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Leakage current measurements of a pixelated polycrystalline CVD diamond detector

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ABSTRACT: Diamond has several desirable features when used as a material for radiation detection. With the invention of synthetic growth techniques, it has become feasible to look at developing diamond radiation detectors with reasonable surface areas. Polycrystalline diamond has been grown using a chemical vapour deposition (CVD) technique by the University of Augsburg and detector structures fabricated at the James Watt Nanofabrication Centre (JWNC) in the University of Glasgow in order to produce pixelated detector arrays. The anode and cathode contacts are realised by depositing gold to produce ohmic contacts. Measurements of I-V characteristics were performed to study the material uniformity. The bias voltage is stepped from -1000 V to 1000V to investigate the variation of leakage current from pixel to pixel. Bulk leakage current is measured to be less than 1nA.

KEYWORDS: Detector design and construction technologies and materials; Radiation damage to detector materials (solid state)

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Contents

1 Introduction

1.1 Background

The properties of diamond, such as high electron and hole mobilities, and high electrical breakdown, make it a suitable material for radiation detection purposes. With the invention of synthetic growth techniques, it has become feasible to look at developing diamond radiation detectors with reasonable surface areas. Diamond is an insulator with the capability of being a semiconductor given that diamond has an indirect band gap. Diamond detectors usually exhibit a p-type semiconductor behaviour with a boron impurity at an energy level of 0.37eV above the valance band [1]. Table 1 shows the electric properties of diamond [2].

This study looked at assessing the electrical performance using a CVD diamond layer that had been grown on an Iridium substrate at the University of Augsburg. One of the important parameters to study is leakage current of the diamond detector. Leakage current occurs due to the limited electric conductivity inherent to semiconductor materials. This paper describes the investigation of the electrical properties of a pixelated CVD polycrystalline diamond detector.

1.2 Pixelated polycrystalline CVD diamond detector

The anode and cathode contacts are realised by depositing gold to produce ohmic contacts. A structure with simple ohmic electrodes in both sides of the diamond detector was fabricated. The sensor is 1.5×1.5 cm in size and is around 200 μm thick. The size of each pixel is 200×200 μm (figure 1) on a 500 μm pitch with 4, 8×8 arrays surrounded by guard rings. The distance between each guard ring is 800 μm. Figure 2 shows the layout of the pixelated diamond detector.

Table 1. Electric properties of diamond.

Property	*Value*
Mass density	3.515g/cm^3
Band gap energy	5.5 eV
Lattice constant	3.567 Å
Young's modulus	1050 GPa
Resistivity	$> 10^{14}$ Ωm
Hole mobility	2100 cm^2/V.s
Electron mobility	2000cm^2/V.s

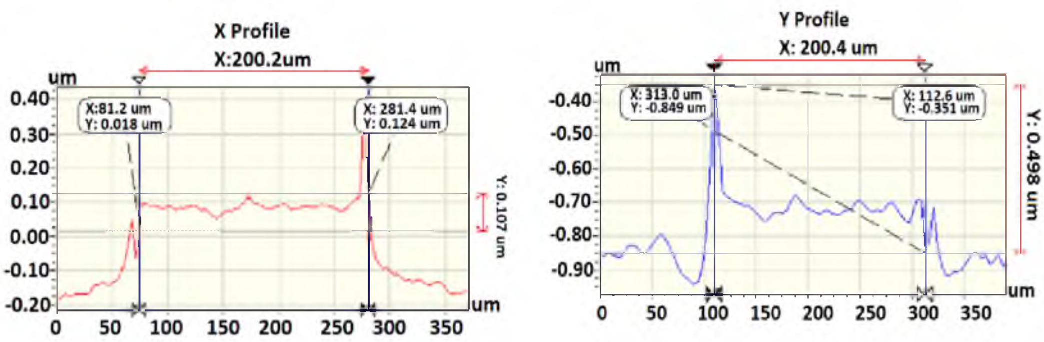

Figure 1. Size of pixel in X and Y profile.

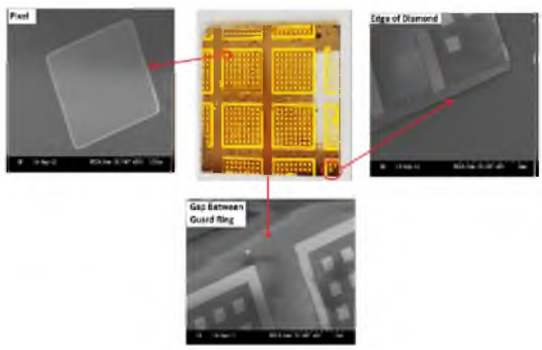

Figure 2. Pixelated diamond detector.

1.3 Experiment setup

In this project we have used a Wentworth S3000 probe station, a Keithley 6485 picoAmmeter and a Keithley 237 source-measurement unit to precisely measure the I-V characteristics. Figure 3 shows how the experiment has been setup. The measurement is arranged so that the bias voltage is applied to the cathode and the setup also measures the leakage current at the anode by using the picoAmmeter. The bias voltage is stepped from 0 to 1 kV for both polarities to investigate the variation of leakage current from pixel to pixel.

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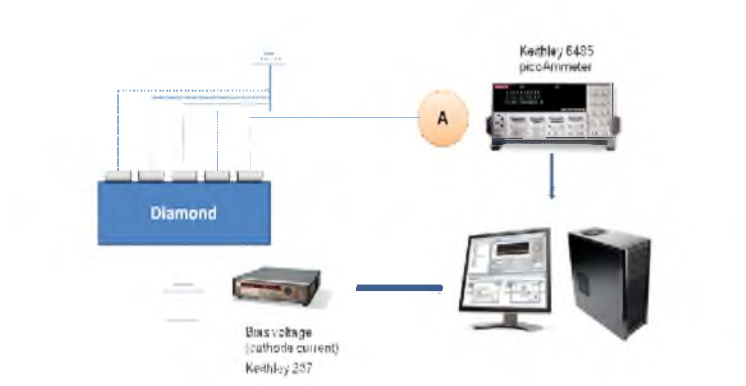

Figure 3. Experimental setup of the IV measurement.

2 Measurement

2.1 Leakage current measurement

The resistivity of diamond is much higher than any other semiconductor material as the band gap of diamond is so great. The numbers of free carriers in the diamond lattice are much lower than in other semiconductor materials due to the greater energy required to create free carriers in the material. The leakage current of a diamond detector occurs due to the limited electric conductivity inherent in semiconductor materials. The two kinds of leakage current are due to the bulk and surface properties of the material. Bulk current is primarily caused by carriers that are thermally energetic enough to cross the band gap of diamond [3]. This bulk leakage current is inversely proportional to carrier lifetime. Surface leakage current is attributed mainly to the manufacturing process, measurement methods, electrode conductivity, etc. Since leakage current contributes to noise, low leakage current is very desirable in radiation detection applications. This is an important issue for semiconductor radiation detectors because it affects the performance of the detector, directly influencing energy resolution and signal to noise ratio. When a diamond has a high concentration of boron impurity, the resistivity is quite low [4]. At present diamond detectors require a high bias voltage.

The leakage current was measured at room temperature with the bias voltage applied to the anode. Figure 4 shows a typical leakage current measurement taken from A2 pixel #2. When the bias voltage of up to 1.0 kV was applied, there was no break down and the leakage current of the diamond detector was only 7pA. These measurements agree with other results reported on CVD polycrystalline diamond material [5].

In order to assess the stability of the IV measurement setup the bias was swept from 0V to 1000V in steps of 10V then back from 1000V to 0V and also then to -1000V and back to 0V. The result in figure 5 shows no polarisation effect and also no appreciable fluctuation of the current on successive passes.

2.2 Uniformity of material

Mapping of leakage current over A2 was performed and the uniformity of leakage current over the area is shown in figure 6. The leakage current exhibits some pixel to pixel variation which is greater near the outer pixels and also may be influenced by the non-uniform surface of the diamond

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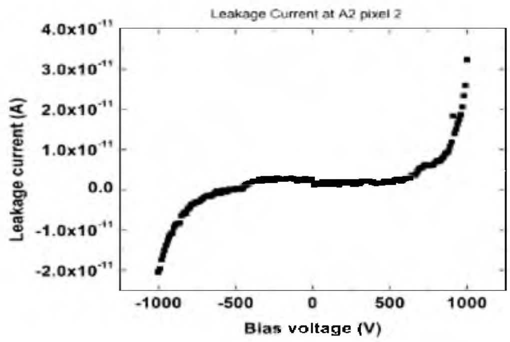

Figure 4. Leakage current measurement.

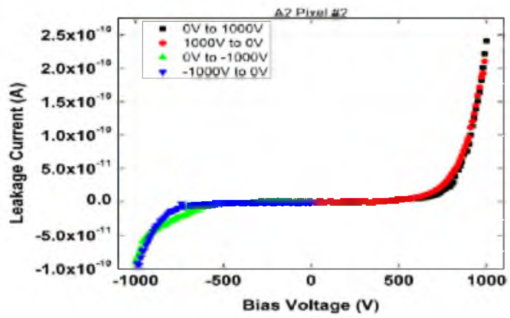

Figure 5. Different magnitude of bias voltage.

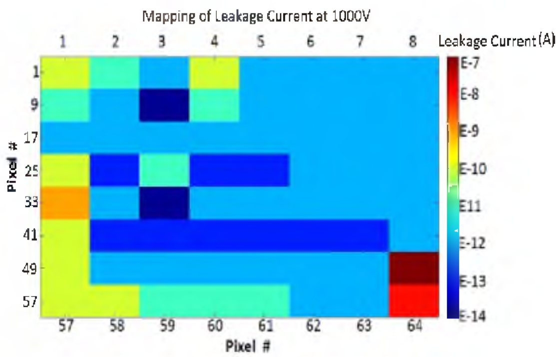

Figure 6. Mapping of Leakage current over A2.

sample. Figure 7 shows the surface profile of the grown sample. Additionally, this result shows that the leakage current of the diamond detector was lower by up to 3 orders of magnitude than for silicon detectors [6].

2.3 Bias stability test

Different bias voltages were applied in a stability test over 3000s in order to study the stability performance of detector. Figure 8 shows that 800V, 850V, 900V and 1000V bias voltage are stable within the time frame at room temperature. The result of 1100V bias shows a variation of 8.6 % of leakage current.

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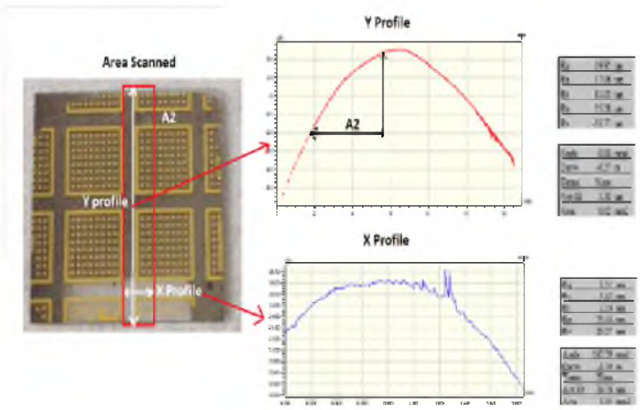

Figure 7. Surface measurement.

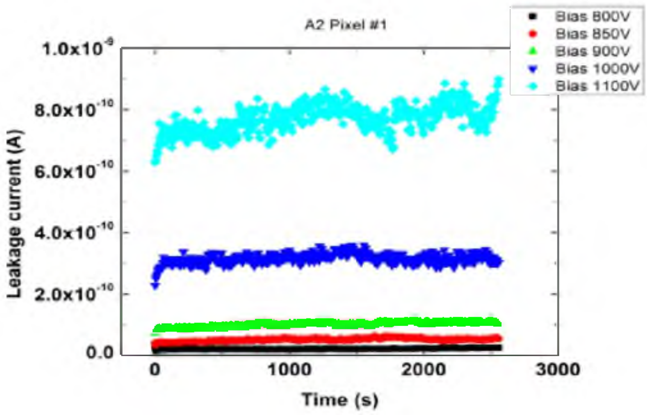

Figure 8. Bias stability measurement.

3 Conclusion

The basic properties for our diamond detector have been measured. It has been fabricated in a pixelated pattern using gold ohmic contacts. Each pixel of the detectors performed well and it was demonstrated that detector is stable. For bias voltages up to 1 kV the leakage current was found to be less than 1nA. There is no polarisation effect observed when switching bias from positive to negative or ramping the bias up and down. These are the initial results of test on this material and further investigation is necessary to measure the detection performance. It is our intension to investigate α-particle and γ-ray detection and study diamond properties through transient current technique.

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