Beam profile and intensity measurements with a commercial transparent x-ray camera

Benjamin W. Martin [1] Valerie E. Fleischauer [1] Erik Muller [2,3]

[1]*Sydor Technologies, Fairport, NY* [2]Brookhaven National Laboratory, Upton, NY
[3]Stony Brook University, Stony Brook, NY

ABSTRACT

Measuring x-ray beam position, profile, and intensity at synchrotron beamlines provides valuable information for all experiments. Sydor's transparent x-ray camera (TXC), based on technology originally developed at Brookhaven National Laboratory[1], enables in-situ measurements with experiments for live feedback. The TXC has a low beam profile that fits within a standard vacuum flange width and is composed of diamond material for 90% transmission of $>$ 5 keV x-rays, minimizing disruption of beamline space and the x-ray beam itself. Standard device parameters include 32 x 32, 60 μm pitch pixels, linearity over a 10^7 – 10^{16} photons/s dynamic imaging range, $<$ 40 pA noise floor, > 30 frames/s image rates, and total flux measurement mode.

Device performance has been evaluated using a pinhole mask with a benchtop silver x-ray tube at Sydor, at the X-ray Footprinting of Biological Materials (XFP) beamline at NSLS-II, and at the Forming and Shaping Technology (FAST) beamline at CHESS. This work highlights the features of this commercial beam diagnostic, test results, and future directions of the technology.

SYSTEM DESIGN

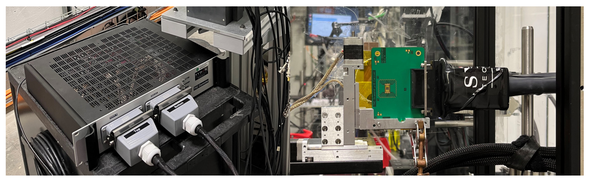
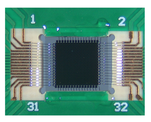


Figure 1. *left* Sydor TXC readout/control electronics. *right* TXC sensor on carrier board during testing at NSLS-II.

Figure 2. Microscope image of diamond carrier board focusing on the diamond virtual "pixels".



- 80 μm pixel width, 15 μm spacing to maximize array size
- 32 horizontal (readout), 32 vertical strips (bias)
- platinum electrodes on single crystal CVD diamond

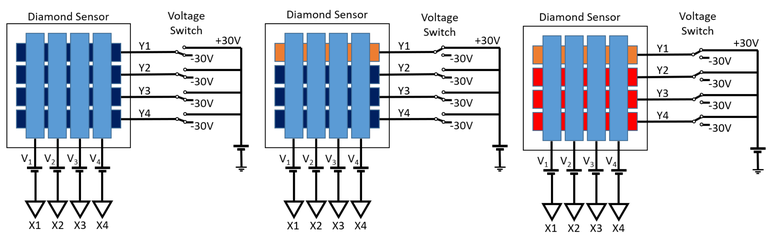


Figure 3. Cartoon of TXC system readout sequence. *(left, flux background measurement)* All bias strips are applying 0 V, "off". *(middle, imaging mode)* Bias voltage is cycled for each strip. Virtual pixels are generated as rows are read out with bias cycling. *(right, flux measurement)* All bias strips are on. Subtracting the background from the left-most image results in a total flux measurement.

SYSTEM SPECIFICATIONS

Table 1. Sydor TXC standard system specifications.

Specification	Commercial Prototype
Pixel pitch	60 μm
Array size	32 x 32
Sensor material	IIa diamond
Sensor thickness	40 μm
Frame rate	>30 Hz
Noise floor	<40 pA
Max current (gain^{-1} pixel^{-1})	300 nA, 100 μA , 5 mA

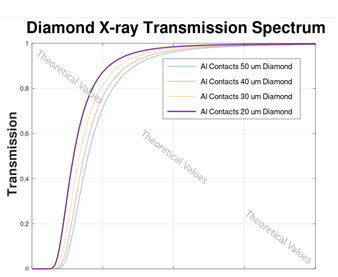


Figure 4. Calculated quantum efficiency of aluminum coated CVD diamond.[2]

CHESS BEAMLINE TESTING

FAST focuses on high-energy diffraction experiments of in-situ mechanical loading experiments from 20 - 70 keV. The conditions for the experiments discussed here were:

- 20 keV
- 0 C
- 2 mm (h) x 1 mm (v) beam size
- TXC placement between 2 ion chambers, upstream of samples

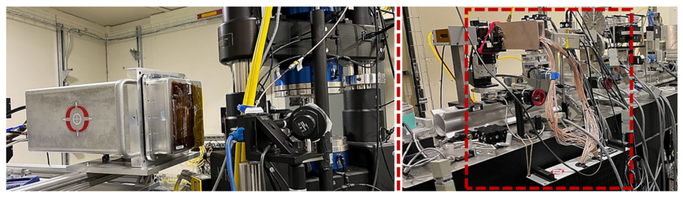


Figure 5. Commercial prototype TXC at the Cornell High Energy Synchrotron Source Forming and Shaping Technology (FAST) beamline (outlined with red box). Beamline flux during these experiments ranged from 10^{10} – 10^{13} photons/s at peak energies from 20 - 40 keV. Beam measurements were taken to monitor characteristics during concurrent Bragg diffraction measurements using Sydor's Mixed-Mode Pixel Array Detector (MM-PAD, left).

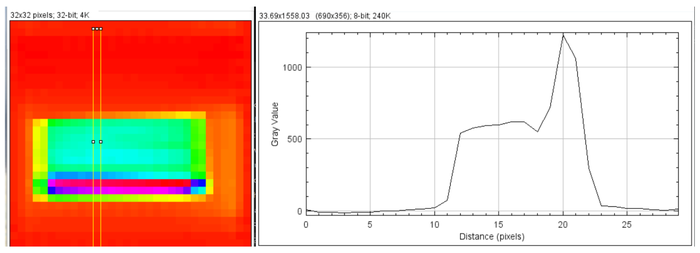


Figure 6. 32 x 32 pixel image and line out showing intensity changes in the beam across the vertical profile during experiments at FAST. Data was collected using the medium gain stage of the TXC where 1 ADU = 0.19 nA. Mono beam energy: 20 keV, flux 10^{10} photons/s.

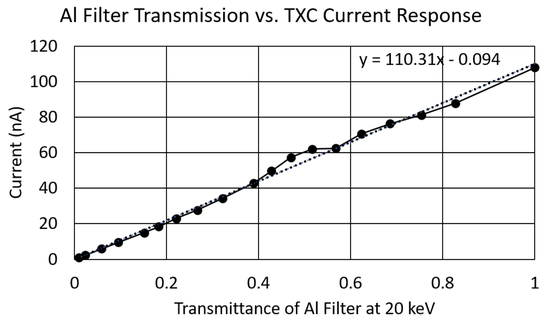


Figure 7. Linearity vs. flux measurements at FAST using a monochromatic 20 keV setup, medium gain range, aluminum filter wheel attenuator (5 - 0.2 mm). This plot represents 2 of the 7 experimentally determined orders of magnitude of linearity for this family of diamond monitor.[2]

USER INTERFACE

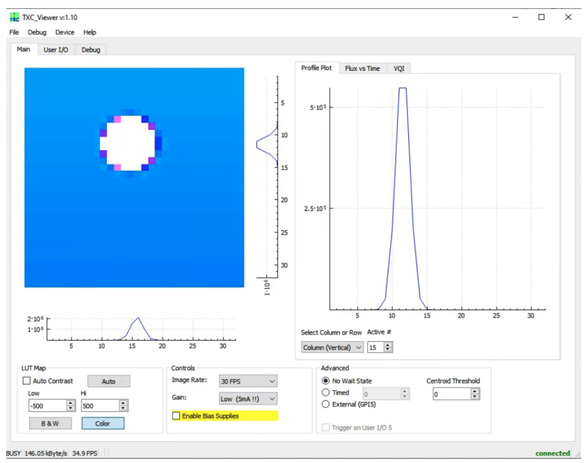


Figure 8. Screen Shot of Sydor TXC Software. The UI is Windows or Linux Compilable. The software contains: X and Y line profiles, Imaging Mode, Quadrant Mode, Instantaneous Total Flux. Features in Development: EPICS IOC, live current to flux estimation.

NSLS-II BEAMLINE TESTING

The 17-BM XFP beamline at NSLS-II has a 450 μm x 120 μm to 2.7 mm x 2.7 mm beam size with a flux of up to 1.6 x 10^{16} photons/s (5 - 16 keV, pink beam).[3]

During testing, the TXC was mounted in a temporary inert gas chamber to prevent damage to the sensor from use with the high energy beam in air. X-Y translation stages in the chamber were used for beam alignment.

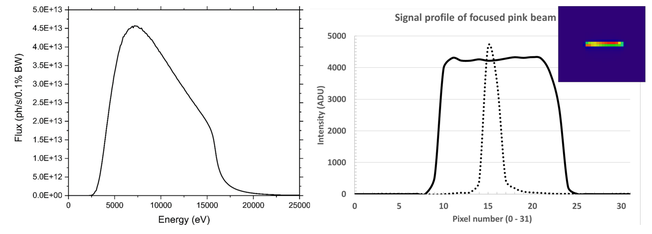


Figure 9. *(left)* Beam energy profile at XFP at NSLS-II. Reproduced from [3]. *(right)* 32 x 32 pixel image and line out showing intensity changes in the beam across the vertical profile during experiments at XFP. Data was collected using the low gain stage of the TXC where 1 ADU = 0.19 nA.

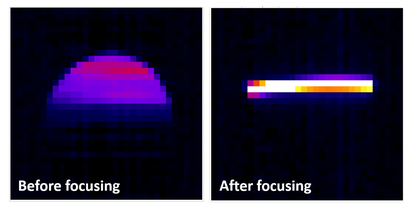


Figure 10. Results of a beam focusing video during prototype testing at the XFP beamline at NSLS-II. The beam at XFP is an intense broadband pink beam, from 4.5 - 16 keV and beam size of 100 x 400 μm to 3 x 3 mm determined by a toroidal mirror.

Table 2. Total current measured by the TXC was varied by changing beam focus, and Al or Cu attenuation thicknesses at XFP using beam with the approximate characteristics shown in the focusing image above.

Total flux	Gain	Al Filter (mm)
8.8 mA	low	0**
1.9 mA	low	0*
8.5 μA	medium	1.5
0.71 μA	medium	3.0
0.16 μA	high	4.5
28 nA	high	7.5
5 nA	high	12
0.94 nA	high	4.5 & 0.5 mm Cu

- (*) Measurements with no attenuation were obtained, with focused full pink beam over approximately 28 pixels
- (**) unfocused full pink beam with no observed damage to the detector in subsequent testing
- The maximum current per pixel on low gain is 5 mA for less than 5 minutes
- Further analysis is required to evaluate the linearity across multiple gain stages of the detector while taking into consideration how the attenuation affects transmission of the different wavelengths in the beam spectrum.

ACKNOWLEDGMENTS & REFERENCES

DOE SBIR Grant # DE-SC0019578
Sydor's team of most excellent engineers and techs
Sean Robinson, Don Pinelli, and the High-Density Interconnect Laboratory at BNL
Erik Farquhar and NSLS-II XFP beamline
Kate Shanks and Amlan Das at the CHESS FAST beamline

[1] Tianyi Zhou, Wenxiang Ding, Mengjia Gaowei, Gianluigi De Geronimo, Jen Bohon, John Smedley, and Erik Muller. Pixelated transmission-mode diamond X-ray detector. *Journal of Synchrotron Radiation*, 22(6):1396–1402, Nov 2015. doi: 10.1107/S1600577515014824. URL https://doi.org/10.1107/S1600577515014824.

[2] Jen Bohon, Erik Muller, and John Smedley. Development of diamond-based X-ray detection for high-flux beamline diagnostics. *Journal of Synchrotron Radiation*, 17(6):711–718, Nov 2010. doi: 10.1107/S0909049510031420. URL https://doi.org/10.1107/S0909049510031420.

[3] Awuri Asuru, Erik R. Farquhar, Michael Sullivan, Donald Abel, John Toomey, Mark R. Chance, and Jen Bohon. The XFP (17-BM) beamline for X-ray footprinting at NSLS-II. *Journal of Synchrotron Radiation*, 26(4):1388–1399, Jul 2019. doi: 10.1107/S1600577519003576. URL https://doi.org/10.1107/S1600577519003576.