Diffraction contrast suppression in Lorentz microscopy by application of fast pixelated detector imaging in STEM

Krajnak, M.[1,2], McGrouther, D.[3] and McVitie, S.[3]

[1] Department of Materials Engineering, Monash University, 3800, Australia, [2] SUPA, School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, Australia, [3] SUPA, School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, United Kingdom

Lorentz microscopy in field free scanning transmission electron microscope (STEM) can be very sensitive to non-magnetic imaging contributions from diffraction effects in polycrystalline films. Currently this imaging mode, known as differential phase contrast (DPC) imaging uses a segmented detector, allows measurement of the Lorentz defection of the beam due to the in-plane magnetic induction of the specimen [1]. Due to the segmented detector design, any changes of electron beam intensity and homogeneity will add diffraction contributions to detected magnetic induction. Using an annular segmented detector allows a degree of suppression of the diffraction contribution [2]. However for thin polycrystalline films the diffraction effects can result in images where the magnetic signal variation is very weak in comparison. In order to combat this much more effectively we propose using a pixelated detector in STEM imaging, where the sensitivity to magnetic signal variation can be improved by at least an order of magnitude [3].

The imaging was carried out in a field free STEM. To prove the principle, we firstly used a CCD camera as the detector. Convergent beam electron diffraction (CBED) pattern in the form of central disk was recorded at each point in the 2D scan resulting in a 4D dataset. Analysis of these diffraction patterns by image processing and computer vision algorithms allowed a large degree of reduction of the diffraction effects. The substantial improvement is demonstrated in images obtained from a 20nm thick polycrystalline Permalloy (Ni80Fe20) in Fig.1. This figure shows an image of integrated magnetic induction of an 180° magnetic domain wall using a) segmented and b) CCD camera. In the standard DPC image in a) the diffraction contrast due to the 5-10nm grains almost masks the domain contrast whereas in b) the domain contrast is the dominant. Linetraces from the images demonstrate the improvement further with the standard DPC image showing the large small scale diffraction effect in c) whilst the pixelated linetrace shows the smooth variation across the wall in d).

The CCD camera is not an ideal detector in STEM due to the speed of the acquisition (17 frames/s) and charge spreading. Therefore, after proving the principle we used the direct electron detector (Medipix3) which allowed much faster (550 frames/s) and more practical imaging with better noise characteristics. Fig.2 shows a result of direct electron detector imaging, where 256x256 pattern was acquired in 2min from a magnetic vortex structure in 20nm thick patterned Permalloy sample. Image a) is the bright field image reconstructed by summing each CBED central disk pattern, images b) and c) are two orthogonal images of the integrated magnetic induction, which are combined in d) with the colour wheel showing the direction and magnitude of the induction. We utilized an algorithm which allows sensitivity to subpixel deflection of the probe [3] to analyse this dataset. Such significant improvement can be used to measure very thin magnetic layers such as perpendicularly magnetised materials, which depends on tilting of the specimen in the microscope to generate contrast [4].

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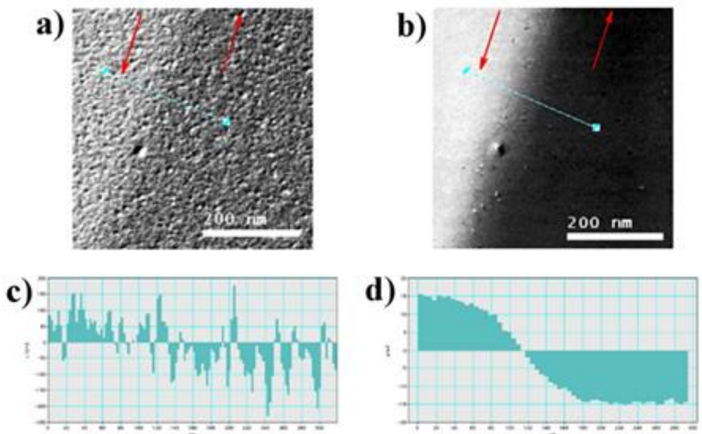

Fig. 1: Comparison of magnetic imaging of domain wall in 20 nm thick Permalloy, a) segmented detection b) pixelated detection, c) single line profile of domain wall (segmented detection), d) same profile (pixelated detection). Integrated magnetic induction orientation is shown by red arrows. Probe convergence semi-angle was 0.537mrad and camera length was 3 m.

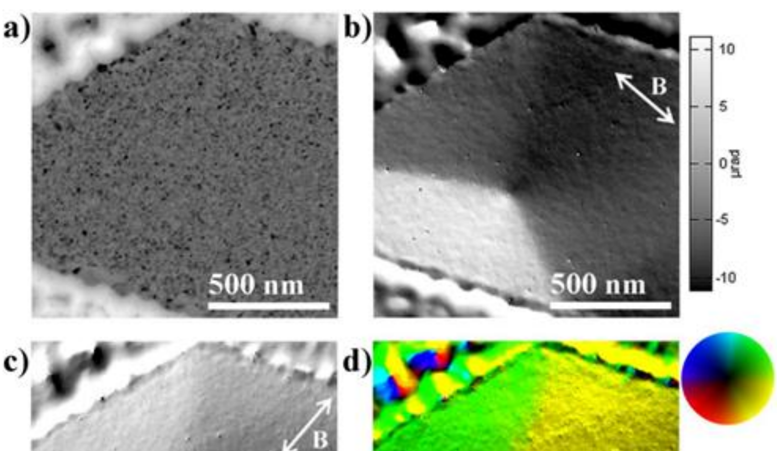

Fig. 2: Medipix3 imaging of patterned 20 nm thick Permalloy in which a magnetic vortex was formed. (a) is a bright field image reconstructed by sum of CBED disk, (b) and (c) are two orthogonal components of integrated magnetic induction, orientation is shown by double-headed arrows, (d) a colour image showing the orientation and magnitude of the induction. Probe convergence semi-angle was 2.15mrad and camera length was 6 m.