ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWI052

RESPONSIVITY STUDY OF DIAMOND X-RAY MONITORS WITH nUNCD CONTACT

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Abstract

Nitrogen doped ultrananocrystalline diamond (nUNCD) grown on the surface of a CVD single crystal diamond is tested at various beamlines covering an x-ray photon energy range of 200eV to 28 keV. The nUNCD has much lower x-ray absorption than metal contacts and is designed to improve the performance of our device. The responsivity of nUNCD diamond x-ray detector is compared with the conventional platinum coated diamond x-ray beam position monitor and the results are presented in this paper.

INTRODUCTION

The ultrananocrystalline diamond (UNCD) thin films exhibit similar physical properties to single crystal diamond in the aspects of mechanical, thermal and resistance to radiation damage. Current UNCD thin films are prepared by microware plasma chemical vapor deposition (MPCVD) or hot filament chemical vapor deposition (HFCVD) with mixed H_2/CH_4 or Ar/CH_4 plasma chemistries. Nitrogen is introduced to UNCD thin film to improve its electrical conductivity to semi-metallic level, and therefore can be considered as a replacement of metal to function as an electrode in various applications like biomedical devices, biosensors, and in our case the x-ray monitors. [1, 2]

In this paper, a diamond device prepared with nitrogen doped ultrananocrystalline diamond (nUNCD) on both sides as electrodes is studied and results are compared with the device fabricated with traditional platinum contact.

EXPERIMENTAL

In order to improve the performance of the diamond x-ray monitor, nUNCD layers of 200 nm ~ 500 nm are grown on a 4 mm × 4 mm × 0.3 mm electronic grade ([N] ~ppb) single crystal CVD diamond as contact electrodes at Argonne National Laboratory (ANL).

X-ray white beam topography and birefringence images were recorded for this sample prior to device fabrication. X-ray topography was performed at Beamline X19C, National Synchrotron Light Source (NSLS) and birefringence images were taken using a polarized microscope. 2D current maps and calibrated responsivity vs photon energy of this diamond were collected at various beamlines in NSLS, covering a photon energy range of 0.2~28keV. Beamline U3C provides monochromatic beam of photon energy from 0.2~1 keV, while beamline X8A provides x-ray from 1~6.5 keV and beamline X15A from 6.5~28 keV, with an intensity ranged from 10^{-9}~10^{-6} W/mm^2. [3] Measurements at U3C are performed in a vacuum level of 10^{-7}torr and at X8A in a vacuum of 10^{-6} torr due to the high absorption rate of air for low energy photons, and is in air at X15A. Incident x-ray power is calibrated using silicon photodiodes at both U3C and X8A (with thickness of 25 μm and 52 μm respectively), while air-filled ionization chamber is used at X15A. Various biases in the saturated range of either DC level or in the form of square wave with adjustable magnitude, frequency and duty cycle, were applied on tested diamond plates to assure full collection of desired charge carriers (positive biases for hole collection and negative biases for electron collection).

RESULTS AND DISCUSSION

Figure 1 shows the compared results of the 2 imaging techniques. The nUNCD contact is completely transparent under the white beam at X19C (Fig.1a). The dark circled area in Fig.1b indicates the nUNCD contacts on both sides of the diamond. Prominent contrast of slip bands in diamond single crystal was observed in both topography and birefringence images.

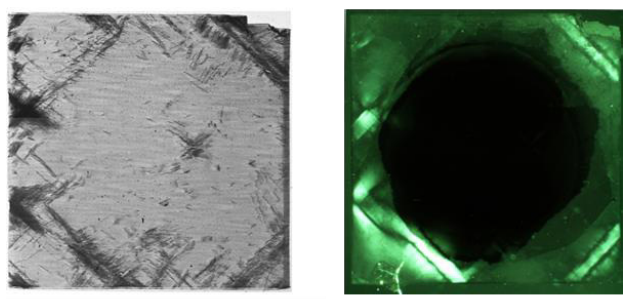

Figure 1: (a) X-ray topography and (b) birefringence images of the nUNCD coated diamond.

2D current maps of this diamond are collected at various beamlines at different energies. The values of x-ray attenuation length of diamond (the depth into the diamond measured along the surface normal where the

*Work was supported by U.S. Department of Energy under grants KC0407-ALSJNT-I0013 and DE-FG02_08ER41547. Use of the National Synchrotron Light Source, Brookhaven National Laboratory, was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-98CH10886.
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intensity of x-rays falls to 1/e of its value at the surface) at these energies are listed in Table 1. According to x-ray database CXRO, a minimum energy of 1350eV is needed for a photon to travel all the way through a 300 µm thick diamond. [4] Since it is difficult to control the growing process of the nUNCD layer, the thickness of this contact may vary in a range of 200nm to 500nm.

Current maps collected at the listed energies and representative results of these measurements are presented in Fig.2. Both positive and negative biases were applied with duty cycles for electron detrapping. [5]

Table 1: Diamond X-ray attenuation length at various energies from CXRO X-Ray Database [4]

Beamline	Photon Energy (eV)	X-ray attenuation length (µm)
U3C	350	0.0878
X8A	1000	1.2888
X15C	19000	7129.76

From Table 1, we can tell that at low energies, most of the incident beam is absorbed by the nUNCD layer. This is verified in Fig.2a and 2b. A halo ring is observed in the response maps at low energies, indicating a thicker area in the center of the contact where a larger absorption of the incident beam occur, resulting in a weaker signal than the edge area. Fig.2c and 2d are showing a relatively flat response over the contact, though photoconductive gain was observed at the edge of the contact. Similar features are observed in responsivity maps collected at other energies for this diamond.

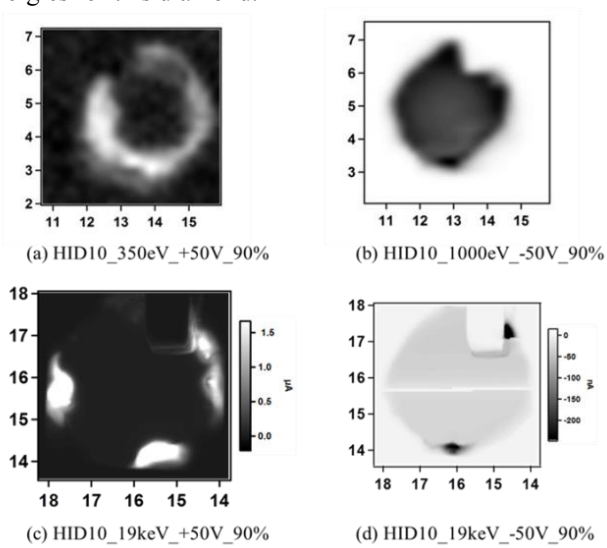

Figure 2: 2D responsivity maps for diamond with nUNCD grown as a contact. Measurements were taken at (a) 350eV, (b) 1keV, and (c) (d) at 19 keV.

A proposed model modified from that of metal contact diamond device [3] shown in Equation 1 has been introduced to describe the device responsivity of diamond device with nUNCD contact:

$$S = \frac{1}{W} e^{-\frac{t_{UNCD}}{\lambda_D}} \left(1 - e^{\frac{t_{dia}}{\lambda_D}}\right), \qquad (1)$$

where t_{nUNCD} and t_{dia} are the thickness of the nUNCD layer and the diamond plate, respectively. The effect of the dead carbon layer can be included in the thickness of the nUNCD layer.

Current mode responsivity data for nUNCD coated CVD diamond tested under monochromatic x-rays are presented in Fig.3. It is reported for Platinum coated diamond, a bias of 100V is found to be sufficient to extract over 95% of the available photocurrent. For nUNCD, this voltage is found to be 50V for both carriers at most energies. The calculated theoretical responsivity using Equation 1 is plotted as a reference using mean ionization energy W=13.6eV, which is a value with 4% difference from the reported value 13.3eV. In other words, the measured curve fits the theoretical model within a range of 4%, which is also observed in the previous study. [6] The fitting thickness of the filter is using 480 nm, including a combined effect of the nUNCD layer at the incident side and the dead carbon layer inside the diamond. The latter was theoretically predicted and also observed for Pt contact diamond. [7] The diamond thickness is found to be 380 µm by fitting the tail of curve between 4keV and 6keV.

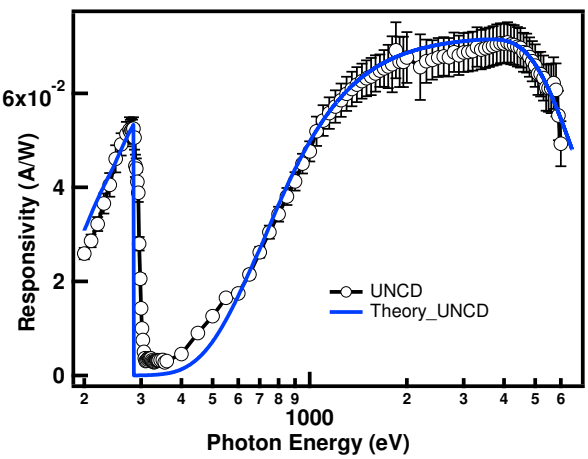

Figure 3: Responsivity of a 380 µm thick diamond coated with nUNCD diamond on both sides as contacts with theory curve calculated by Equation 1.

The responsivity of diamond with nUNCD contact is compared with a calibrated diamond detector which is 68µm thick and has 20nm Pt contacts on both sides, in an energy range of 0.2 to 6keV where both data sets overlap. (Fig.4) We have discussed in detail the effects of Pt layer has on diamond device responsivity. [8] In Fig.4b, where the 2 plots are magnified at the carbon edge, the nUNCD diamond has a higher response while the Pt filter gives a lower response in the Pt diamond detector. However, the nUNCD sees a much more dramatic effect in the post carbon area, where the attenuation length for diamond drops to its lowest value and carriers are lost either due to

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beam power absorbed in the nUNCD itself or the carrier diffusion that happens very close to the diamond-nUNCD interface (corresponding to a small recombination length). [8]

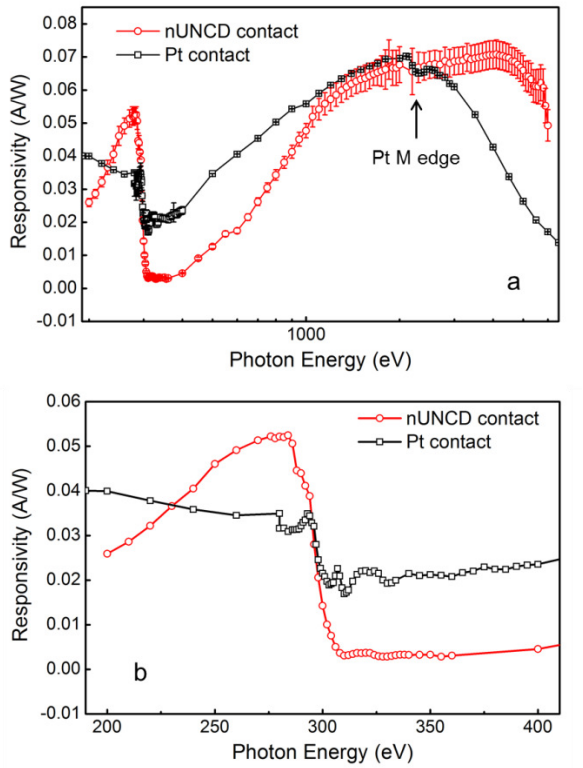

Figure 4: (a) Diamond responsivity of nUNCD as contacts compared with that of Pt as diamond contacts from an energy range of 0.2~6 keV. (b) Comparison between the 2 samples at carbon edge.

CONCLUSION

The nUNCD contact diamond has a flat response and does not suffer from annealing. Photoconductive gain observed on the edge indicating that an improvement is needed for the surface treatment and growth process. The nUNCD as a contact for diamond based beamline monitor is found to be more sufficient than the traditional noble metal contact such as Pt and Ti at low energy ranges due to less x-ray absorption and potentially can be designed as a diamond device for soft x-ray applications. The charge generation and transport mechanisms are not fully understood in the nUNCD contact and therefore further investigation is needed to adapt this low absorption contact for diamond detectors.

ACKNOWLEDGMENT

Special thanks are given to Dr. Bin Dong, Dr. James Distel and Dr. Zhong Zhong for their scientific and technical assistance at beamline U3C, X8A and X15A at National Synchrotron Light Source, Brookhaven national Laboratory.

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