Development of diamond particle detectors

E. Alemanno [1 2] A. Caricato [1 2] G. Chiodini [1] G. Fiore [1] M. Martino [1 2] R. Perrino [1] S. Spagnolo [1 2]

[1]Istituto Nazionale di Fisica Nucleare, Sezione di Lecce, Italy

[2]Dipartimento di Fisica, Università del Salento, Italy

The recent reached high quality, the confirmed radiation hardness and the wafer size availability of synthetic polycrystalline diamond, produced by Chemical Vapor Deposition (CVD), make this material an attractive choice as ionizing particle sensor for extremely demanding applications, such as ultra radiation tolerant vertex detector for the next generation of collider experiments. Further applications, for such challenging detectors, are envisioned in several fields, ranging from high energy physics to radiotherapy and nuclear fusion reactors.

There are still some technological steps in order to fulfill the requirements for the above applications. The most crucial ones are the development of low noise pixel front-end electronics for diamond sensors and the realization of reliable and radiation-hard ohmic contacts on diamond.

The experiment DIAPIX is addressing these issues, with the support of the INFN Technology and Interdisciplinary National Scientific Committee. The collaboration is made of several INFN groups from: Firenze, Laboratori Nazionali del Sud, Lecce, Milano Bicocca, Pavia, Perugia, Roma 3, and organized in four 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. The Lecce group has the spokesperson-ship of the experiment and is involved in the 1-st and 4-th working package. In addition, it is responsible of the 4-th working package.

We acquired from Diamond Detectors Ltd three detector-grade polycrystalline diamond sensors with a surface of 5x5 mm^2, 0.3 mm thick, and ultra-polished on both sides. One of the three sensors was metalized on both faces with Diamond Detectors Ltd proprietary contact technology, glued on a ceramic electric circuit with two SMA connectors, and packaged in an anodized aluminum small box. We used such a real diamond pad detector to acquire experience in a relative short time and to establish: experimental set-up and techniques; a series of characterization measurements and the detector working point.

Figure 1 shows the measured diamond detector pulse height spectra induced by collimated

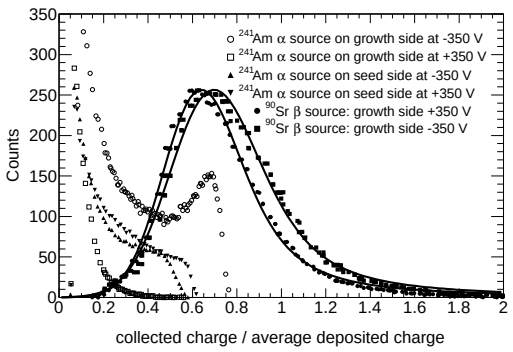

Figure 1. Normalized charge spectra for α and β sources for positive and negative high voltage. The α irradiation is done on both growth and seed sides. The β spectra are shown with a fit superimposed obtained from a Landau convoluted with a Gaussian curve. The measurements were made after 2 days of exposure to uncollimated ^{90}Sr β source with an activity of 37 MBq (pumping).

α and β sources in air. The high voltage bias was applied at the irradiated contact via an 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 electronic chain was calibrated in terms of collected electrons using a reference pulser and the average energy needed to create an electron hole pair in diamond (13.2 eV in diamond, compared to 3.6 eV in Silicon).

The end-point energy (2.283 MeV) of the β particles from ^{90}Sr source allowed us to trigger with an external Silicon diode and select events in the high energy tail. These events create about 36 e-h/μm almost uniformly along the detector thickness, simulating a minimum ionizing particle, and the free charge carriers are collected in opposite electrodes, according to charge and bias sign.

The energy (5.48 MeV) of the α particles from ^{241}Am source corresponds to a range of about 15 μm in diamond. The α particles stop just at the entrance and the induced current is only due to the free charge carrier collected at the opposite electrodes. In this way it is possible to study elec-

trons and holes transport properties separately, but the spectra are acquired in self-trigger mode, because a simple external trigger is not feasible.

The β spectra show a 10% asymmetry when the bias polarity is reversed, thus indicating a space charge formation inside the sensor due to polarization phenomena. The effect is even more dramatic with the α spectra. In fact, a suppression of the hole signal (positive bias applied to the side where the source is located) is observed when the irradiation happens from the growth side. Conversely, the electron signal is strongly amplified (negative bias applied to the side where the source is located). When the irradiation is on the seed side, both electrons and holes can be collected but an asymmetry is still evident.

Bulk polarization phenomena are expected for intrinsic and strongly irradiated semiconductor detectors, because trapping and recombination centers are not filled or neutralized. In our case, the measurements show instead surface polarization, typically due to bad ohmic contact, in this case on the growth side.

The electrical contact on intrinsic semiconductor material (such as Diamond, CZT, and CdTe) is a critical technological step. Due to the large band-gap of these materials with respect to any metal, the contacts prevent fast removal of the free charge created by the nuclear radiation. The L^3 laboratory at the Università del Salento is facing this problem with a novel idea: graphitization of the diamond surface with a gas excimer laser and creation of nano-graphite layer of about hundred nanometers.

A test device was prepared by front and back irradiation of the diamond surfaces with a 248 nm UV ArF excimer laser (Lambda Physik LPX305i). The laser emitted 20 nsec long pulse with an energy of about 160 mJ/pulse at 10 Hz repetition rate. The laser beam with a transverse size of about 20×10 mm^2 , was directed onto a chrome-on-quartz mask. The mask pattern was then directly projected via a thin and plain convex lens onto the sample placed on a manual x-y-z stage. The focused image was a square of 3 mm^2 and the local laser fluence of about 5 J/cm^2 at the sample surface was constant within the radiation spot. The device was treated in air using up to 500 laser pulses on both sides (Figure 2).

The measured resistance of a 3 mm^2 graphite pad was about 100 Ω. The resistivity was also estimated by evaluating the depth of the contact from the known laser fluence, according to Ref. [2]. It resulted in about $8\text{-}9\cdot10^{-6}\Omega\cdot$m, in agreements with literature graphite resistivity values.

The voltage-current curves were measured to assess the nature of the obtained contact. Figure 3 illustrates that the ohmic nature of the contact ranges approximately from 200 V to 400 V when

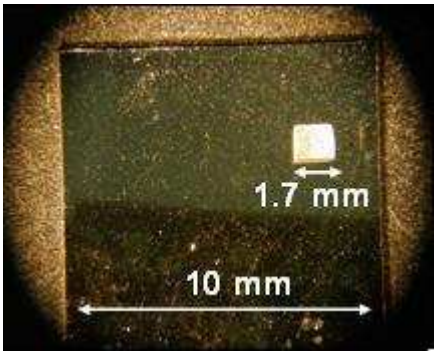

Figure 2. Optical microscope picture of a square graphite spot induced by excimer laser on thermal grade diamond at L^3 laboratory of Salento Physics Department.

a nano-graphite layer is created between the diamond and the silver paint used to apply the high voltage.

These preliminary results were very important to establish crucial properties of reliable electric contacts: mechanical adhesion, good charge injection properties and mechanical stability.

This promising technique must be further consolidated by showing that the nano-graphite layer is also polarization free. Work is in progress in order to realize such electric contacts on detector grade diamond and characterize them in terms of electric and nuclear radiation detection properties.

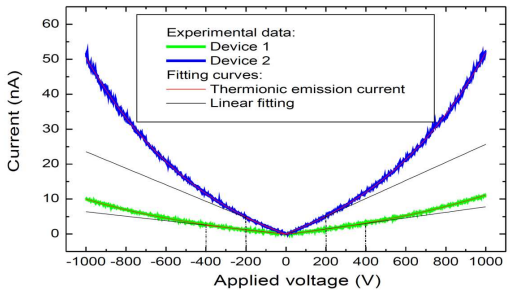

Figure 3. IV curve of thermal grade diamond with (Device 1) and without (Device 2) nano-graphite created by laser techniques.

REFERENCES

1. "Advanced Diamond Particle Detectors", E. Berdermann for the NoRHDia collaboration, Nuclear Physics New, Vol. 19, No. 2, 25-31 (2009).

2. “Thermal analysis for graphitization and ablation depths of diamond films”, Jen-Fin Lin, Jia-Wen Lin, Pal-Jen Wei, Diamond & Related Materials 15, 1-9 (2006).