Measurements and simulations of diamond detector response to radioactive sources.

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DIAPIX is an experiment addressing key issues related to diamond detectors [1] and it is supported by INFN Technology and Interdisciplinary National Scientific Committee. Our group has the spokesperson-ship of the experiment which involves several INFN groups from: Catania, Firenze, Laboratori Nazionali del Sud, Lecce, Milano Bicocca, Pavia, Perugia, Roma 3.

It is organized in five working packages: ultra-radiation hard pixel diamond; pixel diamond for radiotherapy; pixel diamond with integrated first stage amplification; electric contact on diamond sensor by laser techniques, and fast timing with diamond detectors. Our group has responsibility of the 4-th working package and are involved in the 1-st, 4-th, and 5-th working packages.

We acquired from Diamond Detectors Ltd several detector-grade diamond sensors in order to understand and simulate in great details the response to radioactive sources with and without an external magnetic field. In fact, we realized several detector configurations:

Detector-I : 5x5 mm2, 0.3 mm thick, poly-crystal sensor metallized on both sides with a large pad.

Detector-II : 10x10 mm2, 0.5 mm thick, poly-crystal sensor metallized on the front-side with four 1.5 mm pitch strips and on the back-side with a large pad.

Detector-III : 4.7x4.7 mm2, 0.5 mm thick, mono-crystal sensor metallized on the front-side with two 1.5 mm pitch strips and on the back-side with a large pad.

Detector-IV : Three 8x8 mm2, 0.5 mm thick, poly-crystal sensor metallized on the front-side with 32 by 128 pixel cells and on the back-side with a large pad.

Detectors I,II, and III were readout by a traditional Ortec 142 A charge sensitive preamplifier and the signal output passed to an Ortec 570 shaping amplifier followed by a multichannel analyzer for the pulse height spectra acquisition.

The three pixel detector IV were sent to IZM Berlin for the pixel matrix and back-plane metallization and for the bump-bonding to superPIX0 readout chip [2]. In order to employ the superPIX0 chip we signed an agreement with the SuperB Collaboration which is extremely interested to evaluate the pixel diamond detector with such a small readout pitch.

We used detector I to measure the response of poly-crystal diamond to α, β, and γ radiation. We used all three type of radiation because they give complementary information. The α radiation stops 12 μm after crossing the diamond surface. The β radiation crosses all diamond bulk and can mimic the energy release of a minimum ionizing particle. Finally, the γ radiation creates mostly short-path low-energy Compton electrons uniformly along the diamond bulk depth.

We simulated the charge distribution released in diamond by the above mentioned radioactive sources using the simulation software Geant4. In order to compare with the measured spectra we evaluate the elementary induced charge q_{ind} by the elementary released charge q_{rel} using the Hecht's equation:

$$q_{ind} = q_{rel}\frac{l_i}{d}(1 - e^{-\frac{d}{l_i}}), \quad (1)$$

where d is the detector thickness, l_i is the mean free path of the free carrier of type i due to trapping or recombination phenomena. The mean free path is related to the free carrier lifetime $\tau_{e,h}$ by the formula $l_{e,h} = v_{e,h}\tau_{e,h}$, where $v_{e,h}$ is the drift velocity.

The β spectra of a detector-grade poly-crystal diamond is very well simulated by a Landau-Vavilov function convoluted with a Gaussian function which takes into account the bound energy of the atomic electrons and the electronic noise. The agreement is possible assuming an average collected charge given by $q_{ind} =$

$q_{rel}\frac{CCD}{d}(1 - e^{-\frac{d}{CCD}})$ where CCD=180μm. The parameter CCD is called Charge Collection Distance and is about 350μm for the best poly-crystal diamond. In fact, trapping and recombination centers, due to impurity and lattice imperfection, reduce the free carriers lifetime.

We used Geant4 to simulate the charge losses in air of the α particles. This, together with the introduction of the CCD for the two types of carriers, to limit the charge collection efficiency, seems not enough to reproduce correctly the shape of the measured α spectra. The exponential and flat parts of the spectra (see Figure 1) can be reproduced by assuming large inefficiency localized between the poly-crystal grain boundaries. The crystal grains alter significantly the α spectra shape because the released charge is strongly localized and make poly-crystal diamond not suited for spectroscopic applications.

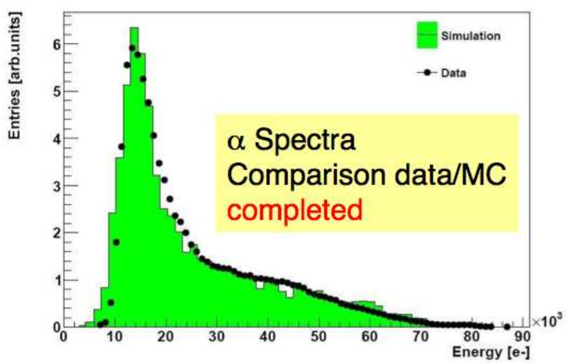

Figure 1. Comparison between measurements and simulations of the response of a detector-grade poly-crystal diamond to a α source.

We used detector II to study charge-sharing phenomena between adjacent strip in a poly-crystal detector with and without magnetic field. We performed these measurements at CERN (Geneva) where we have available a room temperature dipole magnet with big aperture assigned to us by the Normal Conducting Magnet division. The magnet can generate a magnetic field up to about 1.8 Tesla in a relative large aperture. We placed our detector, the first stage of the electronics, and the α source inside the magnet. The α particle bending in magnetic field between the collimator aperture end and the detector is simulated by Geant4.

In order to simulate the charge-sharing is necessary to evaluate in details the carriers movements, the induced signal in complex electrodes configuration, trapping-recombination, and diffusion phenomena. We implemented several MATLAB scripts to solve each problem in a modular way. In particular, we solved the Poisson equation to evaluate the drift field and the weighting field by means of the MATLAB Partial Differential Equation solver.

To measure charge-sharing we placed the collimated source on the detector back-side below two adjacent strips (named 2 and 3) and measured the pair of induced pulse heights (Q_2 and Q_3). Charge-sharing is defined by events with both collected charges above a threshold of about 10,000 electrons. For poly-crystal diamond the spectra of charge-sharing events is clearly lower than single strip charge spectra due to incomplete collection of the charge below the two strips. For the same reason the charge-sharing fraction is also relatively high. In these conditions the relation between the beam spot position and the charge-sharing asymmetry, defined by A=$\frac{Q_2-Q_3}{Q_2+Q_3}$, is expected to be highly nonlinear. The extraction of the Lorentz angle in magnetic field is possible only if the simulations are very reliable.

To verify the correctness of the method and of the simulation, we repeated the same measurements with mono-crystal detector with two readout strips with spatial separation similar to poly-crystal detector. A detector-grade mono-crystal diamond can collect all generated charge and the charge-sharing measurements should be easier to interpret making sure that the systematic errors are under control. In Figure 2 the charge-sharing asymmetry is plotted for the case of mono-crystal diamond strip detector and without magnetic field. It is possible to see how the charge-sharing part is relatively flat, as expected for uniform irradiation between the two strips.

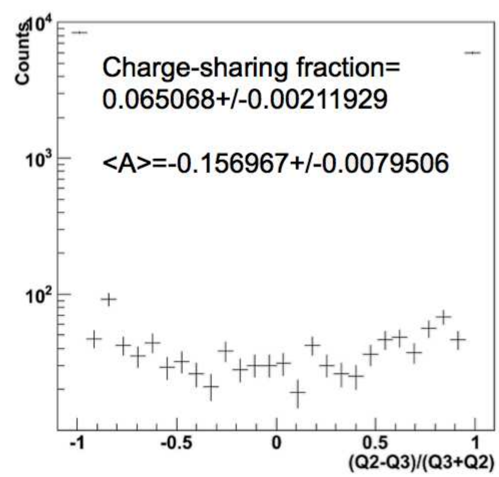

Figure 2. Distribution of the collected charge asymmetry between two adjacent readout strips in mono-crystal diamond irradiated with a α source from the back-side and without magnetic field.

REFERENCES

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