Nanoscale magnetic and structural characterization of Ne+ irradiated FeAl thin films using pixelated STEM

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Recent advances in 2-dimensional pixelated direct electron detectors have enabled the development of high acquisition rate imaging of the diffraction pattern in the scanning transmission electron microscope (STEM), resulting in the acquisition of a 4D STEM dataset of a full diffraction pattern for every scan position. One use for this is STEM differential phase contrast (DPC) imaging [1], which allows for quantitative measurements of the in-plane magnetic induction when operating the microscope with the objective lens turned off. This imaging mode is essentially convergent beam low angle diffraction, allowing for structural information to also be extracted from the diffraction patterns (Fig. 1b). This novel technique enables both strain and magnetic information to be extracted from a single dataset.

In this work we have simultaneously characterized both magnetic and physical (crystal) structure of patterned ferromagnetic stripes in $Fe_{60}Al_{40}$. As-deposited $Fe_{60}Al_{40}$ has an ordered B2 structure and is paramagnetic, but irradiation with Ne^+ ions causes transformation to a disordered A2 ferromagnetic BCC structure with a larger lattice parameter [2]. This allows for arbitrarily shaped ferromagnetic regions to be written using a focused ion beam (FIB) with a Ne^+ source. By using a JEOL ARM200cF probe aberration corrected STEM equipped with a MERLIN 1R (Medipix3) fast pixelated detector [Quantum Detectors Ltd], we are able to acquire datasets at 1 nm spatial resolution in aberration-corrected field-free Lorentz (objective-off) mode from patterned stripe structures with lateral dimensions from 0.02 - 4 um and lengths of 10 um (Fig. 1a). These possess unexpected domain structures in which a large fraction of the magnetization deviates away from the long-axis, against shape anisotropy. To uncover the origin of the induced magnetic anisotropy we determined the strain profile in the nanowires from the diffraction patterns, which was also found to be very anisotropic, with the lattice parameter along the long axis clamped to something close to that of the surrounding film (orange trace in Fig. 1c) whereas the lattice parameter along the short axis is significantly larger (blue trace in Fig. 1c), as expected from the irradiation. Our data shows that the resulting shape-dependent anisotropic strain fields exert a strong influence on observed magnetic domain structure.

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[2] Rantej Bali, *et al.*, Nano Letters, 14 (2014) 435-441, doi:10.1021/nl404521c

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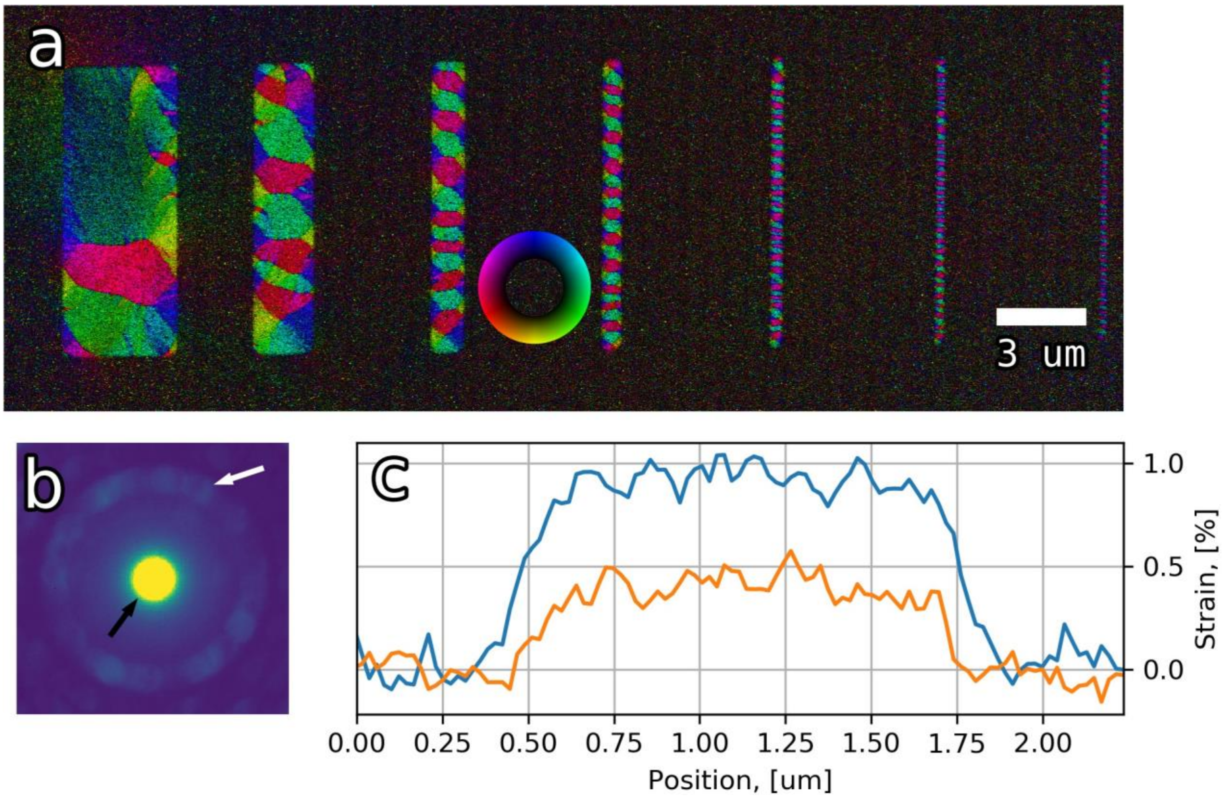

Fig. 1: a) STEM-DPC image showing the patterned ferromagnetic domains. b) Convergent beam diffraction pattern. Black arrow: direct beam, used to extract magnetic information. White arrow: diffraction spots, used to find structural information. c) Strain in the 3rd stripe from the left, in the long axis direction (orange) and the short axis direction (blue).