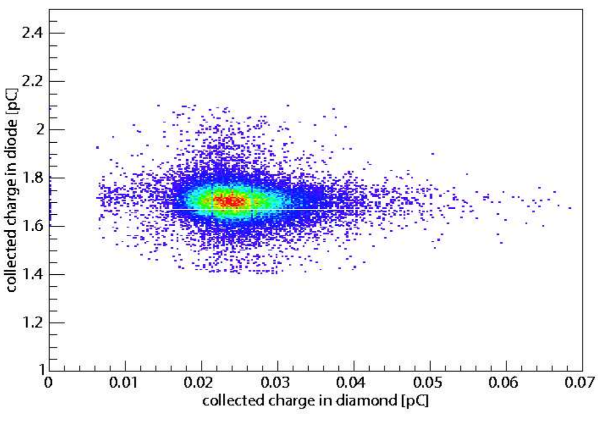

Fig. 1: Total energy of the front side of the diamond detector versus the residual energy measured in the diode.

3.2 Variation of Thickness

From the energy width in the diode stop detector the variation of thickness of the diamond substrate can be determined. From ATIMA calculations a typical energy straggling of about $\frac{\sigma E}{E} = 1.07\,\%$ is expected, while a energy width of 4.93 % was observed. This corresponds to a variation of thickness of ± 0.4 mg/cm^2 which transforms to a variation of about $\pm 1\,\mu$m for a 17.5 mg/cm^2 (50 μm) diamond material, what is still within the specifations.

3.3 Charge Collection

In fig. 1 the typically wide energy distribution measured with CVD-diamond is already clearly visible. The material is polycristalline and the charge carriers recombine at the grain boundaries of the diamond. On average the electron hole pairs generated only drift a fraction of the detector thickness in the electric field within their lifetime. This is called charge collection efficiency. Due to inhomogeneity of the material charge collection is spread. The measured spread of the backside of the diamond is about $\sigma = 18\,\%$. The charge collection of about 24.6 MeV equivalent 25 fC of the diamond corresponds to a charge collection depth of 15 μm. For heavy ions this is a sufficient value.

3.4 Radiation Hardness

The radiation hardness of a 100 μm substrate was tested without trigger diode using ^{16}O which corresponds to the energy loss of ^{36}Kr at 1 AGeV. Assuming a triangular beam intensity profile of 2×3 mm^2 the test went up to a maximum dose of 10^{11} ^{16}O/mm^2 (see fig. 2). This verified the estimates and shows that diamond can be used as tracking detector for high intensity beams.

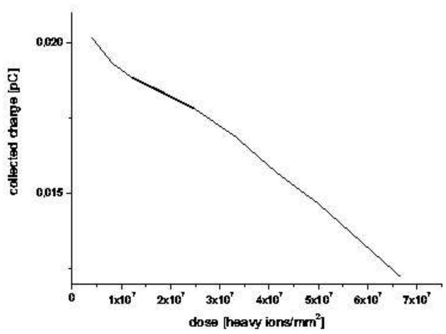

Fig. 2: The collected charge vs. the summed up radiation dose up to 10^{11} heavy ions.

4. Conclusion & Outlook

For the new Fraunhofer material charge collection and efficiency are even better than expected. Even the very thin diamond of 20 μm could be used but is very fragile. A 50 μm shows sufficient charge collection. Due to handling for the large areas, the most promising is 100 μm thick. In the next steps the absolut numbers for charge collection have to be remeasured for different detectors. Macroscopic and microscopic fluctuations of signal size and charge collection will be measured by using smaller reference diodes and the Munich microbeam. For higher segmentation of the diamond detectors lithographic methodes are currently under development.

References

[1] C. Nebel, Semicond. Sci. Technol. 18 No 3 (March 2003) S1-S11, PII: S0268-1242(03)58317-1