100Hz X-ray Beam Profile Measurements from a Transmissive CVD Diamond Detector

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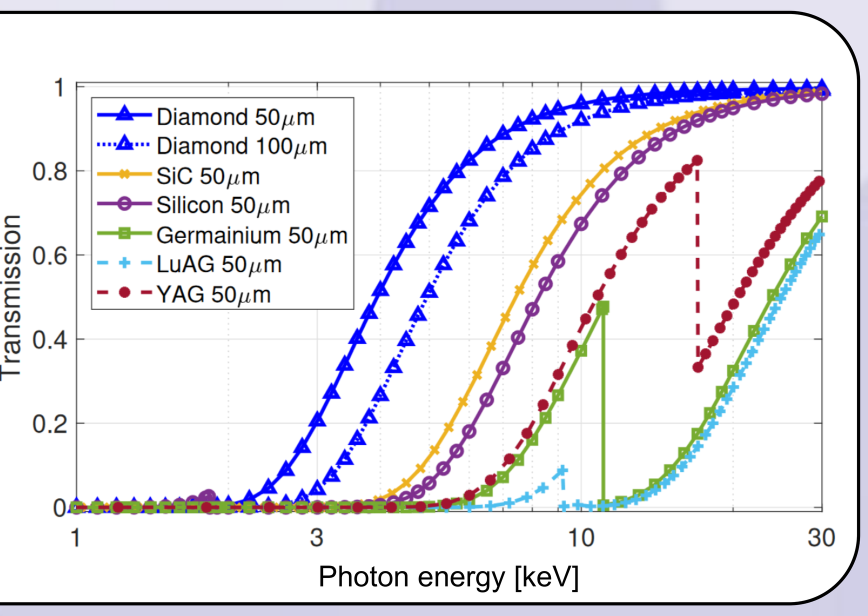
Abstract

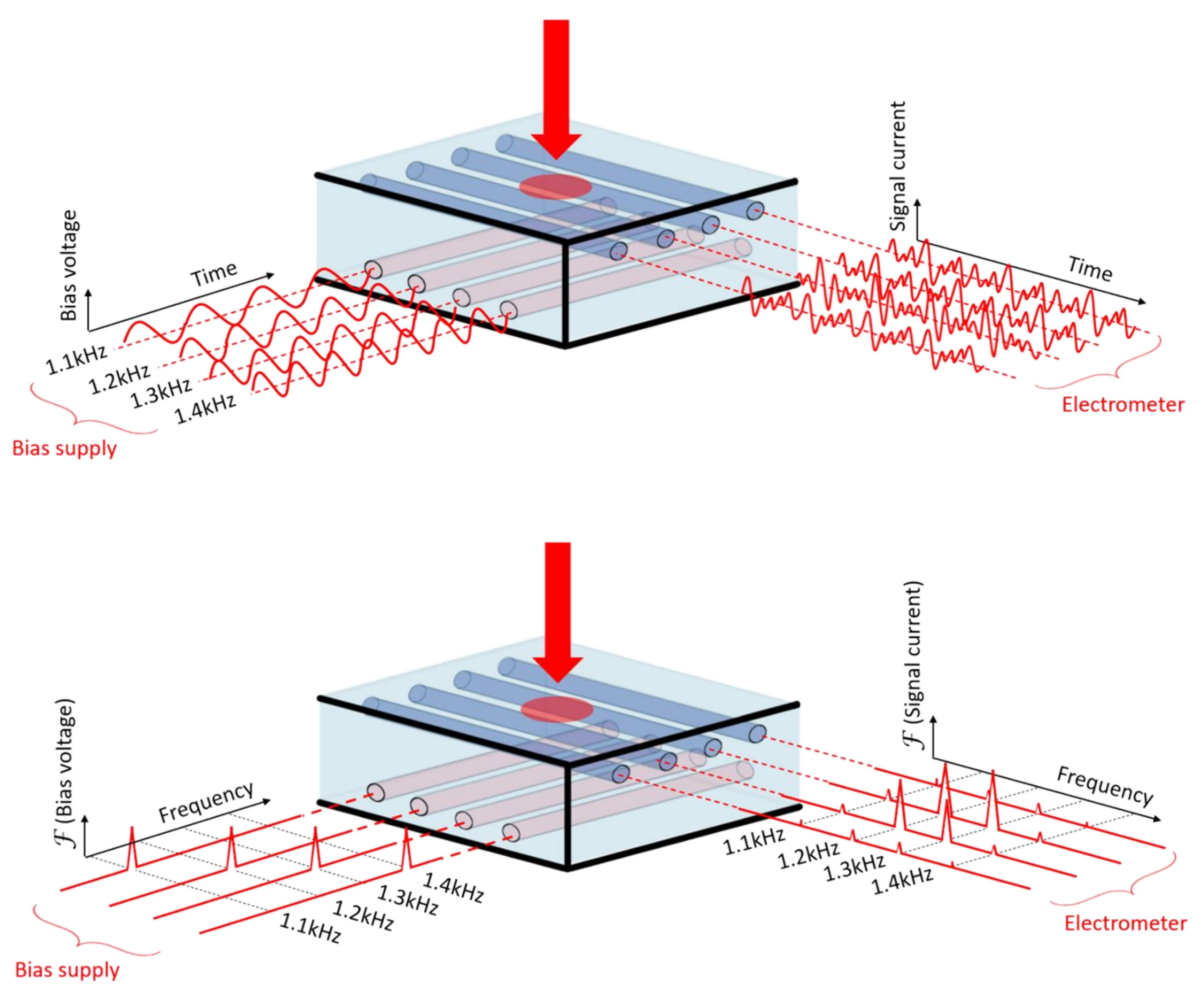
A non-destructive CVD diamond X-ray beam imaging monitor has been developed for synchrotron beamlines. The device can be permanently installed in the X-ray beam path and is capable of transmissively imaging the beam profile at 100 frames per second (FPS). The response of this transmissive detector at this imaging rate is compared to synchronously acquired images using a destructive fluorescent screen. It is shown that beam position, size, and intensity measurements can be obtained with minimal disturbance to the transmitted X-ray beam. This functionality is beneficial to synchrotron beamlines as it enables them to monitor the X-ray beam focal size and position in real-time, during user experiments. This is a key enabling technology that would enable live beam size feedback, keeping the beamline's focusing optics optimised at all times.

Why diamond?

CVD diamond is excellent for X-ray diagnostics: it is extremely transparent compared to other detector or fluorescent screen materials.



Detector operating principles

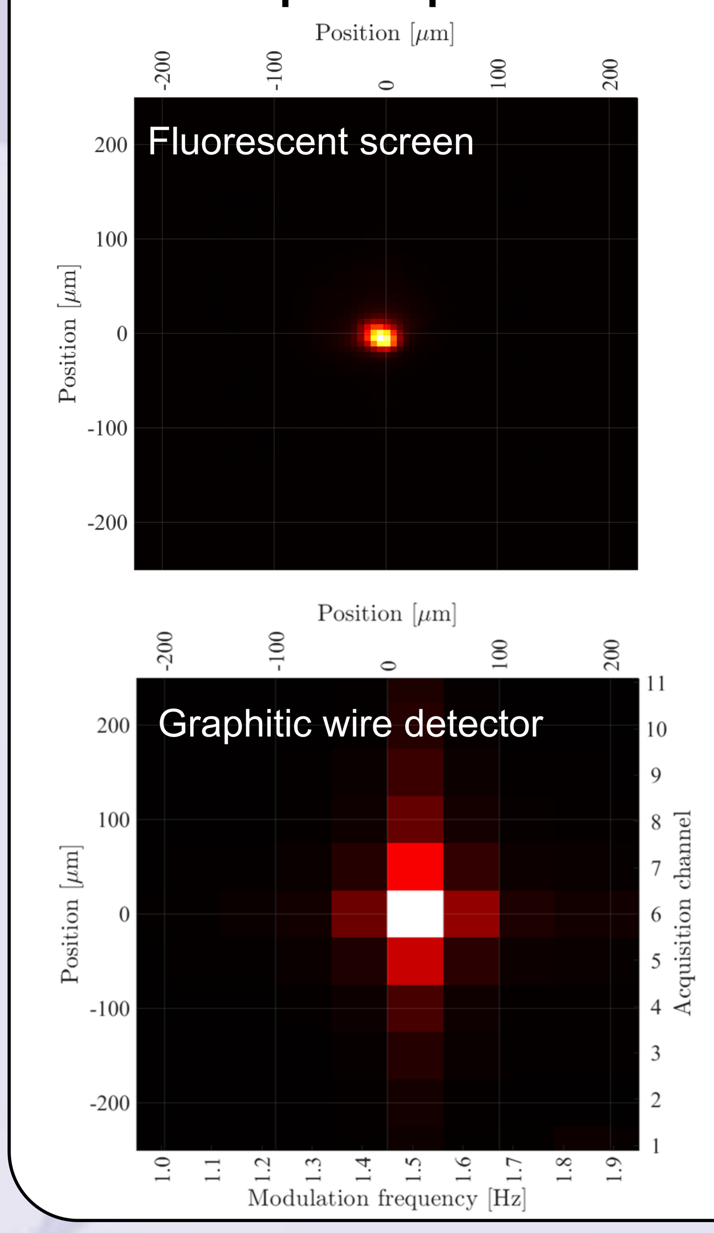


A new type of pixellated diamond X-ray beam profile monitor has been developed. It uses laser-written graphitic electrodes that are buried within the diamond instead of traditional surface metallisation. It also makes use of a novel lock-in readout technique to enable all pixels to be read simultaneously.

Shown opposite is an illustration of the concept. An AC bias voltage with a set frequency is applied to the '**bias**' electrodes, while signal currents are read out from orthogonal '**measurement**' electrodes.

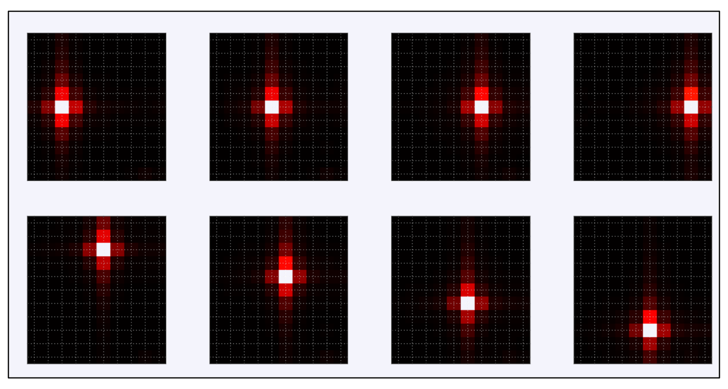
The Fourier transform of the measured signal currents builds up a picture of the 2-dimensional X-ray beam profile passing through the detector.

Detector point spread function



On the I18 beamline at Diamond light Source the X-ray beam was focused down to 20μm x 24μm FWHM in size - much smaller than the 50μm x 50μm pixel pitch of the graphitic wire detector.

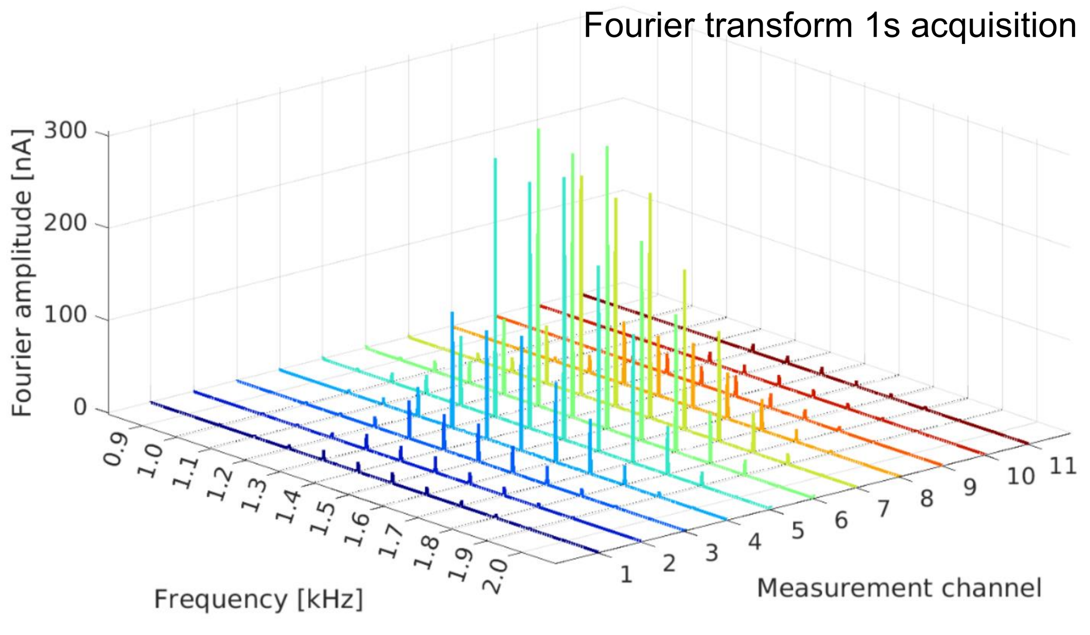
The detector exhibits some 'spectral leakage' into neighbouring pixels. However, this is extremely consistent across the face of the detector.



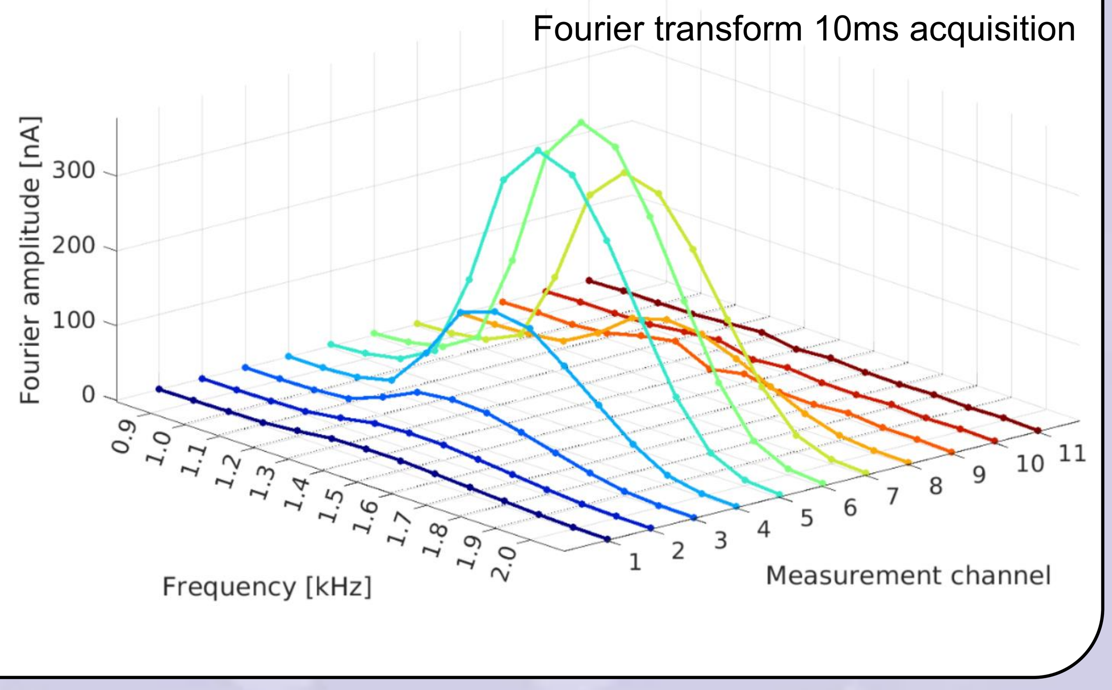
This makes it straightforward to deconvolve and recover an estimate of the original beam profile.

Readout at 100 frames per second

The signals are acquired using commercially available electrometers with a built in 20kHz ADC. Modulation frequencies are then carefully chosen: 1.0kHz, 1.1kHz, 1.2kHz, ..., 1.9kH. The plot (right) shows the resulting Fourier transform from 1s of acquisition.

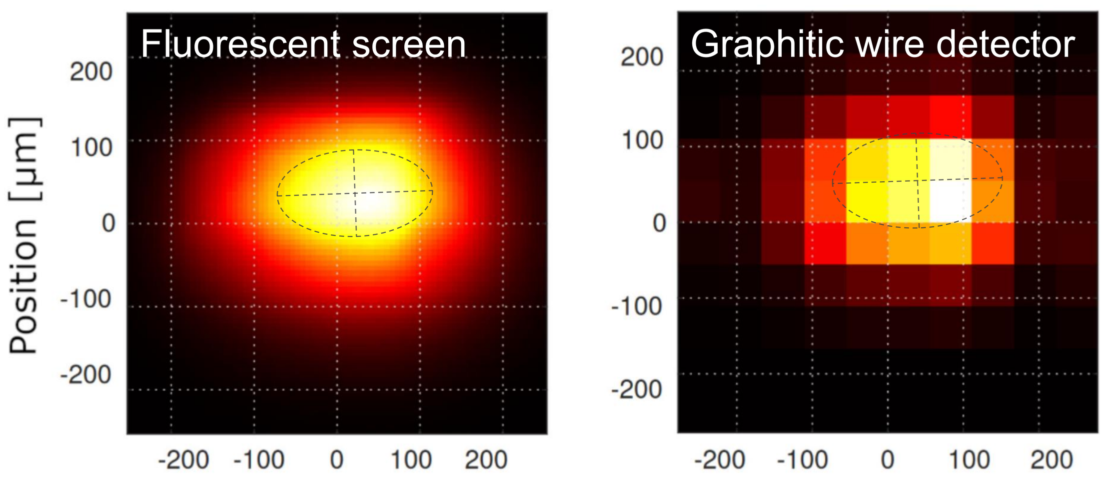


With a 20kHz sampling rate, a 10ms acquisition will contain 200 samples. The discrete Fourier transform of these samples will result in each of the modulation frequencies occupying exactly one frequency bin. Each frequency bin corresponds to one column of pixels on the detector.



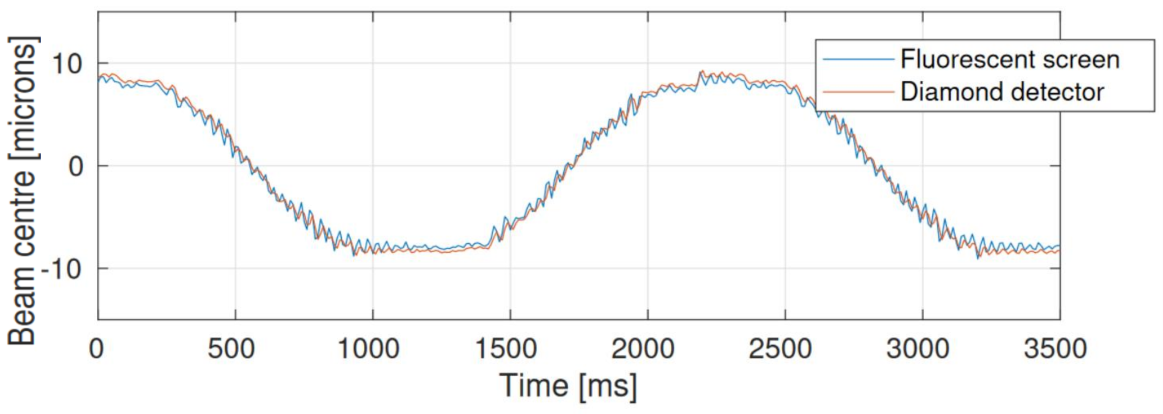
High frame rate imaging results

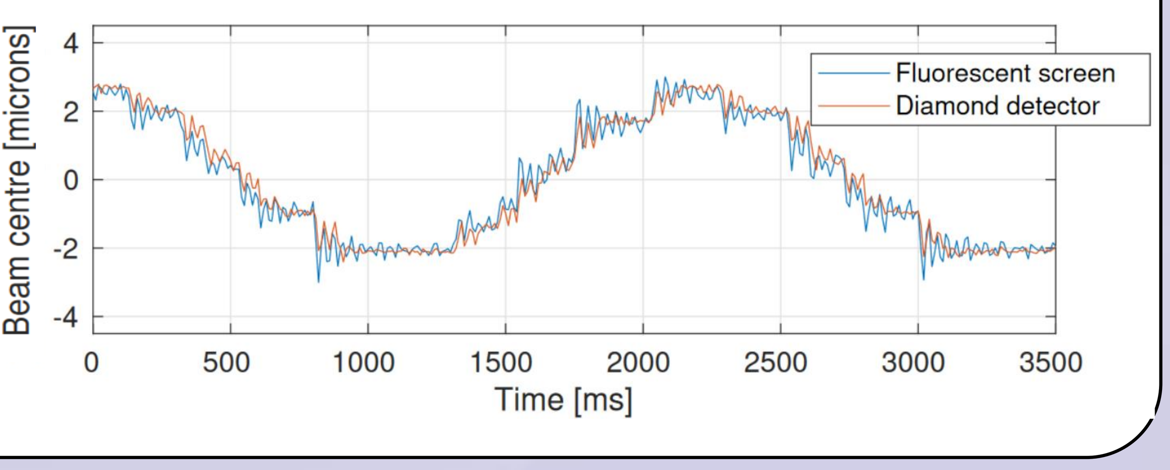
To benchmark the performance of the graphitic wire detector against a traditional fluorescent screen observed by a CMOS camera, both were installed on the I18 beamline at Diamond. The fluorescent screen was mounted downstream of the graphitic wire detector. The beam was focused to 240μm x 180μm FWHM. Both instruments were synchronised and acquiring data at 100 FPS.



A 2-dimensional Gaussian fitting routine was used to find the beam centroid from the obtained 100 FPS images.

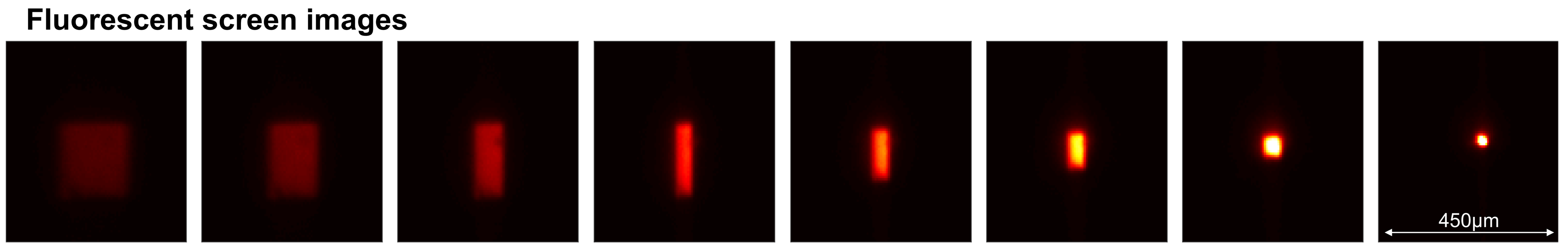
A series of vertical stepper motor sweeps were carried out, moving the graphitic wire detector and the fluorescent screen up and down. Two sweeps are shown opposite: ±30μm (top), and ±3μm (bottom). At 100 FPS imperfections of the motor movement are clearly visible, even though the motion is much less than one 50μm pixel size.



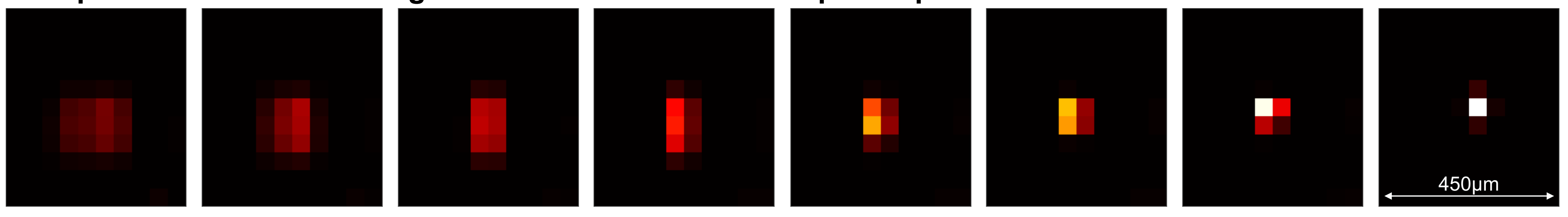


Images acquired during beamline focusing

Fluorescent screen images



Graphitic wire detector images after deconvolution with point spread function



This image sequence was obtained as the beam was focused down at the sample point. The graphitic wire detector can resolve the beam size, shape, and intensity during this operation. Though the resolution is poorer than the fluorescent screen, it is transparent enough to remain permanently in the beam path.

Conclusions

The graphitic wire detector obtained 100 FPS position measurement results are comparable to that obtained from a traditional fluorescent screen, however the X-ray absorption is significantly less than most fluorescent materials. The graphitic wire detector may be permanently installed in the X-ray beam path, offering significant advantages over fluorescent screens or knife-edge scans which generally cannot be used during user experiments.

This detector is beneficial to synchrotron beamlines as it enables scientists and users to monitor the X-ray beam focal size and position in real-time, during user experiments.

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