Thermomagnetic behaviour of an annealed FEBID-grown cobalt nanopattern examined by off-axis electron holography

Trevor P. Almeida[1], Damien McGrouther[1], András Kovács[2], Rafal Dunin-Borkowski[2] and Stephen McVitie[1]

[1]University of Glasgow, UK, [2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Germany

The demand for improved functionality of modern magnetoelectronic devices has led to the rapid development of innovative magnetic materials comprising hard and soft magnets, commonly referred as exchange-spring magnets. However, our current understanding of these exchange coupled CS NPs is limited to bulk magnetic measurements or micromagnetic modelling, and thus not sufficient to explain their tuneable magnetic properties. Modern scanning electron microscopes (SEMs) can incorporate systems for the injection of element- containing gases to fabricate magnetic nanopatterns (NPs) using focused electron beam induced deposition (FEBID). Further, Lorentz microscopy encompasses several techniques within the transmission electron microscope (TEM) that allow imaging of nano-scale magnetism. In this context, we are now in a timely position to use state-of-the-art FEBID and TEM facilities to synthesise CS systems and image directly the effect of localised magnetic behaviour of these bi-magnetic nanostructures.

In this study, the growth of Co NPs on MEMS-based *in-situ* TEM chips for localised magnetic studies is presented. The annealed Co NPs are shown to be polycrystalline and form hetero-structured core-shell NPs through surface oxidation (Fig. 1a,b). Off-axis electron holography is performed to reconstruct their morphology, thickness profile and image their individual magnetic vortex domain states (Fig. 1c,d). Combining off-axis electron holography with *in-situ* heating demonstrates the change in remanent spontaneous magnetisation with temperature of the vortex state (Fig. 1e,f) and change in remanent saturation state to a ‘s- shaped’ domain at 300°C (Fig. 1g), the complexity of which is revealed by a tilt series.

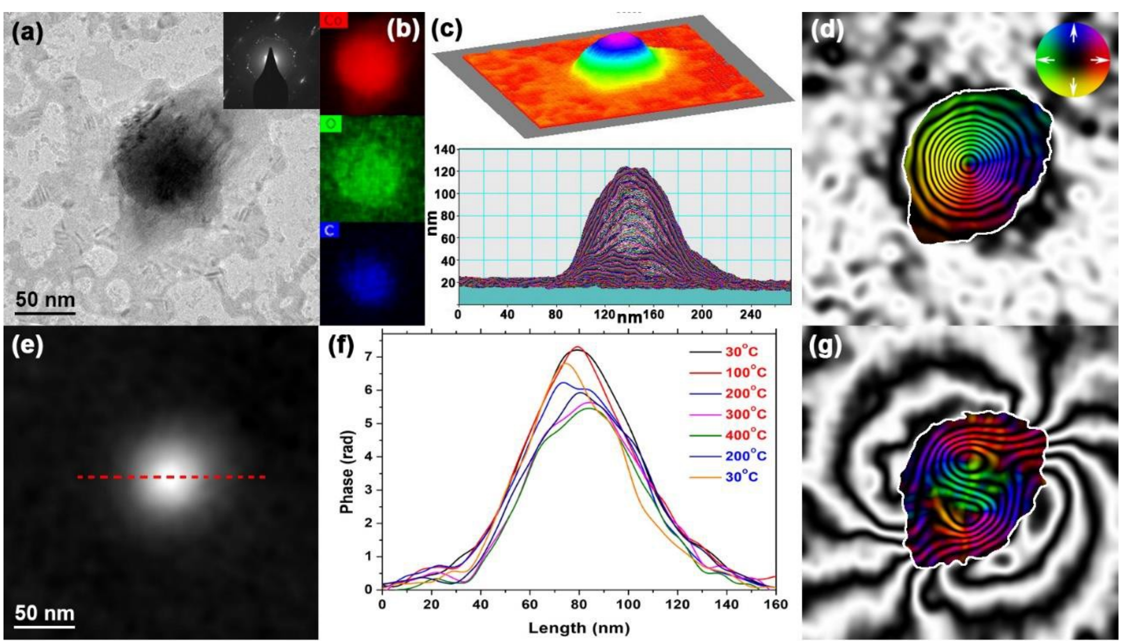

Figure 1. (a) TEM image; and (b) EDX chemical mapping of the annealed Co NP. (c) Morphology, thickness profile and (d) magnetic induction map of the Co NP. (e) Magnetic contribution to the phase and (f) line profiles of the vortex’s thermoremanent behaviour. (g) S-shaped domain state at 300°C.