**Imaging magnetisation using Lorentz microscopy**

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**Simulated images of a test domain structure**

- Test magnetic domain structure
  - Arrows show direction of magnetisation

- Magnetic domains in NdFeB
  - Original Lorentz image of NdFeB showing domain boundaries at the edge of a thin film
    - Thanks to M.J. McCarthy at JOU for this image
  - Region at the centre of the Lorentz image on the left corrected for intensity variations due to specimen thickness

- Magnetic domains in Co
  - Lorentz image of a 15 nm thick Co film within a tunnel junction (IBM Amapers) with an applied field of \(-2.6 \times 10^{-3}\) T
  - x and y components of magnetisation recovered from a) with arrows on left image showing strength and direction
  - c) Histogram of x and y components of magnetisation from b) with the x component horizontally, the y component vertically and the origin in the middle. Dark image higher frequency and it can be seen that the histogram forms an arc of a circle

**Magnetic domains in NdFeB**

- Unfocused, focused 20 μm above specimen
  - Interaction of the electron wave with the test magnetic structure allows an electron microscope to observe the magnetic structure in the electron wave, so that the Lorentz images of this structure are shown on the right.

- Phase change induced in electron wave on passing through test structure
  - Electron phase change recovered from the undiffracted image above

- Magnetisation determined from the phase image (left). The centre of the image indicates the direction of the magnetisation, as shown by the arrows, and the intensity represents the strength of the magnetic field

- Electron phase change recovered from the above image

**Magnetic domains in Co**

- a) Lorentz image of a 15 nm thick Co film within a tunnel junction (IBM Amapers) with an applied field of \(-2.6 \times 10^{-2}\) T
  - b) x and y components of magnetisation recovered from a) with arrows on left image showing strength and direction
  - c) Histogram of x and y components of magnetisation from b) with the x component horizontally, the y component vertically and the origin in the middle. Dark image higher frequency and it can be seen that the histogram forms an arc of a circle

- Lorentz images and histograms of the magnetisation direction (as above) as the Co film is taken through a hysteresis cycle. The field applied for each image is: a) 0, b) \(-2.6 \times 10^{-2}\) T, c) \(-2.6 \times 10^{-3}\) T, d) \(-6.7 \times 10^{-3}\) T, e) \(-2.0 \times 10^{-3}\) T, and f) \(-3.2 \times 10^{-2}\) T. Note that the magnetisation in c) is not recovered properly as there is a reversal of magnetisation across the image on a scale larger than the area of the image, thus making the corresponding histogram difficult to interpret.