Fabrication and Characterization of Diamond Radiation Detector as an Alternative to Silicon Detectors

Manoj Jadhav* and Shyam Kumar, K. Das Gupta, D. S. Misra, P. Sarin, R. Varma
Department of Physics, Indian Institute of Technology Bombay, Mumbai - 400076, INDIA

Introduction

Diamond with its unique properties is expected to replace the place that silicon occupies in radiation detection today. This is primarily driven by the need to prevent frequent replacement of the inner tracking system of almost all major collaborations at LHC after its upgrade. For after LS-1 (Long Shutdown) LHC will deliver an instantaneous luminosity of $10^{34} cm^{-2} s^{-1}$ while in LS-2, the luminosity will be nearly doubled. Moreover, any future competitive international accelerator facility will have to match LHC in terms of luminosity, which renders diamond as future detector material for sensors placed close to the interaction point. It is with this aim that we have taken up the development of diamond detectors at IIT Bombay. This development is also in tune with our future contribution to the PANDA collaboration where we expect the sub nano second timing of diamond sensors to improve the Particle Identification capabilities of the PANDA detector.

Diamond Detector

With a high band gap of $E_g = 5.5$ eV, diamond gives negligible intrinsic carrier densities even at room temperature, allowing to operate diamond as a detector. As there is no pn-junction, the polarity of the electric field is irrelevant. The dark current of the diamond samples, including both bulk and surface currents, is less than 1 nA.cm^{-2} at an electric field of 1 V.μm^{-1}[2]. Due to the high carrier mobilities in diamond, the charge collection is very fast, taking about few picosec in detectors of approximately 300 μm thickness.

*Electronic address: manoj.jadhav10@iitb.ac.in

Fabrication of Detector

Detector is prepared from 300 μm thick single crystal CVD diamond samples with an area of 3.5 mm $\times$ 3.5 mm.

A. Diamond Preparation

Before contacts were deposited, the diamond surface was cleaned. Firstly to remove graphite and grease residue from thinning. The diamond was cleaned using a saturated solution of chromic acid, rinsed with deionized water, cleaned in dilute solutions of ammonium hydroxide and hydrochloric acid and finally rinsed in deionized water. Then to remove any traces of chemicals, fingerprints, etc., diamond was cleaned in ammonium hydroxide; rinsed with deionized water, acetone, methanol, and deionized water; and then placed in an oxygen plasma etcher for final surface preparation[3].

B. Metallization

A metallic thermal evaporation technique was used to coat both sides of the diamond with successive metals: Cr (300 Å) and Au (2000 Å) [4]. Chromium was used since it easily forms carbide structure which provides ohmic contacts, Au was used to prevent oxidation of the Cr layer and for ease of wire bonding. The evaporations were performed successively, first Cr coated tungsten wire and then the gold from an alumina coated tungsten evaporating source boat. Then sample was annealed at 580°C in an N_2 environment to allow the chromium to form a carbide with the diamond.
For preliminary tests, the sensor was connected to outside electronics using copper wire bonded by silver epoxy on gold. The chip was mounted on a modified IC-base. Fig.1 shows Sensor with Cr/Au contacts and copper bonding using epoxy mounted on IC mounter.

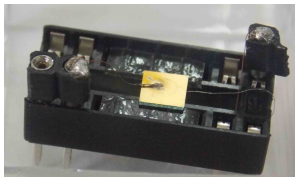
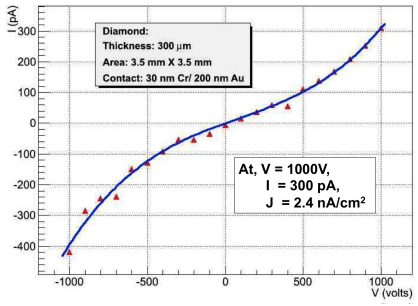


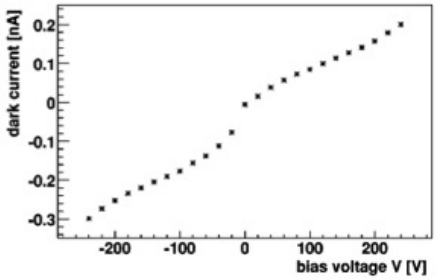
FIG. 1: Diamond Sensor with Cr-Au coating.

1. Characterization

Generally, the metal in contact with the diamond determines the electrical properties of the contact. To supply voltage, Keithley 2410 source meter was used which also measured the current through device. I-V characteristics voltage range selected from -1000 V to +1000 V. A current-voltage curve from contacts is shown in Fig.2(a) indicating high resistivity and low leakage current which is comparable with a data of a commercial detector sample from element6 UK shown in Fig.2(b).



(a)3.5 mm x 3.5 mm = 12.25 mm^2, 300μm IIT Bombay



(b)4 x 4 mm^2, 470μm Element6, UK

FIG. 2: I-V characteristic indicates dark current.

For capacitance study Keithley 4200 SMU setup was used. Capacitance of the device obtained with the above measurement is 2.2 pF at 0 V (shown in Fig.3) which is also in good agreement with Element6 data which is having capacitance of 3 pF for 470 μm device[5]. Considering a 70-80 Volts of operating voltage, the detector should show timing of few pico sec.

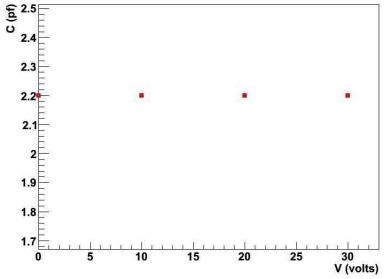


FIG. 3: C-V characteristics

Future Plans

1. Characterize the detector developed by studying the charge collection distance and charge collection efficiency with a radiation source as well as with cosmics.
2. To test this detector with minimum ionizing particles to test the improvement in particle identification capabilities by TOF if silicon is replaced with diamond. Simulations have already been performed and will be presented.
3. Develop a strip detector with silicon & diamond to be installed in PANDA collaboration after suitable test beam runs.

Acknowledgments

We are thankful to CEN lab facility at IIT Bombay. Also we are thankful to the PANDA collaboration.

References

[1] Technical design Report PANDA, 2009.
[2] W. Adam et al. (RD42 Collaboration), CERN/LHCC 98-20, 1998.
[3] NIMPR A 354 (1995) 318-327
[4] S. Zhao, PhD. Thesis, The Ohio State University (1994).
[5] Pernegger et al, J. Appl. Phys. 97, 073704 (2005)