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.