Characterization of diamond detector with laser made graphitic electrodes.

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We studied a device based on detector grade polycrystalline CVD diamond plate with graphite electrical contacts fabricated on both faces of the diamond surfaces (called "Sandwich" configuration). The device was prepared by front and back irradiation of the diamond bulk by a 193 nm ArF excimer laser.

In literature, several techniques to produce graphitic layers on diamond surface were suggested and realized such as by ion implantation. The purpose of this work is to prove that electrodes made by laser graphitisation is an Ohmic electric contact and it is capable to detect nuclear radiation in counting mode. Usually, Ohmic contacts for diamond detectors are made by metal deposition on diamond surface and followed by thermal annealing, in such a way to create a carbide layer.

In this work we used ArF excimer laser light, because it has an emission wavelength of 193 nm, which is absorbed by diamond surface and a graphitised layer can be created. The absorbed laser energy is converted to lattice thermal energy making transition diamond to graphite energetically favourite. In the same time laser light power density and laser shoots are kept lower than diamond ablation thresholds. The authors showed that a graphitic layer was created, and not another allotropic carbon structure, making use of micro-Raman scattering spectroscopy. The graphitic layers have a strong mechanical resistance. In fact, we couldn't remove graphite pieces by any mechanical instrument, such as cutters or knives.

We performed electric resistance measurements on graphite electrodes by a common digital multimeter KDM-350 CFT. We collected 100 measurements, along the horizontal and vertical directions, and we obtained a mean value for all cases of about 40 Ω. Consequently, we can assume that the irradiated area was uniform. In order to evaluate the sheet resistance R_S and to give an estimate of the layer thicknesses, we applied the Van Der Pauw method given by the equation:

$$e^{-\pi R_{vertical}/R_S} + e^{-\pi R_{horizontal}/R_S} = 1. \quad (1)$$

Assuming the condition $R_{vertical} = R_{horizontal} = R = 40\Omega$, we can calculate the sheet resistance R_S:

$$R_S = \frac{\pi R}{ln2} = \frac{\rho}{t}, \quad (2)$$

where the third member of Eq. 2 is given by the definition of sheet resistance, i.e. t is the sheet thickness of the graphite pad and ρ is the graphite resistivity. We assume that ρ is in the range $8 \times 10^{-6} \div 15 \times 10^{-6}\Omega$·m as expected for a carbon nano film produced by thermal annealing and estimate a thickness t in the range 44 nm ÷ 83 nm. In literature, graphite depth of about 60 nm for laser fluence of about 3 J/cm^2 is reported. This is quite consistent with our finding although we employed a laser fluence of about 5 J/cm^2.

We biased the device by fixing the sample between two gold arms soldered to a coaxial SMA connector. A small anodized aluminum box was used as a Faraday shield to avoid any type of electrical noise during dark current-voltage (IV) measurements. We employed the instrument 6487 Keithley pico-ammeter/voltage source with voltages ranging from 0 to 400 V. The plot of Figure 1 shows the measured IV characteristic in log-log scale, where it is possible to see three different conduction mechanisms characterized by three different power law relations between current and voltage $I \propto V^k$.

For voltages up to about 90 V the relation between I and V is approximately linear with a measured power index k=1.13±0.02. This behavior can be explained assuming that the graphite/diamond interface behaves like a metal/semiconductor interface with an electrode work function smaller than the semiconductor work function. The diamond acts like a semiconductor with a band gap of about 5.47 eV and very high bulk electrical resistance. From the theory of Schottky contacts this gives a barrier free electrode interface and we obtain an Ohmic contact. In this case electrons are injected from the external circuit by one electrode and collected by the other one. For small applied filed, a space charge region extends only for a limited distance

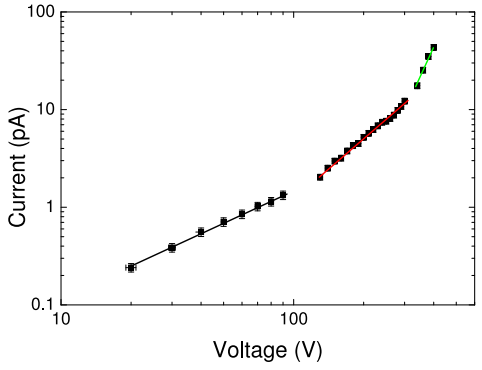

Figure 1. Current-voltage characteristic of the graphitised device in log-log scale. The superimposed fits correspond to power law curves $I \propto V^k$.

inside the insulator and the electrons move in the conduction band. In this case, the conduction process is ruled by the diamond bulk resistivity ρ_d, that can be calculated by the Ohm's law $V = I\frac{\rho_d L}{S}$, where L and S are the diamond sample thickness and the electrode surface, respectively. In this regime, we found a resistivity $\rho_d \propto 10^{14}\Omega \cdot$ cm.

However, increasing further the electric field, the two space charge regions start to overlap each other extending through all the insulator and the conduction process becomes Space Charge Limited (SCL). This happens for high voltages from 120 V to 300 V, where the relation between I and V is quadratic with a measured power index k=2.00±0.03, as predicted by Mott and Gurney for a trap-free insulator.

For higher voltages from 300 V to 400 V the dependence of I with respect to V is very rapid, with a measured power index k=5.60±0.36. Rose has derived a Trap Filled SCL conduction mechanism described by the following relation:

$$\propto V^{(T_e/T+1)}, \tag{3}$$

where T is the bulk temperature and T_e is a characteristic temperature describing the exponential distribution of defected states localized near the valence and conduction band. We performed the measures at room temperature and from the value of power index k we evaluated a T_e of about 1686 K. In fact, the polycrystalline structure of the diamond can't be neglected because the grain boundaries or defects inside the grains, destroy the long-range order of the lattice. We measured the IV curve both for positive and negative voltage values and we didn't observed any hysteresis cycle. This can be interpreted as an absence of permanent or intrinsic polarization effects.

We measured the detector response for a 120 GeV proton beam produced at the Fermilab Test Beam Facility (FTBF), which corresponds to a minimum ionizing particle and is expected to release about 36 e-h pairs/μm. The signals were amplified by a fast 100 MHz bandwidth charge sensitive preamplifier having a gain of 8mV/fC, a rise time of about 3 ns and a fall time of about 8 ns. In order to match the oscilloscope sensitivity, a 1.5 GHz bandwidth voltage amplifier, having a gain of a factor 100, was used. The charge distribution of the 120 GeV protons is shown in Figure 2. The peak in the spectra correspond to a charge of about 5,400 electrons and is just an artifact of the oscilloscope threshold used to trigger the signal and reduce the noise contributions. However, we can conclude that our device is capable to work as radiation detector in counting mode. Anyway, we cannot exclude that a sizable amount of charge collection inefficiency is present due to traps in diamond bulk.

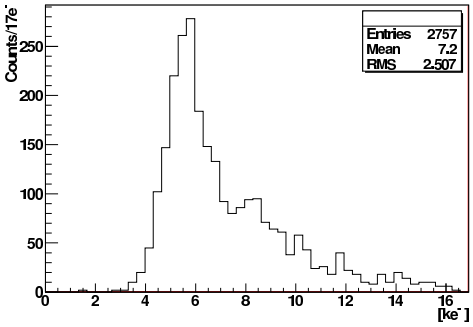

Figure 2. Charge distribution from a 120 GeV proton beam measured by diamond detector with laser-graphitised electrodes. The data correspond to an applied high voltage of 300 V.

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