CVD-Diamond-Based Position-Sensitive Detector Test with Electron Beam from a Rhodotron™ Accelerator

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Abstract

A position-sensitive detector using insulating-type CVD diamond as its substrate material has been developed at the Advanced Photon Source (APS), Argonne National Laboratory, and was tested with a 5 MeV electron beam from a CW Rhodotron™ accelerator at the STERIS Corporation. The preliminary test result shows that the free-standing insulating-type CVD-diamond acts as a solid-state ion chamber under the 5 MeV electron beam. Potential applications of the CVD-diamond-based position-sensitive detector, e.g., as a high-dose-rate beam profiler for industrial electron accelerators and radiation technologies are discussed in this paper.

1 INTRODUCTION

CVD diamond offers superior thermal-physical properties, such as high thermal conductivity, a low thermal expansion coefficient, and good mechanical strength and stiffness under heat, that are critical for the Advanced Photon Source (APS) insertion-device beamline x-ray beam position monitors (XBPM) performances. As a heat-sink blade material (coated with gold and other metals, more than 176 pieces of CVD-diamond blades have been installed at the APS insertion-device beamline front ends. They have been operational for the use of high-heat-flux photoelectron emission-type XBPM since 1996 [1].

Insulating type (type IIa) synthetic diamond (from high-pressure cells as solid-state ionization chamber radiation detectors have been studied for biological applications with alpha-particle and gamma radiation since 1987 [2]. Compared with other photoconductors, diamond is a robust and radiation-hardened material with high dark resistivity, large breakdown electric field, and is sensitive to hard x-rays [3]. At the APS, an x-ray-transmitting position monitor using CVD diamond was developed for combining filter/window and XBPM functions [4]. Several different configurations, including a quadrant pattern for a x-ray-transmitting beam position monitor and 1-D and 2-D arrays for beam profilers, have been developed. Tests on different photoconductive position-sensitive detector (PSPCD) devices with high-heat-flux undulator white beam, as well as with monochromatic hard x-ray beams have been done at the APS and the European Synchrotron Radiation Facility (ESRF) [5]. It was proven that the insulating-type CVD diamond can be used to make a hard x-ray position-sensitive detector based on the photoconductivity principle and that acts as a solid-state ion chamber [6,7].

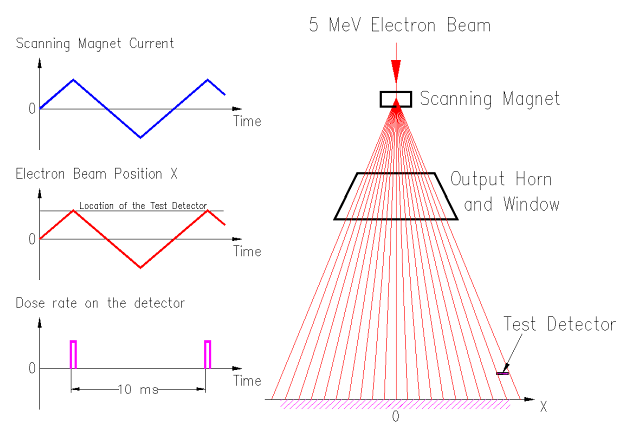
In February 2000, a CVD-diamond-based position-sensitive detector test was performed under a 5 MeV electron beam from a IBA TT200 CW Rhodotron™ accelerator at the STERIS Corporation. In this paper, the test setup, the results, as well as its potential applications, e.g., as a high-dose-rate beam profiler for industrial electron accelerators and radiation technologies, are discussed.

2 ELECTRON BEAM PARAMETER

The Rhodotron™ accelerator is a compact, high power, electron beam accelerator system, that is extensively used in various industrial processes, such as sterilization of medical devices, modification of polymers and more. In the Rhodotron™ accelerator, electrons are accelerated as they pass through properly oriented electrical fields in the Rhodotron™ single coaxial-shaped cavity. Using deflection magnets, the electrons can be reintroduced into the main body of the accelerator for additional crossings of the cavity, up to 12 passes, and finally achieve an energy output of 5 MeV [8,9]. Table 1 shows the electron beam parameters of the TT200 Rhodotron™ accelerator used for CVD-diamond-based position-sensitive detector test at the STERIS Corporation.

As shown in Fig. 1, during the test, an APS CVD-diamond-based position-sensitive detector test unit was installed in the Rhodotron accelerator beam exposure area at 400 mm above the floor. Experiments were done in ambient air conditions at a distance from the Ti foil window of about 150 cm.

Fig 1. Scanning electron beam on the test detector.



The scanning mode of the electron beam in the area of irradiation leads to a pulsed mode of the beam on the test detector, as shown in Fig. 1[10].

Table 1 Electron beam parameter of the TT200 RhodotronTM accelerator

Kinetic energy	5.0 MeV
Beam current	0.5 – 16 mA
Diameter of electron beam	8 cm
Repetition of beam scanning	100 Hz
Trajectories of scanning beams	parallel

2 TEST SETUP

The working principle of the CVD-diamond-based position-sensitive detector can be described as follows: a thin CVD-type diamond disk is patterned on both surfaces with a thin layer of electrically conductive material, such as aluminum, etc., as shown in Fig. 2. These coated patterns are individually connected to a biased current-amplifier circuitry through an ohmic contact. When the electrically biased CVD disk is subjected to the 5 MeV electron beam, the high-energy electrons activate the impurities in the CVD diamond causing a local conductivity change, hence a local current change through the contact points. The amount of the generated current is a function of the electron beam flux.

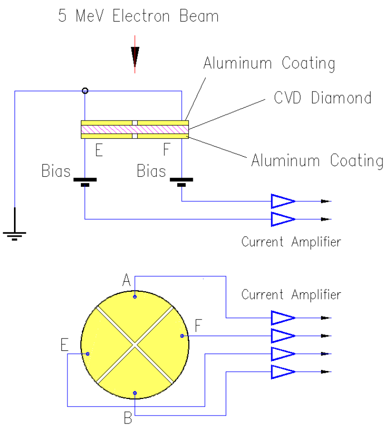


Fig. 2. Schematic of the CVD-diamond-based position-sensitive detector test setup.

The test detector uses a 25-mm-diameter, 175-micron-thick CVD-diamond disk with 0.2-micron-thick electrically isolated quadrant patterns of an aluminum coating on both sides of the diamond disk. The CVD-diamond disk was clamped on a copper aperture with water-cooling structure, as shown in Fig. 3. A DC bias voltage was used to generate the current signal, which is based on photoconductive properties of the CVD diamond. If the beam size is compatible with the dimensions of the detector, the output signals from individual quadrant zones will provide the beam position information as a quadrant beam position monitor.

3 PRELIMINARY TEST RESULTS

Two different sample setup cases were arranged for the experiments, as shown in Fig. 4. In configuration 1, the signal output aluminum coating on the CVD- diamond disk was mounted facing to the 5 MeV electron beam, and the copper cooling base (the grounding side) was mounted on the other side. In the configuration 2, the grounding side was facing the electron beam.

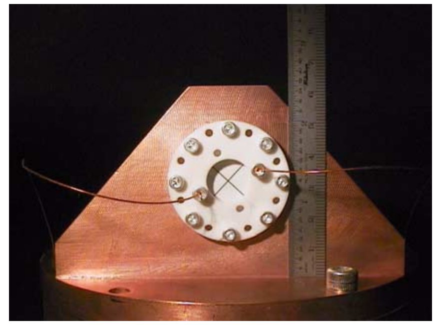


Fig. 3. Photograph of the CVD-diamond-based position-sensitive detector with the water-cooling structure.

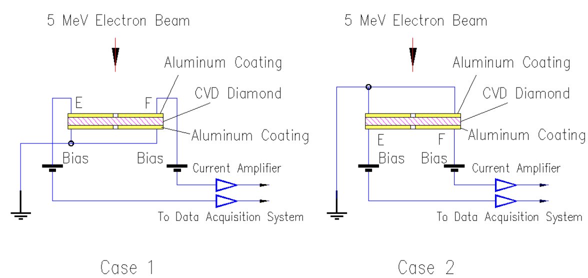


Fig. 4. Schematic of two setup configurations for the CVD-diamond-based position-sensitive detector.

We have measured the detector current output from one quadrant zone as a function of the 5 MeV electron beam current in both setup configurations. Linear relations were observed in both cases, as shown in Figs. 5 and 6. During the measurement, a 1.5 V DC bias was applied to the detector. The current signal was amplified by a set of Kiethly 427 current amplifiers and digitized with a PC-based data acquisition system. Fig. 7 shows both the 5 MeV electron beam current and the detector output as a function of the time.

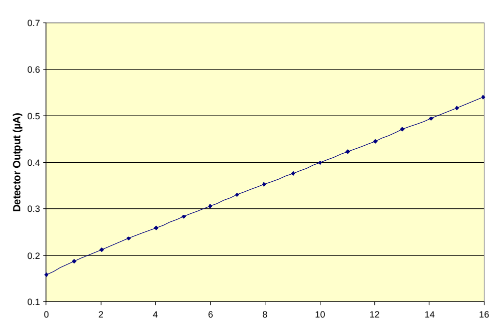


Fig. 5. The detector output current as a function of the electron beam current in configuration 1.

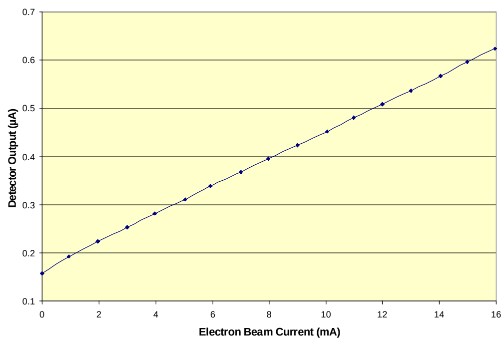


Fig. 6. The detector output current as a function of the electron beam current in configuration 2.

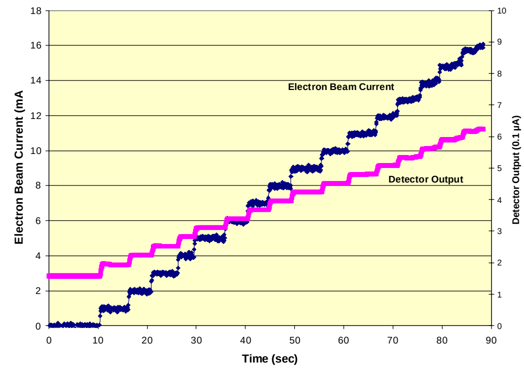


Fig. 7. 5 MeV electron beam current and the detector output as a function of the time in configuration 2.

The differences in detector current output in the two cases is partly due to a space charge effect caused by incident electrons near the detector plate facing the beam.

4 DISCUSSION

We have tested a novel CVD-diamond-based position-sensitive detector using free-standing insulating-type CVD diamond as its substrate material. We showed that the insulating-type CVD diamond can be used to make a high-dose-rate detector for industrial electron accelerators. The high-energy electrons activate the impurities in the CVD diamond causing a local conductivity change, and that acts as a solid-state ion chamber. The detector current output showed a good linear response to the 5 MeV incident electron beam flux. There are potential applications of the CVD-diamond-based position-sensitive detector, e.g., as a high-dose-rate beam profiler for industrial electron accelerators and radiation technologies.

This experiment is a preliminary test for the proof of the principle. Further experiments are planned to measure the detector's detailed performance, including beam position sensitivity and its response to the different bias voltages.

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