An Experimental Comparison of Single Crystal CVD Diamond and 4H-SiC Synchrotron X-Ray Beam Diagnostics

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- Experimental Set-up
- Surface Signal Uniformity
- Temporal Response
- Bias Requirements
- Flux Linearity
- Conclusions

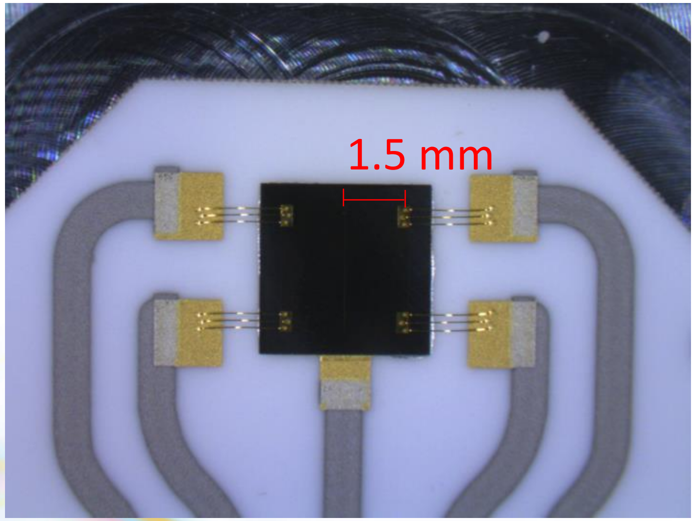
Background

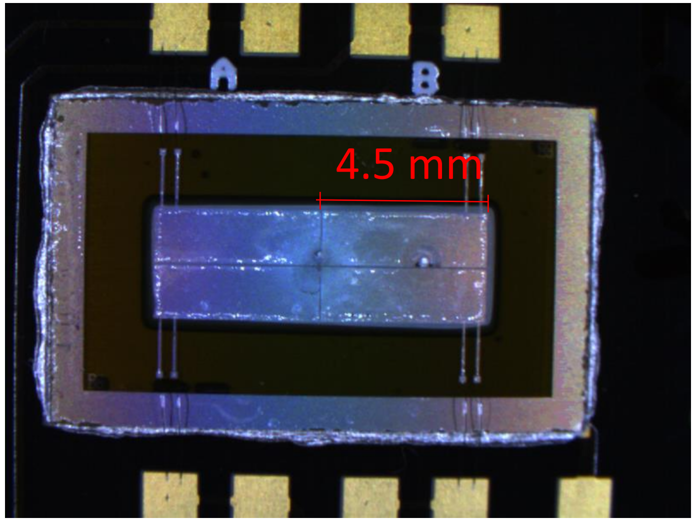
Non destructive X-ray Beam Position Monitors (XBPMs) are vital for real-time monitoring of beam position and intensity.

Currently single crystal CVD diamond XBPMs (sc-diamond) are well established for the detection of ionising radiation due to their transparency, radiation hardness and thermal conductivity (see talk by Chris Bloomer).

4H-SiC XBPMs are a recent development that have potential to provide the same benefit with larger apertures.

A direct comparison between these two devices has yet to be completed on a synchrotron X-ray beamline.

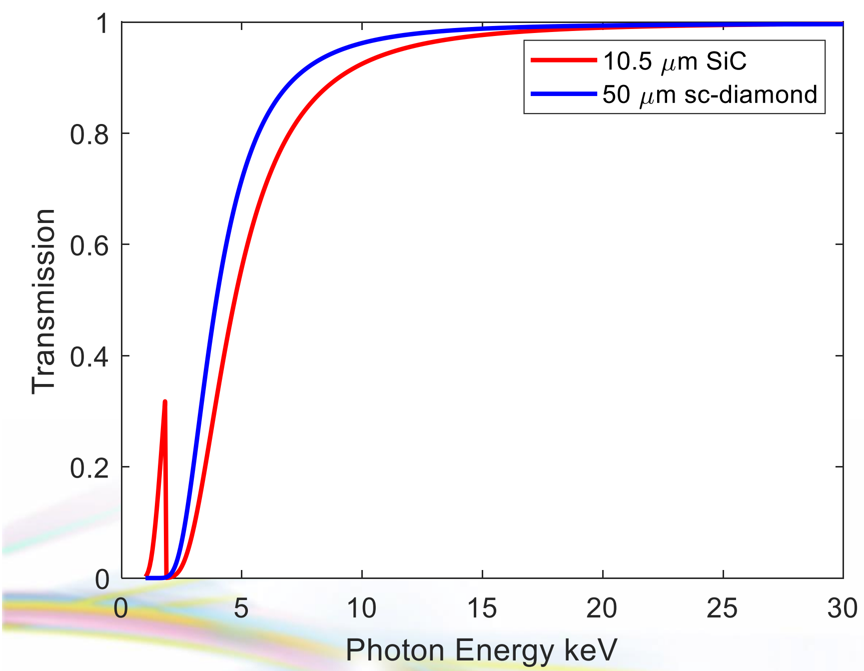


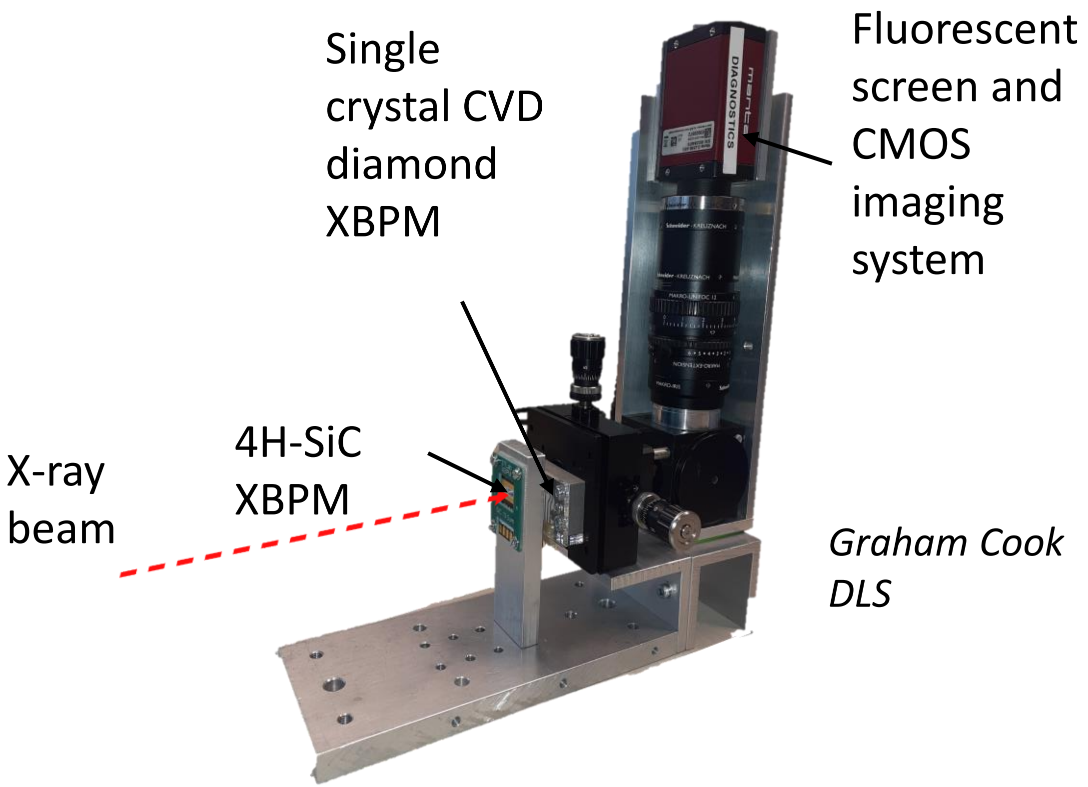


Experimental Set-up

Two X-ray Beam Position Monitors (XBPMs) have comparable X-ray transmission used for direct comparison:

- A 10.5 µm thick 4H-SiC XBPM
- A 50 µm thick sc-diamond XBPM





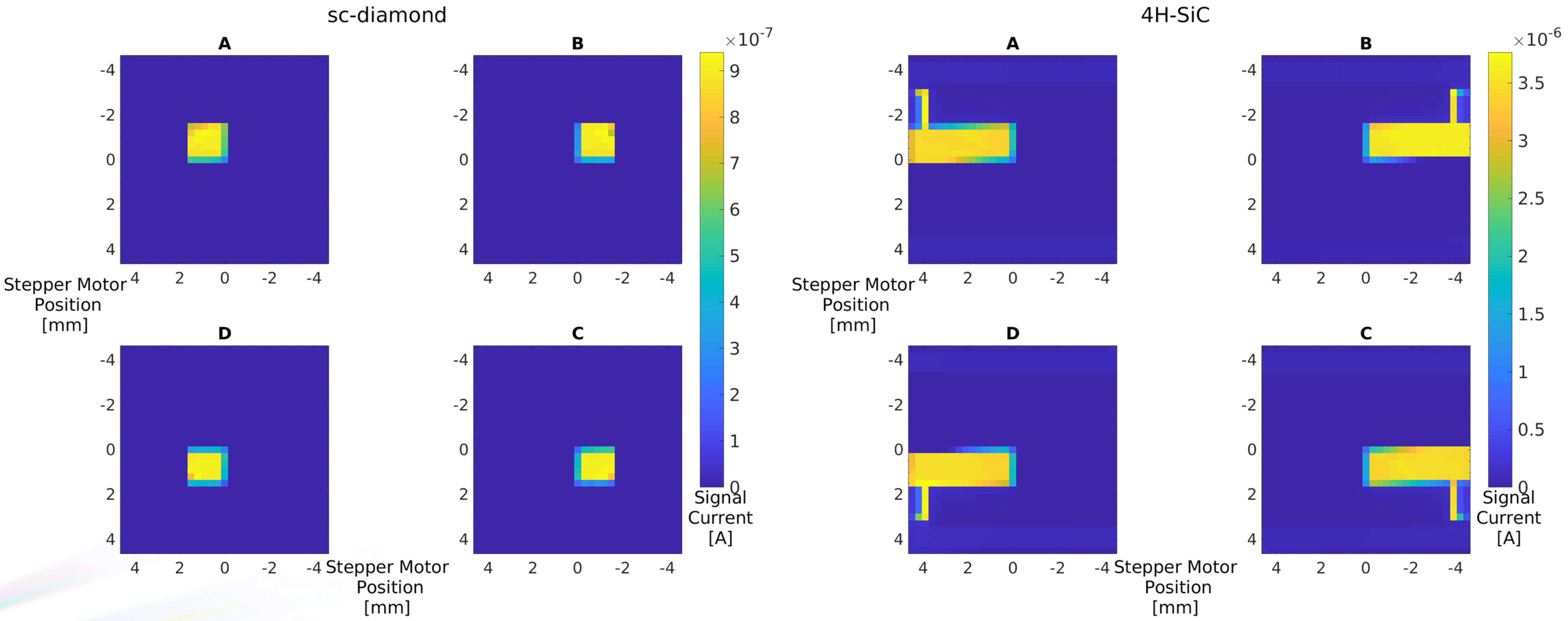
Graham Cook DLS

The two XBPMs were mounted in series with the camera upstream, the whole detector system was mounted on a x-y motion stage.

The distance between the three devices is small enough the incident beam can be considered identical.

Surface Signal Uniformity

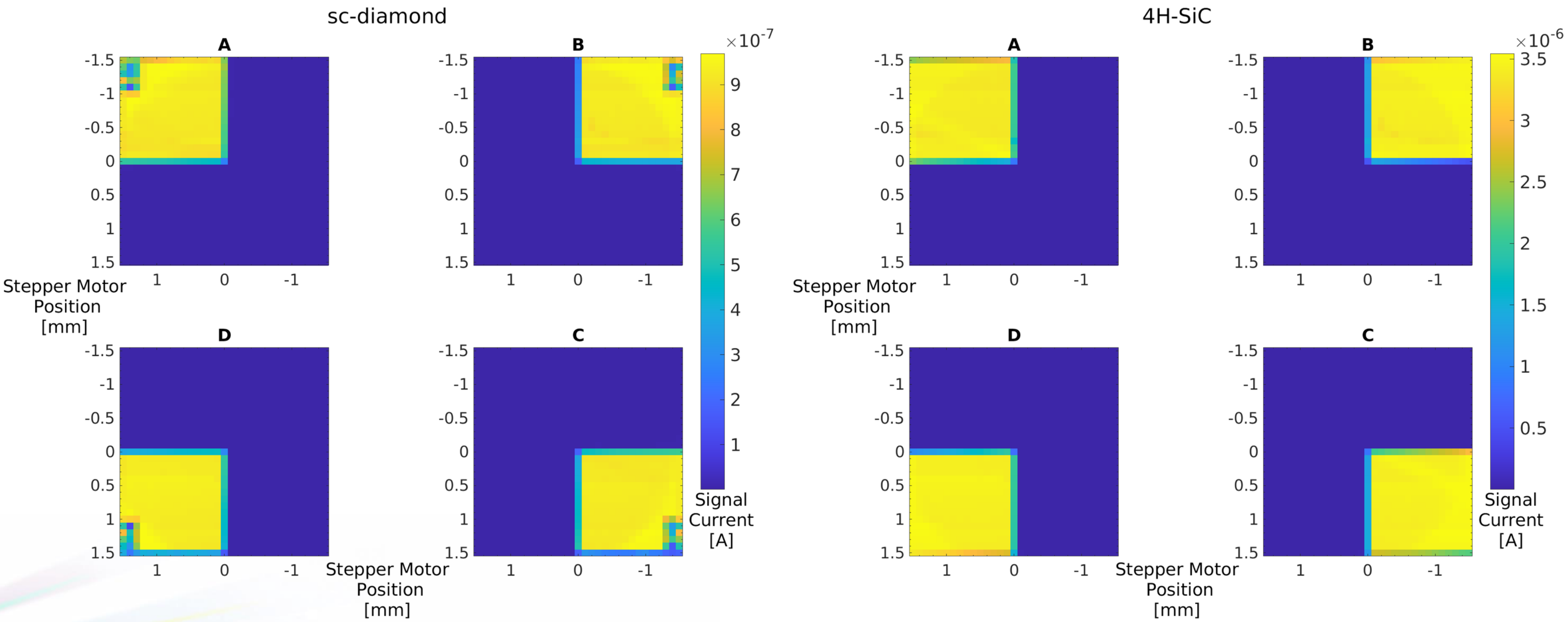
A 4.5 mm 2D raster scan across the surface of both XBPMs, showing the signal current on each quadrant



Validation that 4H-SiC active region is larger than sc-diamond.

Surface Signal Uniformity

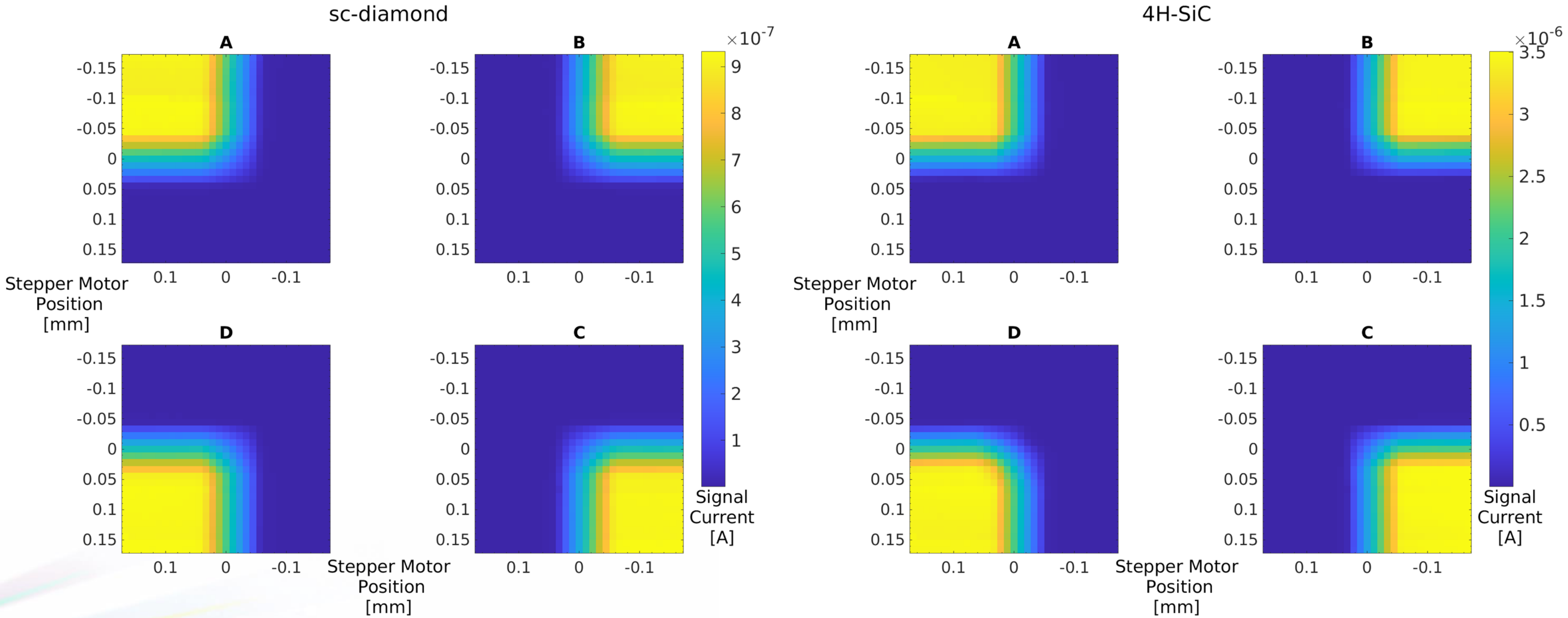
A 1.5 mm 2D raster scan across the surface of both XBPMs, showing the signal current on each quadrant



Observation of some defects at the edges of sc-diamond

Surface Signal Uniformity

A 0.17 mm 2D raster scan across the surface of both XBPMs, showing the signal current on each quadrant

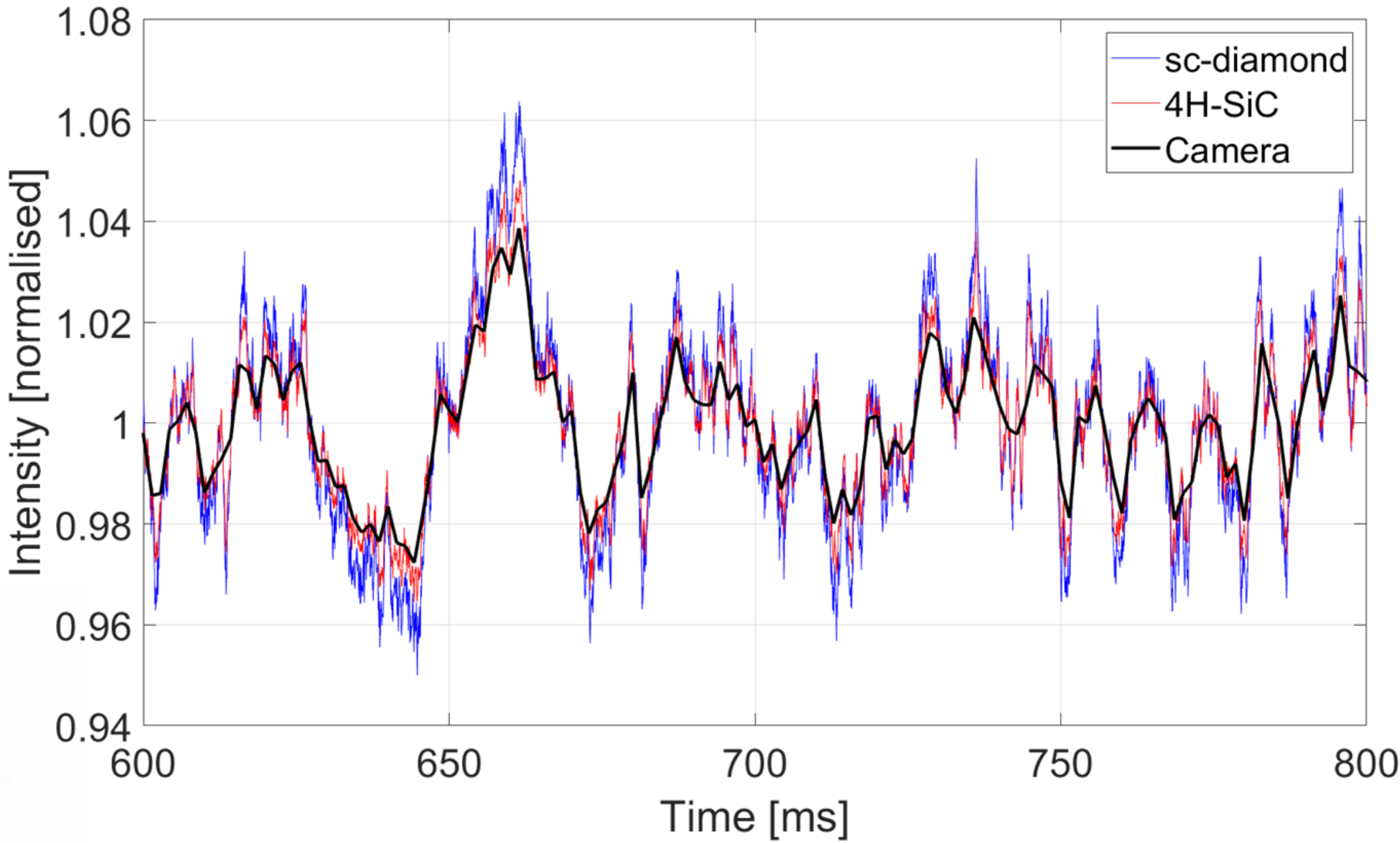


Both XBPMs visually indistinguishable

Temporal Response: Intensity

Taking synchronous intensity data from both XBPMs at a rate of 20 kHz along with 700 Hz data from a camera upstream.

The motion on both XBPMs is correlated and also visible on the camera, suggesting the resolution of the devices are comparable.



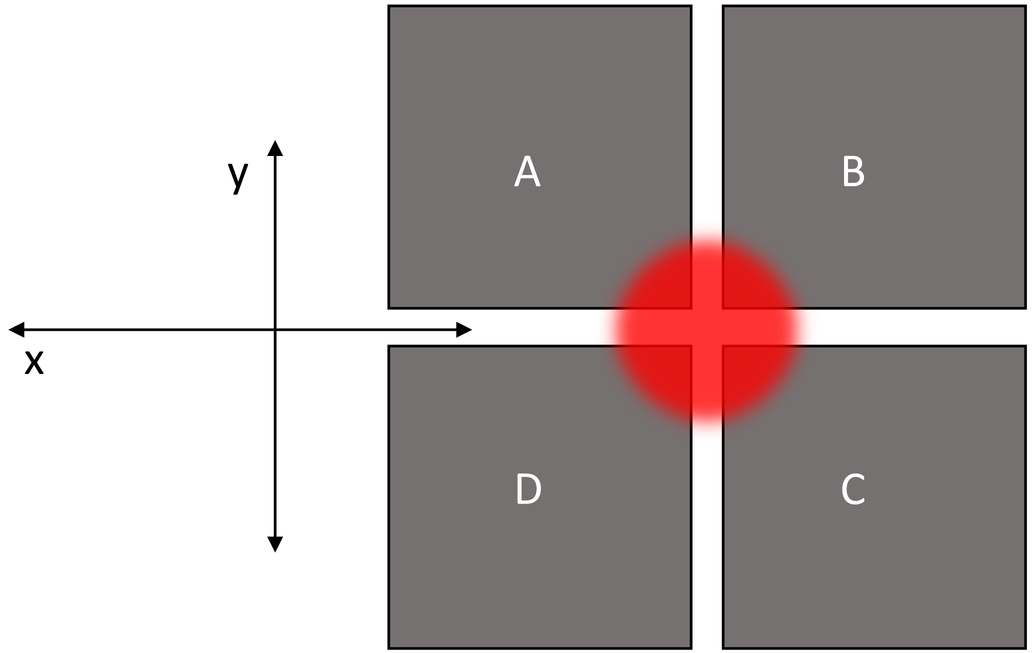
Temporal Response: Position

The four quadrants of the XBPMs can be used to calculate the position of the beam.

As the beam passes through the XBPMs electron-hole pairs are generated these travel to 4 electrodes, a combination of the current gives rise to the position of the beam.

$$x = K_x \frac{(A+D) - (B+C)}{A+B+C+D}$$

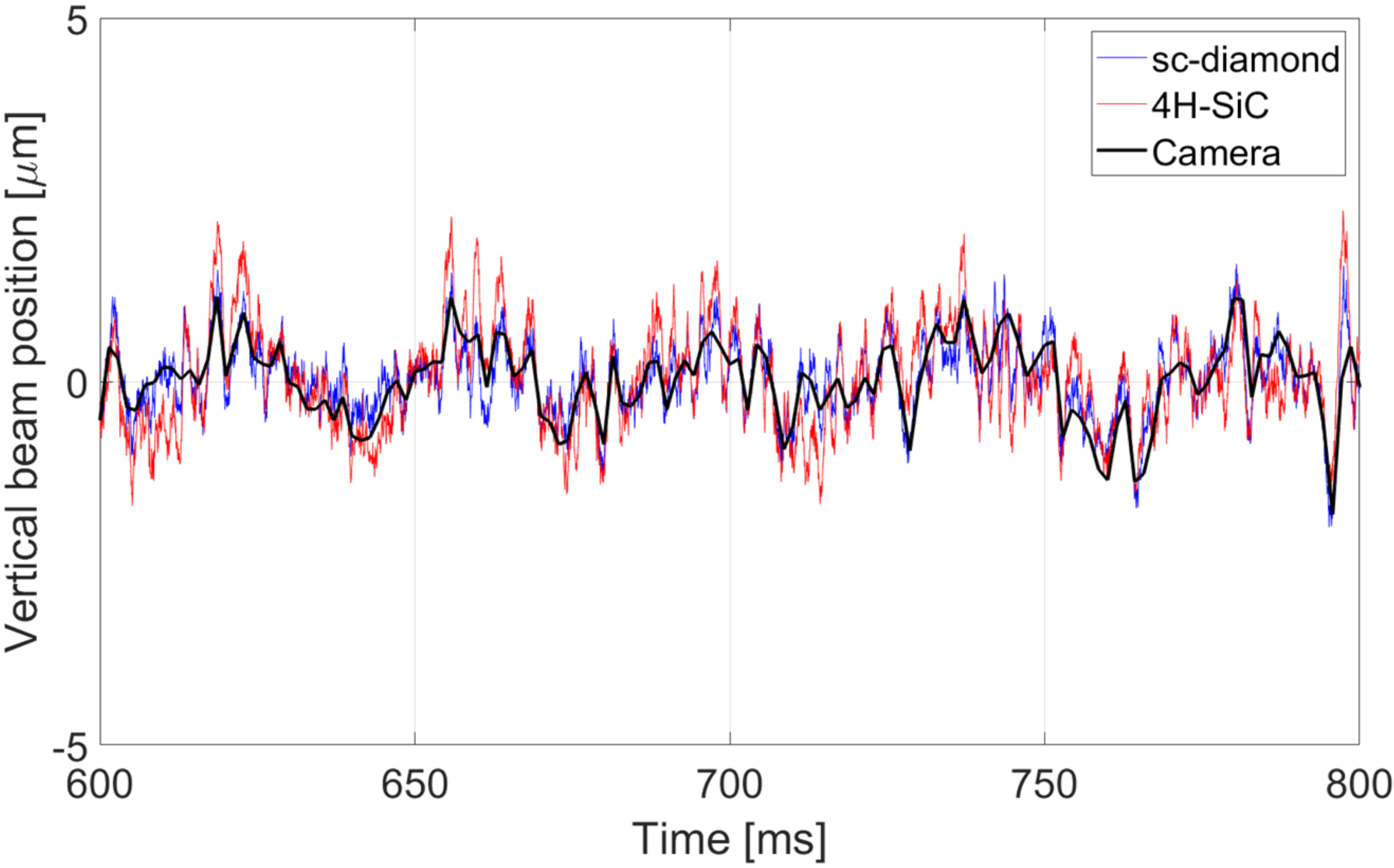
$$y = K_y \frac{(A+B) - (C+D)}{A+B+C+D}$$



Temporal Response: Position

Both the XBPMs measure comparable vertical beam position variation over a 200 ms data collection.

The beam motion is relatively small, ~ 4% the beam size, both XBPMs are able to measure this motion with greater resolution than the camera.

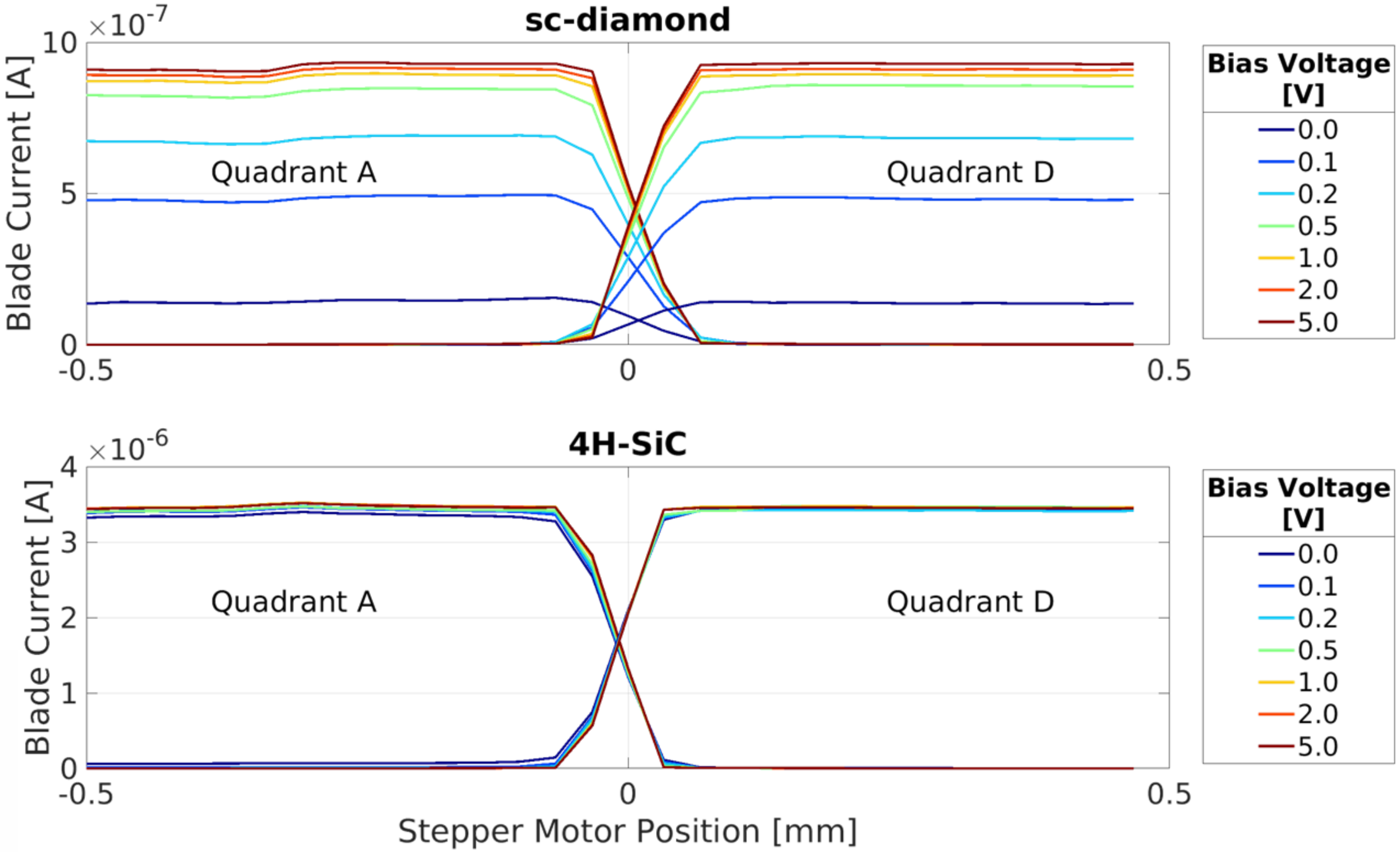


Bias Requirements

A one dimensional stepper motor scan was completed, during which the bias voltage applied to both XBPMs was varied.

The sc-diamond XBPM requires an applied bias voltage > 0.5 V in order to achieve a high signal current.

Interestingly the 4H-SiC XBPM can operate without any bias voltage applied

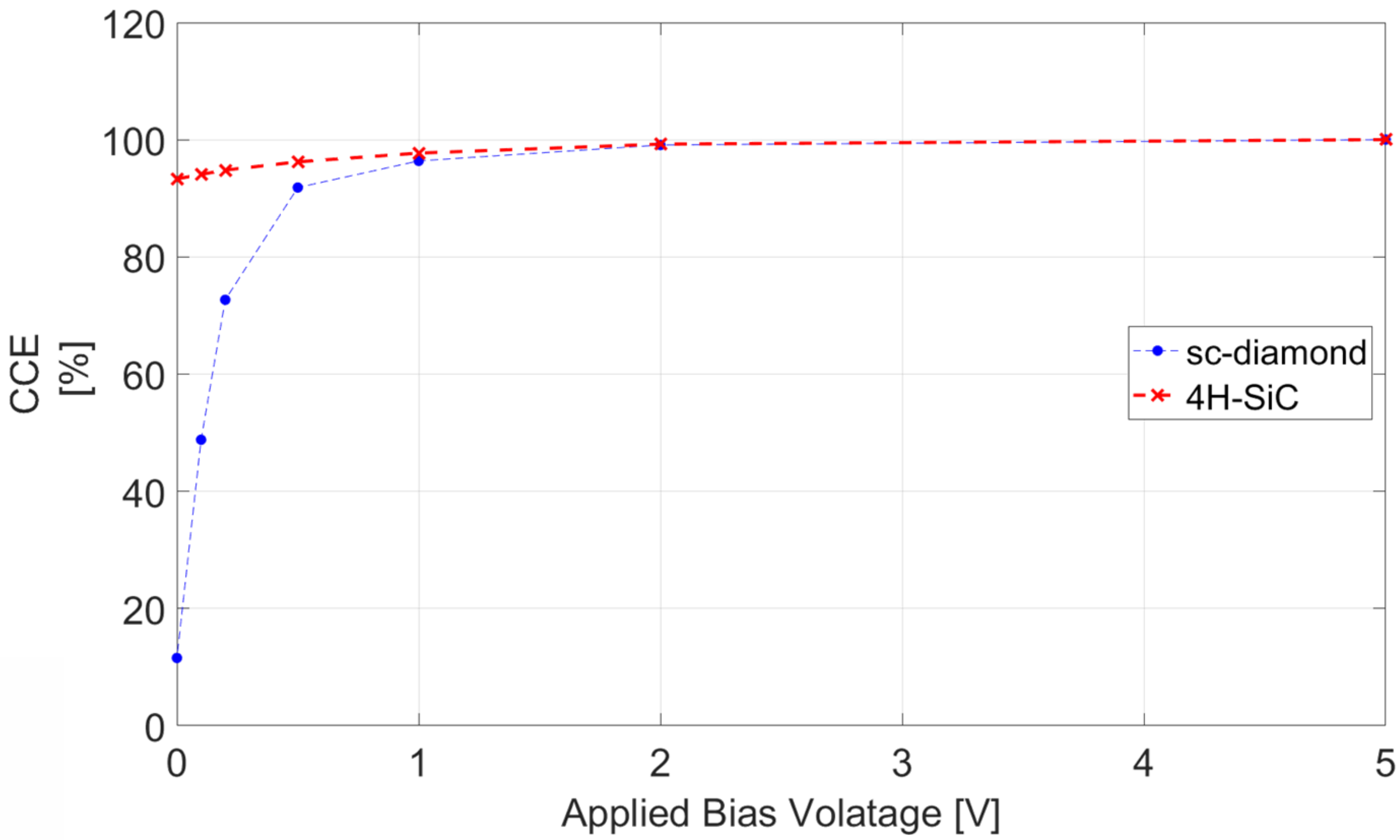


Bias Requirements: CCE

The Charge Collection Efficiency (CCE) demonstrates the difference in the performance of the two XBPMs with various applied bias voltages.

The 4H-SiC XBPMs can operate without a bias due to the doping of the surface. The device can be thought of as a p-n junction diode.

When there is no bias applied to 4H-SiC, there is still a built-in bias causing the charge carriers to flow to the electrodes.

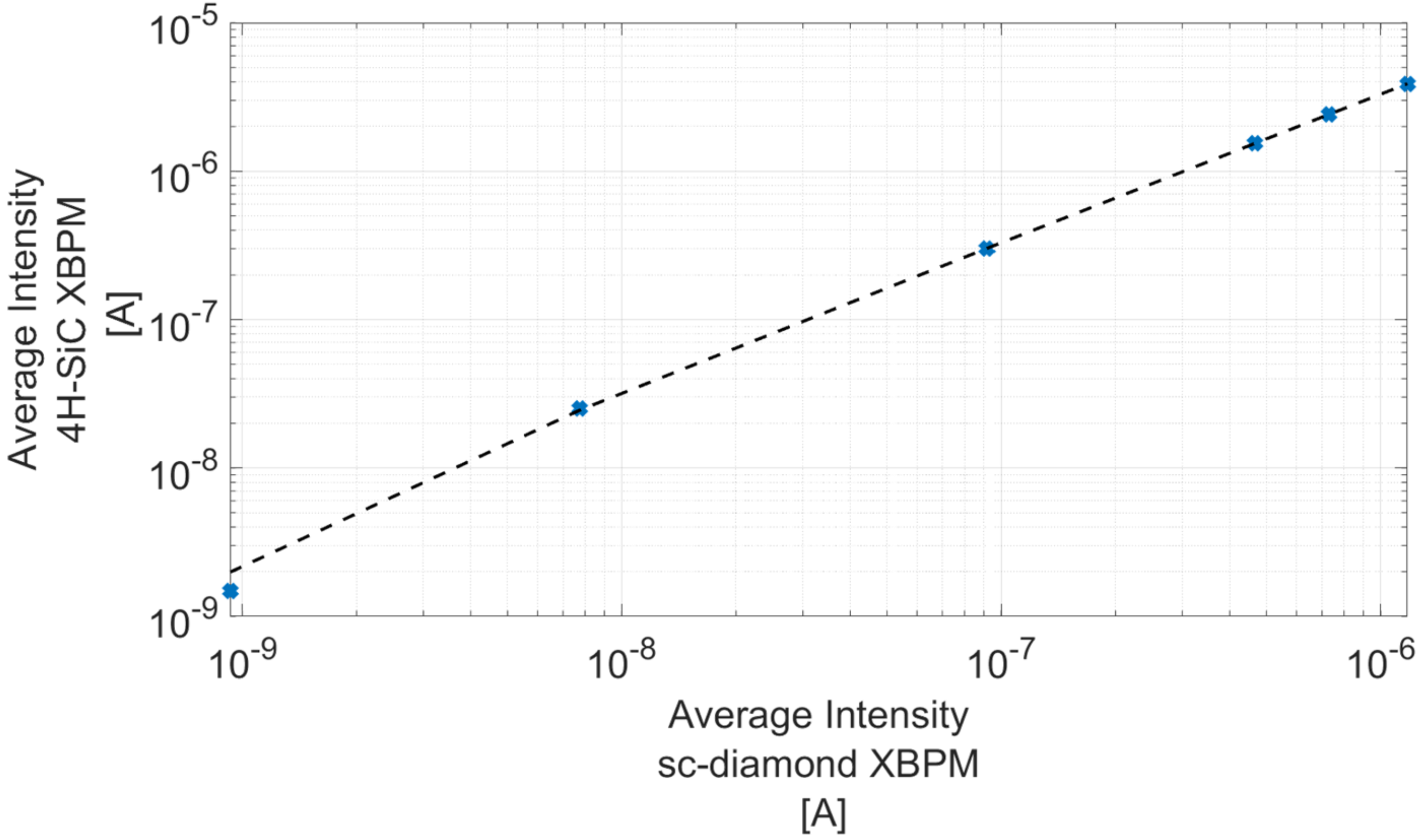


Flux Linearity

The flux of the incident beam was varied by use of different thicknesses of aluminium filters available on the beamline.

The average total intensity was measured over 30 seconds of 20 kHz data.

The linearity of the graph shows the similarity in the performance of the 10.5 µm thick 4H-SiC XBPM and the 50 µm thick sc-diamond.



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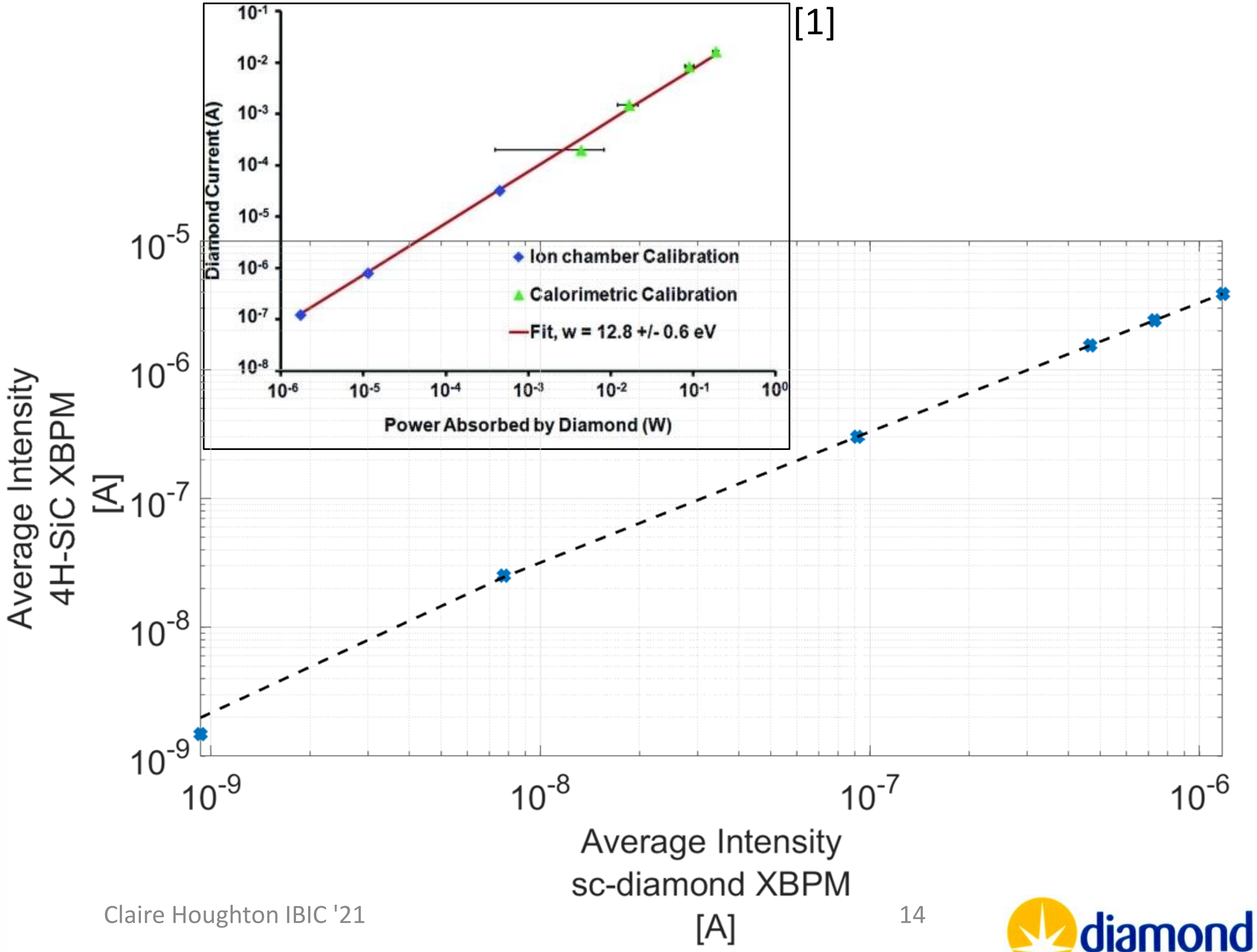
50 µm sc-diamond XBPM has previously been shown to be linear with flux[1]



[1] Bohon J et al. J Synchrotron Radiat. 2010;17(6):711-718.

Conclusion

An experimental comparison between the existing commercially available sc-diamond and a new 4H-SiC non-destructive X-ray Beam Position Monitors has been conducted.

- The 4H-SiC XBPM has equivalent operational performance to the sc-diamond XBPM in signal uniformity, temporal resolution and flux linearity.
- 4H-SiC XBPMs can be operated without a bias voltage simplifying the installation on beamlines.
- For beamlines with large beam size the 4H-SiC has a larger surface area to allow for in situ beam position measurements
- The XBPMs were tested in a nitrogen environment, with no differences in the handling despite the thickness.
- The cost of the two devices is roughly equivalent.

Based on these results the 4H-SiC should be considered an option for non-destructive monitors for synchrotron X-ray beamlines in the future.

Acknowledgements

I would like to thank Konstantin Ignatyev and the whole of DLS I18 for giving the beam time necessary for the experiment. I would also like to thank Codrutza Dragu for her work on the synchronous trigger system used in this work and Graham Cook for his work on the mounting system.

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