Radiation Measurements 73 (2015) 18–25

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

Diamond sensor arrays for neutron detection: Preamplifier signal dependence on sensor array configuration

Eric Lukosi [a, *], Mark Prelas [b]

[a] Department of Nuclear Engineering, 315 Pasqua Nuclear Engineering, University of Tennessee, Knoxville, TN 37996, USA
[b] Nuclear Science and Engineering Institute, E2433 Lafferre Hall, University of Missouri, Columbia, MO 65211, USA

HIGHLIGHTS

- Computational study of diamond detector array designs on output signals.
- Series detector arrays are intrinsically limited due to sensor impedance.
- Parallel detector arrays increase detection efficiency and maintain signal integrity.
- Experimental verification of series and parallel diamond detector arrays.

ARTICLE INFO

Article history:
Received 30 March 2012
Received in revised form
12 December 2014
Accepted 13 December 2014
Available online 16 December 2014

Keywords:
Diamond detectors
Neutron detection
Spectroscopy
Signal summing
Series array
Parallel array
Detection efficiency

ABSTRACT

Experimental verification of simulated results of series and parallel diamond detector arrays is reported. Eight commercially available electronic grade single crystal CVD diamond plates were used in series and parallel array configurations and were characterized through alpha particle and neutron exposures. It was found that a series array of diamond detectors is inherently limited due to the impedances of the diamond plates. Plutonium–beryllium neutron exposures were conducted with each of these diamond plates and on a parallel array of all eight diamond plates. It was found that the detection efficiency scaled linearly with the number of plates and that the pulse height from the preamplifier was not affected by the parallel array configuration. However, the additional capacitance introduced to the charge sensitive preamplifier indicates that there is a limitation to the total size that can be realized with a parallel diamond sensor array before significant signal degradation occurs.

1. Introduction

CVD single crystal diamond has been reported in recent years as an emerging option for radiation detection and spectroscopy (Amosov et al., 2011; Isberg et al., 2004, 2002; Lukosi et al., 2013; Oh et al., 2013). One challenge in the use of diamond as a radiation sensor is the available substrate area. Historically, high quality diamond growth suitable for radiation detection requires a diamond substrate, thereby limiting the maximum achievable area. Further, optimum diamond growth for radiation detection is along the <100> direction, which is self-limiting due to the pyramidal formation it creates (Silva et al., 2008). Therefore, large area substrates are required for reasonable detection efficiencies outside of beam tracking applications. Significant effort has been invested into epitaxial diamond growth to overcome this challenge (Regmi et al., 2012), but to-date the adaption of these techniques to produce high quality thick substrates for radiation detection and electronic applications has not yet been achieved.

An alternative approach to overcoming the challenge of small diamond substrates is to combine them together in a detector array. Using signal summing, an array of diamond sensors in a series or parallel design may provide a larger detection efficiency without the cost of additional signal processing electronics for each substrate in the array. The evolution of the pulse height spectrum induced by 14.1 MeV neutrons as a function of sensor thickness and signal collection design has already been reported (Lukosi et al., 2012) and indicated that the energy resolution of the detection system was still below experimentally determined values for both

* Corresponding author.
E-mail address: elukosi@utk.edu (E. Lukosi).

http://dx.doi.org/10.1016/j.radmeas.2014.12.007
1350-4487/

alpha particles and the 8.4 MeV $^{12}C(n,\alpha)^{9}Be$ peak from 14.1 MeV neutron interactions (Pillon et al., 2008). In addition, this computational investigation indicated that this technique can achieve an intrinsic detection efficiency of approximately 25 percent with minimal secondary neutron interactions. The purpose of this paper is to report the experimental and computational investigation on the properties of signals generated from diamond detector arrays in series and parallel array configurations.

2. Diamond sample preparation

Eight diamond samples were obtained from Element 6, further called here as electronic grade diamond samples (EGDS). These EGDS had quoted dimensions of 2 × 2 mm with nitrogen and boron concentrations less than five parts per billion and fifty parts per trillion, respectively. The thickness of each sample was measured using a micrometer and are given in Table 1.

The EGDS were characterized via Raman and a single peak at 1332 cm^{-1} was observed. The samples were also characterized with an S.I. Photonics Model 440 UV/Visible Spectrophotometer where light absorption did not take place below a photon wavelength above 227 nm, indicating a band gap of 5.47 eV with no perceivable absorption lines due to any energy levels within the band gap. These results were conclusive enough to indicate that the samples were single crystal and that impurity levels were below the detection threshold of the spectrophotometer used.

The EGDS were chemically cleaned using a modified RCA-1 process followed by a chemical oxidation to increase surface resistivity. Each sample was then placed in an oxygen plasma to ensure complete surface oxygenation. Electrical contacts were of the broad face design, created through a combination of thermal evaporation and magnetron sputtering to produce a metallization pattern of Ti/Pt/Au (50 nm/25 nm/200 nm) followed by thermal annealing at 600 °C for twenty minutes for contact adhesion. The IV characteristics of each sample determined good Ohmic behavior with a current not exceeding 5 nA for any sample at an absolute bias of 500 V, providing a resistance of no less than 100 GΩ for each plate. A picture of EGDS 1 is given in Fig. 1.

3. Experimental investigation of diamond detector arrays

3.1. Single detector characterization

3.1.1. Alpha particle exposures and charge carrier properties

Alpha particle exposures were conducted on each diamond sample to characterize their charge collection properties through charge collection efficiency measurements utilizing Hecht's theory (Leroy and Rancoita, 2009). The pressure pin system shown in Fig. 2 provides a means to use the same test system for all EGDS for alpha particle exposures. The alpha source used was a type A-2 100 ^{210}Po source from Eckert and Ziegler. This alpha source is not electroplated, and therefore exhibits a broad alpha emission spectrum peaking around 5.05 MeV, verified through a silicon detector in a Canberra Quad Alpha Spectrometer Model 7404, as shown in Fig. 3. Also shown is the calibration ^{239}Pu alpha source from Eberline with an energy resolution of 2.96%. Unfortunately, the emission rate of the ^{239}Pu calibration source was too low to effectively acquire high statistical worth alpha spectra with the detector housing shown in Fig. 3, so the broad energy spectrum ^{210}Po source was used in all measurements.

Table 1
Thickness of all EGDS used in this work.

EGDS	Thickness (μm)
1	521
2	511
3	495
4	495
5	467
6	498
7	470
8	511

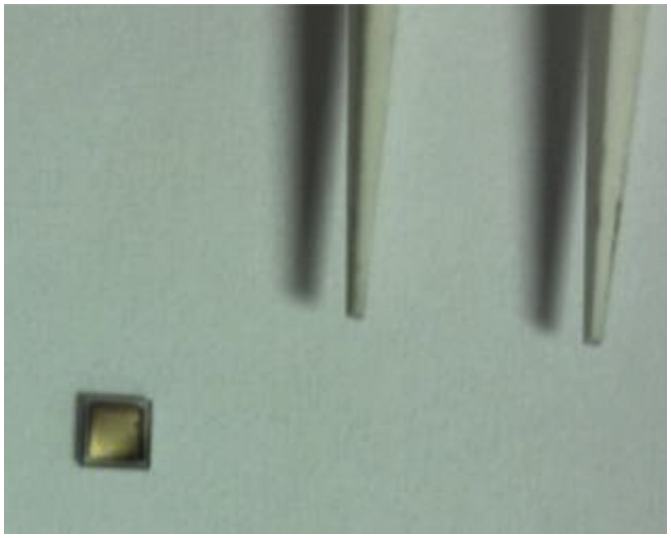

Fig. 1. Picture of fully prepared EGDS ready for experiments.

The detector housing base was placed approximately two millimeters away from the surface of the ^{210}Po source during all measurements. The detector chain consisted of an ORTEC 142 PC preamplifier, Canberra model 2026 amplifier set to a gain of 10 and a shaping time of 0.5 μs, and a Canberra Multiport II multichannel analyzer buffer. All data was collected with Genie™ 2000.

Hecht's theory describes the charge collection efficiency as a function of the mobility, μ, the trapping time constant, τ, the applied electric field, E, the detector thickness with respect to the charge collection distance, W, and the location of charge carrier creation with respect to the charge collection electrode (Leroy and Rancoita, 2009).

$$Q_c = Q_o\left[\frac{\mu_e\tau_e E}{W}\left(1-e^{-\frac{x}{\mu_e\tau_e E}}\right)+\frac{\mu_h\tau_h E}{W}\left(1-e^{-\frac{W-x}{\mu_h\tau_h E}}\right)\right] \quad (1)$$

Further, the detector thickness is equal to the charge collection distance at 63.2 percent charge collection efficiency, and the ratio of the detector thickness to the electric field at this collection efficiency is equal to the mobility-trapping time constant product (Berdermann et al., 2004; Schmid et al., 2004), as shown in Equation (2).

$$\mu_{e/h}\tau_{e/h} = \frac{W}{E} \quad (2)$$

To obtain the mobility-trapping time constant for each sample, a spectrum was collected on each EGDS with the ^{210}Po source. For reference, spectra collected using EGDS 1 is given in Fig. 4. It can be seen that, as the bias increases, the spectrum shifts to higher channels numbers asymptotically and eventually approaches a constant value, which corresponds to maximum charge collection. The peak location was determined through statistical analysis over a Gaussian distribution fit due to the broad intrinsic alpha particle emission energy spectrum from the ^{210}Po source used.