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Diamond detector for alpha-particle spectrometry

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HIGHLIGHTS

- Diamond detectors show pA leakage current due to its large band gap.
- Diamond detectors are comparable with continuous air monitoring system.
- Diamond detectors with standard contacts can be operated under ambient light.

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ABSTRACT

An artificially grown high purity diamond was used as a detector for alpha-particle spectrometry. Diamond detectors can match the performance of silicon detectors employed in standard continuous air monitoring systems. Its radiation hardness and electronic properties make them ideal to work under extreme condition such as high temperature and ambient lights. A 50 μm thickness single-crystal diamond detector has been compared with a 300 μm passivated implanted planar silicon detector, under ambient conditions.

1. Introduction

Pure carbon crystals are formed as diamond when the carbon atoms bond in a perfect tetrahedron (Emsley, 1998). In this way, diamonds can be used as solid-state detectors for Radiation Physics. Although diamond is an insulating material with a very large band gap (5.5 eV), it can be operated as a simple conduction detector by applying electrical contacts to opposite faces of the crystal (Berdermann, 2009). The principal drawback of this type of detectors is their high price and accessibility for medium or large size crystals. To surmount these difficulties, diamond crystals are made in the laboratory using modern techniques of deposition. The technique of chemical vapour deposition (CVD) has been being used to grow artificial diamond materials since the nineties (Werner and Locher, 1998). Conditions during the CVD process and preparation of the substrate can be used to control the nucleation process, and therefore the crystallographic orientation, creating poly- and single-crystal diamond films. Poly-crystal CVD (pcCVD) diamond detectors are not so good as spectroscopy detectors due to inhomogeneities induced by their growth as grains, which diminish the charge collection efficiency and increase the leakage current. On the other hand, single-crystal CVD (scCVD) diamond detectors have shown remarkable physical properties (Pomorski et al., 2005), among many virtues. Its high carrier mobility (about 2–3 times that of silicon) provides a fast response, yielding typical rise times even lower than 60 ps. This feature makes diamond detectors suitable for applications demanding good time resolution. The stability of diamond detectors at temperature around 120 °C has been observed (Tromson et al., 2000), which make them appropriate for harsh environments. The fact of having a large band gap should make diamond detector to be unaffected by visible light. However, irradiated diamond detectors showed a sensitivity to visible light for photons with energies above 1.7 eV (Bruzzi et al., 2003) since they may affect the stability of deep traps (Manfredotti et al., 2003), but this is extremely low under the opaque electrical contacts.

Diamond detectors have been used for alpha-particle spectrometry before (Canali et al., 1979), but the goal of the present work was the implementation of this type of detector for measuring under ambient conditions (Souw and Meilunas, 1997) for the application in the construction of a portable alpha-particle spectrometer (Martín Sánchez and de la Torre Pérez, 2012). A scCVD diamond detector has been then characterized and the results were compared with those reached using a Si detector. Both

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detectors were used under ambient conditions (in air and with light) to measure alpha-particle emitting sources.

2. Diamond detector

The development of the CVD process for diamond manufacture has allowed to produce thin sheets of polycrystalline diamond with centimeter dimensions. However, the production of high purity single-crystals is still limited to the millimeter range because the difficulties of maintaining constant growth conditions over long periods needed larger volumes.

The diamond detector tested here was delivered by Diamond Detectors Ltd as an end product using high purity (less than 5 ppb of nitrogen and boron) single crystal of CVD diamond in a planar configuration, with an area of $4 \times 4\ mm^2$. After mechanical polishing (roughness less than 1 nm) and thinning (50 μm final thickness), the sample was cleaned in a saturated solution of sulphuric acid and potassium nitrate at 300 °C. Finally, it was ultrasonically cleaned in ultrapure water.

The ohmic contacts were fabricated with a novel metallization technique using a diamond-like carbon (DLC) tunneling junction (3 nm) with Pt/Au (16/200 nm) as electrical contacts (Galbiati et al., 2009). The electrodes deliver the collected charges to the preamplifier through gold wire (25 μm diameter) bonding connections. The diamond film was packaged in a circular aluminum housing (2 cm diameter) with nickel/acid gold (10/2 μm) finishing process. The signal was taken outside by a SMA connector. Fig. 1 shows pictures of the diamond detector. The main characteristics of this diamond detector can be seen in Table 1.

3. Silicon detector

A passivated implanted planar silicon (PIPS) detector (manufactured by Canberra Industries Inc.) with $450\ mm^2$ active area (circular entrance window) was employed. To make it resistant to harmful environments and also able to work with ambient lights, the continuous air monitoring (CAM) PIPS detector has aluminum and varnish coatings corresponding to a supplementary absorption layer of about 2 μm silicon equivalent. A summary of the main characteristics of the CAM PIPS detector, obtained from the manufacturer application note, is shown in Table 1.

The typical bias ranged from +24 V to +70 V, which yield an energy resolution of 34 and 38 keV respectively. However, the spectra taken in air at different biases (*i.e.* +24, +50, and +70 V) with the CAM PIPS detector have revealed that the best resolution is achieved at +24 V.

4. Measurements, results and discussion

In this section the performance of the diamond scCVD and the CAM PIPS detectors, in air and ambient light, is revised. First, the scCVD detector was characterized by studying its charge collection efficiency, its energy resolution, and its leakage current. Then, the spectra in air and ambient light for the two detectors were registered with two different α-sources. Finally, the absolute efficiency (ϵ) for both detectors was calculated by

$$\epsilon(\%) = \frac{N}{A_\alpha \cdot t} \cdot 100 \quad (1)$$

where N is the total counts stored under the peak corresponding to a given emission in the measured spectrum, A_α is the activity of the α-source, and t is the measurement time. Both detectors were collimated so the same area was exposed, keeping the distance source-to-detector to 13 mm.

4.1. Characterization of the scCVD detector

Fig. 2(a) shows the charge collection of the scCVD detector when applying positive and negative biases. For this test a standard 5.5 MeV ^{241}Am α-source was employed. Unlike the Si detectors, diamond detectors do not need to be reverse-biased for creating a depletion zone. This fact gives the advantage of selecting the polarity of the bias at will, which may be used for attracting charged ions, for example, 87% of the generated ^{218}Po ions are positively charged (Pagelkopf et al., 2005). For the charge collection study an electronic chain consisting of a ORTEC 142A preamplifier, followed by a ORTEC 572A amplifier, and a CANBERRA 16 K ADC Multiport II, was employed. The obtained distribution at a given bias was Gaussian fitted, and its mean and deviation values (symbols and uncertainty bars respectively) were plotted vs the applied bias. For the positive bias, the saturation value (*i.e.* maximum charge collection) was reached for about 15 V,

Table 1
Main characteristics of the detectors used in this work.

	CAM PIPS[a]	scCVD[b]
Thickness (μm)	300	50
Typical bias (V)	+24 to +70	±50
Capacitance (pF)	270	15
Resolution[c] (keV)	34–38	19 to 21
Leakage current (pA)	8000	< 50
Operable in light to (lux)	5000	18,960

[a] Values obtained from manufacture application note.
[b] Values obtained experimentally by the authors.
[c] Energy resolution for alphas in vacuum.

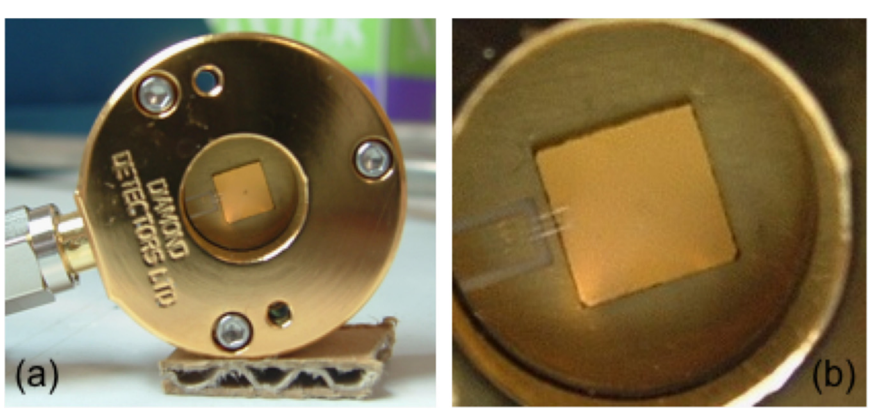

Fig. 1. Photographs of the scCVD diamond detector. (a) General view of the housing. (b) Details of the wire-bonding.