doi:10.1017/S1431927622009503
Microsc. Microanal. 28 (Suppl 1), 2022

Fast Solid-state Segmented Detectors: Improvements and Implications for DPC-STEM

Tiarnan Mullarkey[1,2]*, Jonathan J.P. Peters[1], Grigore Moldovan[3], Jonathan Garel[4] and Lewys Jones[1,5]

[1.] School of Physics, Trinity College Dublin, Dublin, Ireland
[2.] Centre for Doctoral Training in the Advanced Characterisation of Materials, AMBER Centre, Dublin, Ireland
[3.] point electronic GmbH, Erich-Neuss-Weg 15, D-06120, Halle (Saale), Germany
[4.] El-Mul Technologies Ltd, Rehovot, Israel
[5.] Advanced Microscopy Laboratory, Centre for Research on Adaptive Nanostructures & Nanodevices (CRANN), Dublin
* Corresponding author: mullarkt@tcd.ie

Differential phase contrast (DPC) imaging in the scanning transmission electron microscope (STEM) measures the deflection of electrons as they pass through a specimen, providing a visualization of electromagnetic fields. Because of this, it has found application in a number of important research areas including magnetic domains, skyrmionics, p-n junctions, ferroelectrics, and quantum wells [1]. Integrated DPC (iDPC) signals can further provide phase contrast information, allowing the imaging of both light and heavy elements [2]. These capabilities are complemented by compatibility with simultaneous annular dark field (ADF) imaging and as a result DPC imaging has seen increased popularity in recent years.

Measuring the electron beam deflection at each STEM probe position requires special detector geometries, the most prominent of which is the use of a segmented quadrant-detector. More recently, pixelated STEM detectors have been used, though typical readout speeds are several orders of magnitude slower than conventional detectors. Segmented detectors facilitate many microscopists preference for high-speed and low-dose conditions for DPC imaging of in-situ events or imaging beam sensitive materials. In iDPC imaging, the integration process rejects the non-integrable vector fields and can give an improved signal to noise ratio over traditional ADF detectors. Integration approaches however often need to be performed after the full image has been acquired, and integration approximations applicable for real-time analysis can be susceptible to noise [3]. In any case, as the limit of signal to noise ratio is approached, the recoverable information is limited. This in turn limits the minimum dose achievable, or similarly the maximum framerate achievable.

Here we explore the limits of DPC STEM when using a recently developed solid-state 6 segment detector (2 annular rings and 4 annular segments) produced by El-Mul Technologies (**Figure 1**). The use of a solid-state detector delivers minimal segment cross-talk, improved speed and low background noise, whilst the detector geometry allows the fully simultaneous acquisition of low and medium angle annular dark field, DPC and electron energy loss spectroscopy (EELS). Of importance for DPC imaging is the excellent detector uniformity between segments, with minimal variation between individual electron detection events. Never the less, we combine this with our single electron pulse counting technique [4], to further explore DPC STEM with a true zero noise floor and with quantified signals in units of single electrons. To enable image acquisition from in-house developed pulse counting hardware and simultaneous image acquisition from all detectors and segments at high frame rates (as low as 20 ns per pixel), we use a point electronic DISS6 scan generator interfaced with a 300 kV FEI Titan G2 [5].

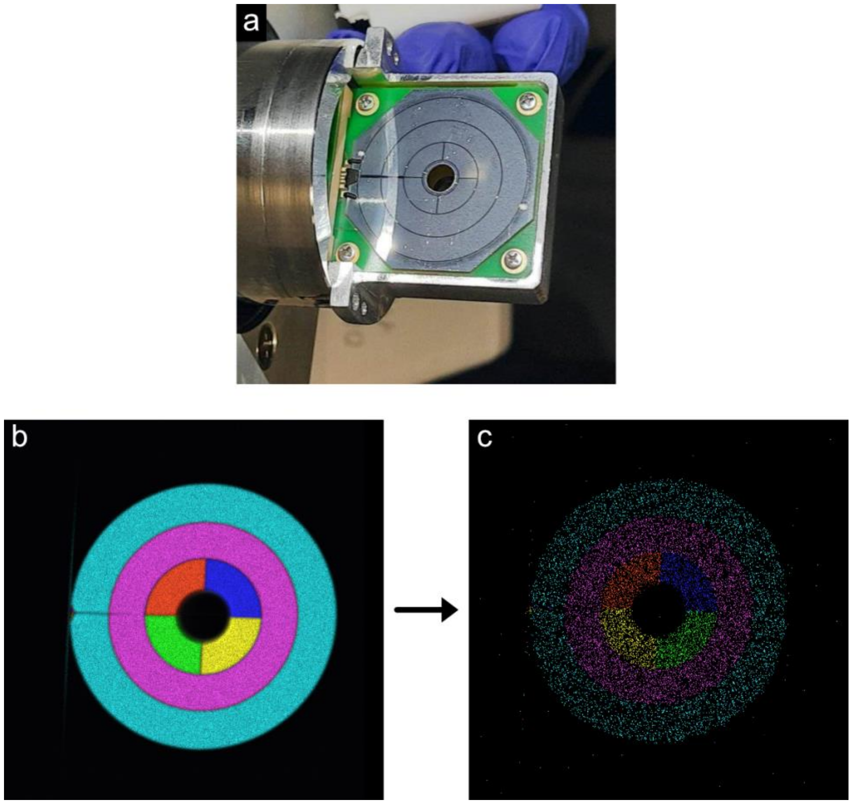

Figure 1. a Photograph of the 6 segment DPC detector before installation. **b** Detector map at high dose with individual segments colored uniquely. **c** Corresponding detector map at low dose with single electron counting.

References:

[1] I. Lazić, E.G.T. Bosch, S. Lazar, Phase contrast STEM for thin samples: Integrated differential phase contrast, Ultramicroscopy. **160** (2016) 265–280.

[2] Y.O. Murakami, T. Seki, A. Kinoshita, T. Shoji, Y. Ikuhara, N. Shibata, Magnetic-structure imaging in polycrystalline materials by specimen-tilt series averaged DPC STEM, Microscopy. **69** (2020) 312–320.

[3] A. Ishizuka, K. Ishizuka, Observation of Phase Objects using STEM-Differential Phase Contrast (DPC) Microscopy, JEOL News. **55** (2020).

[4] T. Mullarkey, C. Downing, L. Jones, Development of a Practicable Digital Pulse Read-Out for Dark-Field STEM, Microsc. Microanal. **27** (2021) 99–108.

[5] The authors would like to acknowledge the Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) and the Advanced Materials and BioEngineering Research (AMBER) Network for financial and infrastructural support for this work. L.J is supported by award URF/RI/191637. J.J.P.P. and L.J. acknowledge SFI grant 19/FFP/6813, T.M. acknowledges the SFI & EPSRC Centre for Doctoral Training in the Advanced Characterisation of Materials (awardreferences 18/EPSRC-CDT-3581 and EP/S023259/1).

https://doi.org/10.1017/S1431927622009503 Published online by Cambridge University Press