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Energy response of diamond sensor to beta radiation

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ABSTRACT

This paper demonstrates the ability of diamond sensors to respond to beta radiation. A Chemical Vapor Deposition (CVD) single crystal diamond was used in this work. The diamond crystal has a dimension of 4.5 × 4.5 by 0.5 mm thick. Metal contacts were fabricated on both sides of the diamond using titanium and palladium metals with thicknesses of 50 nm and 150 nm, respectively. The energy response of the diamond sensor was experimentally measured using three beta isotopes that cover the entire range of beta energy: ^{147}Pm, a weak beta radiation with a maximum energy of 0.225 MeV, ^{204}Tl, a medium energy beta radiation with a maximum energy of 0.763 MeV, and ^{90}Sr/^{90}Y, with both a medium energy beta radiation with a maximum energy of 0.546 MeV, and a high energy beta radiation with a maximum energy of 2.274 MeV. The beta measurements indicate that diamond sensors are sensitive to beta radiation and are suitable for beta spectroscopy. This is important in estimating dose since diamond is tissue equivalent, and the absorbed dose is easily determined from the energy and the mass of the active volume. The high energy betas from ^{204}Tl and ^{90}Sr/^{90}Y penetrates the sensor without depositing sufficient energy in the active area because their range is larger than the thickness of sensor. The sensitivity of the detector is limited because of its small volume and can be improved by combining smaller area sensors since growing large size diamond is currently a challenge.

1. Introduction

Improvements in the development of Chemical Vapor Deposition (CVD) single crystal diamond has led to the production of a low cost, high quality diamond crystals with moderate surface areas. This progress has encouraged wide use of diamond in radiation detection in recent years. Many properties make diamond a unique material for radiation detection applications. Diamond is radiations resistant (Bauer et al., 1995a; De Boer et al., 2007; Nazaré and Foster, 1994) which makes it attractive in high energy physics research, where materials that can withstand harsh radiation environments are required in order to provide reliable information. The high radiation fluxes required in high energy applications often restricts the use of semiconductor detectors such as silicon (Lindström et al., 1999; Bauer et al., 1995b; Friedl, 1999). Radiation damage results in a reduction in performance of the semiconductor detector leading to a reduction in pulse height spectrum due to the production of recombination or trapping centers. Diamond has a high band-gap of 5.47 eV which leads to negligible thermal generated leakage current. The low dielectric constant of diamond results in low capacitive load to the detector thereby producing low noise in the detection system. Diamond has a high breakdown electric field threshold which makes it suitable in a high voltage application. Its high carrier mobility and large carrier saturation velocity leads to fast signal collection, while its large thermal conductivity makes it suitable in high temperature applications where active detector cooling is required.

Diamond detectors have been used in alpha (Wodniak et al., 2011; Wang et al., 2005; Schirru et al., 2014), X-ray (Tartoni et al., 2009; Schmid et al., 2004; Tromson et al., 2000; Manfredotti et al., 1998; Girolami et al., 2012; Kozlov et al., 1977; Balducci et al., 2006; Iwakaji et al., 2008; Yin et al., 2004), extreme ultraviolet (UV) up to the near IR region (Balducci et al., 2005; Souw and Meilunas, 1997; BenMoussa et al., 2006; Pace et al., 2000; Hochedez et al., 2001), ion beam (Zamboni et al., 2013; Pomorski et al., 2005; Berdermann et al., 1998; Berdermann et al., 2000), neutron (Balducci et al., 2006; Angelone et al., 2011; Almaviva et al., 2009; Husson et al., 1997; Angelone et al., 2009; Kozlov et al., 1975; Krasilnikov et al., 1997; Adam et al., 2000; Rebai et al., 2012; Weiss et al., 2012; Marinelli et al., 2006), electron (Khrunov et al., 1990; Björk et al., 2000; Laub et al., 1999), photon (Hoban et al., 1994; Bergonzo and Jackman, 2004; Heydarian et al., 1997; Andreo et al., 2015; Fallon et al., 1990; Rustgi, 1995; Bucciolini et al., 2003) and proton (Meier et al., 1999; Onori et al., 2000; Pietraszko et al., 2010) detection. Diamond detectors are also attractive in radiation dosimetry (Hoban et al., 1994; Rustgi, 1995; Planskoy,

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1980) because they have a small size, high spatial resolution and are tissue equivalent (atomic number Z of diamond is 6 and is close to the effective Z of soft tissue, 7.4). Because diamond is tissue equivalent, there is no need to apply energy dependent signal corrections (Whitehead et al., 2001). Diamond is therefore better than silicon (Z = 14) which is currently used in most available commercial solid-state detectors in radiation dosimetry. The energy response of beta radiation is of interest in radiation dosimetry since dose is determined from the energy deposited per unit mass, and the response function is used to determine the total energy deposited in the detection medium. The dose to skin from beta radiation remains an important problem in radiation dosimetry (Charles, 1991). This property makes diamond very useful for beta spectroscopy.

In this paper, we demonstrate that diamond sensors are suitable for beta spectroscopy. The energy response of CVD diamond samples to beta radiation is demonstrated using beta sources that cover a range of beta energies. These sources include, ^{147}Pm, with a maximum beta energy of 0.225 MeV, ^{204}Tl with a maximum beta energy of 0.763 MeV and ^{90}Sr/^{90}Y with a maximum beta energy emission of 0.546 MeV and 2.274 MeV respectively.

2. Experimental method

The diamond used in this work is an electronic grade single crystal diamond with dimensions of 4.5 × 4.5 × 0.5 mm, obtained from Element Six (Cervix US). The preparation procedure involves cleaning the sample to remove surface contaminations such as dust and grease using the following steps: Aqua Regia (150 °C for 20 min), NH_3OH/H_2O (ratio of 1:1:5 at 150 °C for 20 min), Piranha (150 °C for 20 min), and $H_2SO_4/HNO_3/HClO_4$ (ratio of 1:1:5 at 150 °C for 20 min). Each step was followed by cleaning with deionized water prior to metallization. The metal contacts were made without implantation. The metallization procedure involves depositing thin films of Ti/Pd on both sides of the diamond crystal using a thermal evaporator. Titanium was deposited on the diamond surface by thermal sputtering so as to create a good adhesive contact to the diamond while palladium was evaporated over titanium. The thin metallization layers (Ti/Pd) had a diameter of 2 mm and a thickness of 50/150 nm. The diamond was mounted on a transistor head using silver paste. Both sides of diamond were wire bonded using a 25 μm diameter aluminum (1% silicon) wire as shown in Fig. 1. The detector was characterized using a Keithley model 6487 picoammeter by applying an electric field across the electrodes to determine an optimal voltage region for which the sensor is Ohmic. Since there is no need of a carrier free region generated by a junction, as in the case of the silicon detectors, the charge from the sensor is collected if the voltage bias is large enough to sweep the charge carriers before recombination occurs. The voltage was varied between −400 to 400 V in steps of 25 V. The results are shown in Fig. 2. The results show that the sensor is Ohmic in the voltage range between 100 to about 300 V. To test the diamond sensor with beta radiation, the sensor was mounted in a BNC feed through in a Canberra Alpha spectrometer model 7404 system (Fig. 3). The sensor was connected to a 142C preamplifier, a Canberra 2026 spectroscopy amplifier, an Ortec 459 bias supply and a Canberra multi-channel analyzer (MCA) with the associated Genie™ 2000 Spectroscopy Software for data acquisition. The bias voltage of 200 V was used in this measurement. The beta source was placed about 1–2 mm from the sensor to prevent the fragile aluminum wire from breaking. Measurements were conducted at standard atmospheric temperature and pressure. The measurement setup used in this work is shown in Fig. 4.

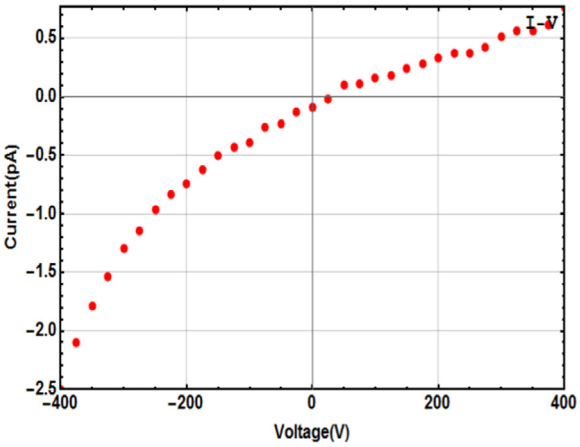

Fig. 2. Current voltage measurement.

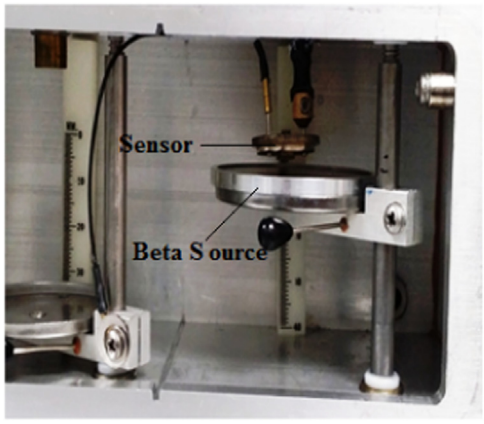

Fig. 3. Sensor in alpha spectrometer.

3. Response of diamond to beta radiation

Three sources were used to measure the response of diamond sensors to beta radiation in this work. The sources used included a low energy beta source,^{147}Pm with a maximum beta energy of 0.225 MeV, a medium energy beta source using ^{204}Tl which emits beta radiation with

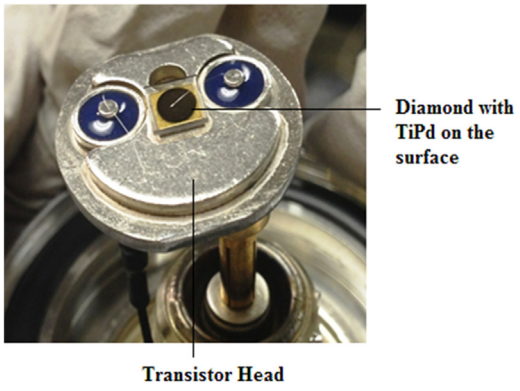

Fig. 1. Diamond sensor on transistor head.

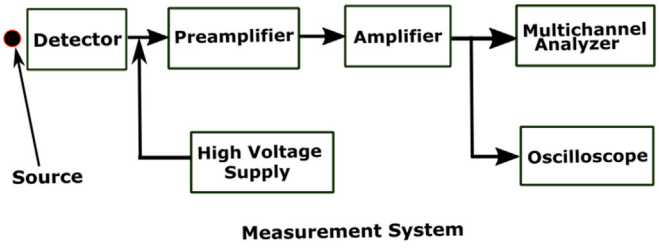

Fig. 4. Pulse height detector setup.