Fabrication and characterization of a single crystal diamond detector with alpha particles and fast neutrons

Amit Kumar[1,2], Pradeep Sarin[3] and Anita Topkar[1,2,*]
[1] Bhabha Atomic Research Centre, Trombay, Mumbai-400085
[2]Homi Bhabha National Institute, Anushaktinagar, Mumbai-400094
[3] Indian Institute of Technology Mumbai- 400076
*anita@barc.gov.in

Introduction

Diamond detectors have specially attracted interest for on line fast neutron monitoring in future fusion facilities such as ITER due to their potential to operate in high temperature, high radiation environment. These detectors can directly measure fast neutrons through n-C interactions without any converter materials [1-2]. We have initiated the development of single crystal diamond (SCD) detectors for the neutron diagnostics in the Indian TBM module at the upcoming ITER Experiment. The details of fabrication and characterization of this detector are presented in the subsequent sections of this paper.

Experimental

The fabrication of the SCD detector was carried out using a 5mm x 5mm x 400 µm single crystal diamond substrate which was subjected to pre-metallization treatments for obtaining an oxygen terminated surface. Al metallization was done on both sides of substrate by thermal evaporation. The detector was mounted in a transistor outline (TO) header using conductive silver epoxy to provide a back contact. The front contact to the top metallization was provided using wire bonding of the gold wire to the header pin. The measurement of current vs voltage (I-V) was performed using a picoammeter with in-built high voltage source. Subsequently, the performance of fabricated detector to charged particles was studied using $^{238+239}$Pu dual energy alpha source by mounting the detector and the source in a vacuum chamber. The detector signal pulse was measured using electronics comprising of a charge sensitive pre-amplifer (CSP) with gain of 44 mV/MeV, a shaping amplifier (SA) with a gain of 50 and a 4k channel MCA. Further transient current measurement of the detector was carried out with alpha particles to study the charge transport in the bulk of the diamond. For this study, a fast broadband amplifier with a gain of 53 dB and bandwidth of 2 GHz was used. The fast neutron response of the detector was investigated using a 14 MeV deuterium- tritium (D-T) source with neutron yield rate of 2.5 x 10^9 n/s. The detector was placed at a distance of 10 cm from the D-T source.

Results and Discussion

The I-V characteristics of the fabricated detector is shown in Fig. 1. The detector current was observed to be quite low with current of about 230 pA at + 400 V. No breakdown was observed up to the voltage of 400 V which correspond to the electric field of 1 V/µm. For negative bias voltages, the current was of similar magnitude. However, the detector showed break down above -365 V. As can be seen from Fig. 1, the IV curve within ±350 V is nearly symmetric around zero voltage indicating an ohmic type of behaviour of the metal insulator junction.

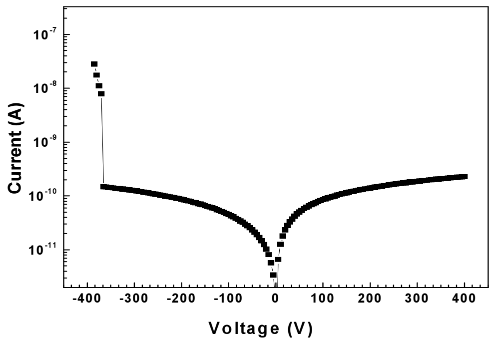

Fig. 1 The leakage current variation of the detector with applied voltage.

When the detector was tested with alpha particles by observing the shaping amplifier pulse amplitude on a CRO, it was observed that the full charge collection occurs at 100 V. Hence pulse height measurements with alpha particles were carried out at a bias voltage of

100 V. The channel number to energy calibration was performed using the two known alpha energy peaks corresponding to 5.156 MeV (^{238}Pu) and 5.499 MeV (^{238}Pu). The pulse height spectrum obtained with the detector shows that the two peaks corresponding to the two energies of alpha particles i.e. 5.499 MeV and 5.156 MeV are well resolved (Fig. 2). From the alpha peak at 5.499 MeV, an energy resolution of 1.9 % is estimated.

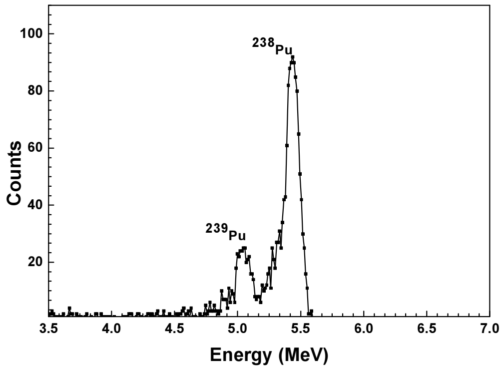

Fig. 2 Alpha spectrum of detector obtained using dual alpha source of ^{238}Pu(5.156 MeV) and ^{239}Pu (5.499 MeV).

The charge transport in the detector was studied using transient current technique (TCT). The typical current pulse observed on a CRO due to a ^{241}Am alpha particle at bias voltage of ± 250 V is shown in Fig. 3. The signal amplitude due to holes (~50 nA) was observed to be more by 10 % than that observed for the electrons (~45 nA). The FWHM of hole signal (1.6 ns) was less than that of electrons (1.9 ns). From the TCT measurements, the mobilities of about 2100 cm^2/V-sec were estimated for the electrons and holes.

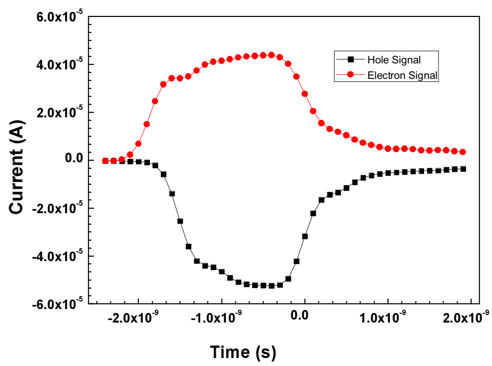

Fig. 3 Transient current response of diamond detector for electrons and holes due to an alpha particle.

The fast neutron response of the detector was measured using the D-T source with neutron flux at the detector position of 2 x 10^6 n/cm^2/sec. The neutron pulse height spectrum shows several peaks corresponding to the various possible nuclear reaction between carbon and neutrons i.e. ^{12}C(n, γ)^{13}C, ^{12}C(n, α)^{9}Be, ^{12}C(n, p)^{12}B, ^{12}C(n, d)^{11}B [1]. The most important peak for fast neutron spectroscopy is the peak at 8.5 MeV due to ^{12}C(n, α)^{9}Be nuclear reaction which is sharp and well separated from other peaks. The observed energy resolution is 4 % at the peak at 8.5 MeV energy. The sensitivity of the detector was calculated to be around 4.8 x 10^{-2} counts per neutron.

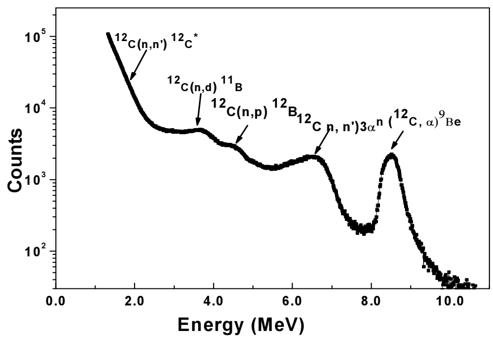

Fig. 4 Pulse height spectrum with diamond detector for fast neutrons showing various peaks for possible nuclear reactions between neutron and carbon.

Conclusions

We have developed a SCD detector with energy resolution of 1.9 % for 5.5 MeV alpha particles. The detector showed expected fast neutron response with energy resolution of about 4 % and sensitivity of about 4.8 x 10^{-2} counts/neutron. Corresponding to the most important nuclear reaction of ^{12}C(n, α)^{9}Be, a well isolated peak at 8.5 MeV was observed. The results presented in this paper clearly indicate that SCD detectors are well suited for the spectroscopy of charged particles and fast neutrons.

References

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[2] M. Mikuz, *et al*, Nuclear Instrumentation Methods A 579, 788, 2007.