CVD diamond-based position-sensitive photoconductive detector for high-flux x-rays

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Introduction

Natural diamonds as photoconductive radiation detectors (PCDs) have been studied since 1956 [1], and only certain diamonds, those with low impurity concentrations (specifically nitrogen), were found to be suitable for use as radiation detectors [2]. Natural diamonds have been used as PCDs for soft x-ray detection with a laser-produced plasma soft x-ray source and a synchrotron radiation source [3]. Insulating type (type IIa) synthetic diamonds (from a high-pressure cell) used as solid-state ionization-chamber radiation detectors have been studied for biological applications with alpha particles and gamma radiation [4]. Compared with other photoconductors, diamond is a robust and radiation-hardened material with high dark resistivity and a large breakdown electric field; diamond is also sensitive to hard x-rays [5].

The working principle of a position-sensitive photo-conductive detector (PSPCD) can be described as follows: a thin chemical vapor deposition (CVD)-type diamond disk is patterned on both surfaces with a thin layer of electrically conductive material, such as aluminum, etc. 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 either monochromatic or white x-ray beam, the photons activate the impurities in the CVD diamond causing a local conductivity change and then a local current change through the contact points. The amount of the generated current is a function of the photon flux.

Methods and Materials

<u>PSPCD tested at the APS with x-rays</u>

A compact filter/mask/window assembly has been designed for undulator beamline commissioning activity at the APS beamlines [6]. The assembly consists of one 300 µm graphite filter, one 127 µm CVD diamond filter, and two 250 µm beryllium windows. A water-cooled Glidcop fixed mask with a 4.5 mm x 4.5 mm output optical aperture and a 0.96 mrad x 1.6 mrad beam missteering acceptance is a major component in the assembly. The CVD diamond filter is mounted on the downstream side of the fixed mask and is designed to also function as a transmitting hard x-ray beam position monitor (TBPM). It has a quadrant pattern configuration. From the test results, we have learned that, compared to a photoemmision-type TBPM, the beam position signal from a photoconductive-type TBPM has less undulator gap dependence [7]. An x-ray-transmitting beam profiler system using two linear-array PSPCDs has been designed for Advanced Photon Source (APS) undulator beamline commissioning [8]. The same insulating-type CVD diamond disk was used as for the linear array substrate. On each disk, sixteen 0.2 µm-thick, 175 µm-wide aluminum strips were coated on one side, and an orthogonal single 175 µm-wide strip was coated on the other side. Hence, looking through the disk, a linear array of 16 pixels was created as the photoconductive sensor elements, with 175 µm x 175 µm pixel size.

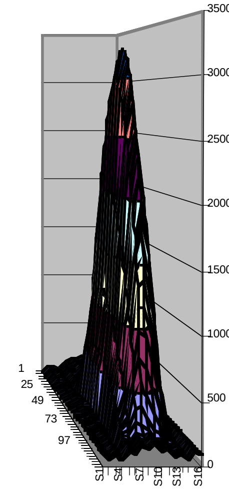

Figure 1: A typical profile of APS undulator white beam directly measured by a 16-pixel linear-array PSPCD.

During the measurement, two sets of 16-pixel linear-array PSPCDs are placed perpendicular to each other into the hard x-ray beam. The two arrays read out the beam's vertical and horizontal profile information simultaneously. To obtain a complete beam 2-D profile, one can scan across the beam. Fig. 1 shows a typical profile of an APS undulator white beam directly measured by a 16-pixel linear-array PSPCD scanning across the beam with the undulator magnet gap setting equal to 15 mm. A 12.7 mm-thick aluminum filter was used for these measurements to eliminate most of the soft x-rays.

A prototype of a 2-D imaging PSPCD has been built at the APS [9]. As shown in Fig. 2, 16 aluminum strips are coated on both sides of the CVD diamond disk creating a 16 x 16 pixel 2-D array with a 175 µm x 175 µm pixel size. The CVD diamond disk was mounted on a water-cooled base with a couple of ceramic connector-interface disks. Preliminary tests proved that a 2-D hard x-ray beam profile image could be read out by a multichannel current amplifier with pulsed bias electronics.

Two sets of multichannel analog switches were synchronized by a clock, which also provides the triggering signal for the computer data acquisition system. For each scanning position, one of the vertical strips was pulsed by a bias voltage, and the 16-channel current amplifier then read out the current signal from the identical column of the imaging pixels on the CVD-diamond disk. A 16 x 16 LED (light-emitting diode) array was used as an imaging screen. The scanning rate was 300–3000 columns per second. A steady 2-D image was observed with the APS undulator white beam at the SRI-CAT 1-ID-B station.

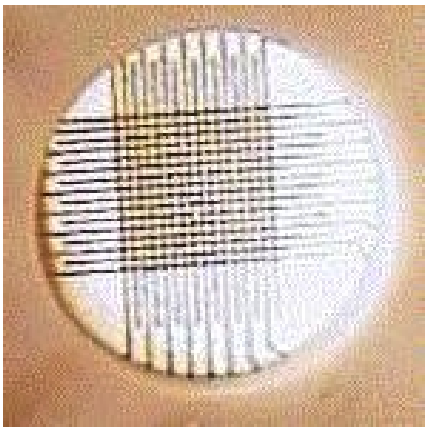

Figure 2: Sixteen aluminum strips are coated on both sides of the CVD diamond disk creating a 16 x 16 pixel 2-D array with 175 μm x 175 μm pixel size.

Results

We have tested the single-pixel response of this 2-D imaging PSPCD using undulator white beam with a 150 μm x 150 μm aperture. It was found that the pixels in this 2-D array PSPCD do not cross talk. Fig. 3 shows different images observed on the LED array with variant beam condition and slit settings. We have also studied several different CVD diamond products from different vendors with different manufacturing process. We found that only certain CVD diamonds, those with low impurity concentrations (specifically nitrogen and graphite), are suitable for use as imaging detectors.

Discussion

We have developed a novel position-sensitive photoconductive detector using free-standing insulating-type CVD diamond as its substrate material. Several different configurations, including 1-D and 2-D arrays as imaging detectors for beam profilers, have been developed. Tests on different PSPCD devices with high-heat-flux undulator white beam, as well as with a high-flux gamma-ray source, have been done at the APS and NIST. 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.

Acknowledgements

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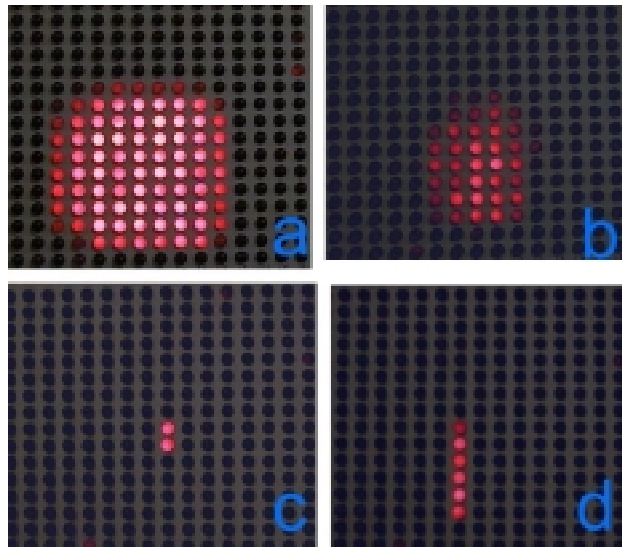

Figure 3: Different images observed on the LED array with various undulator gap sizes and slits settings.

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