Focused ion beam direct writing of the magnonic structures into the metastable iron thin film

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Under normal conditions, at room temperature, iron occurs in the ferromagnetic phase with body-centered-cubic (bcc) crystallographic ordering. We have shown that it is possible to grow thin films of iron-nickel alloy in the paramagnetic phase with the face-centered-cubic (fcc) ordering by evaporation under UHV conditions on a copper single crystal substrate [GLOSS13].

The fcc paramagnetic thin films are metastable, and it is possible to transform them by ion irradiation into the bcc ferromagnetic phase. Using a focused ion beam makes it possible to directly write ferromagnetic nanostructures into the paramagnetic surrounding (Fig. 1a). The resulting structures have favourable magnetic properties (high saturation magnetization and low damping) to be used as magnetic conduits for spin waves. Also, the direct-writing fabrication technique allows rapid prototyping and eliminates problems in the sharp edges of the structures with an inherent demagnetizing field strongly affecting the system's magnetic ordering and spin-wave response.

The system also allows tuning the magnetic and crystallographic properties of created structures [URBANEK18]. This can be achieved by selecting FIB parameters as ion dose, the number of scans, ion energy, and scanning strategy (Fig. 1b). Especially the unique possibility to locally control the magnetic anisotropy direction can eliminate the need for an external magnetic field in spin-wave circuits (Fig. 1c) [FLAJŠMAN20].

The system also allows (via magnetic anisotropy control) to stabilize magnetic textures (magnetic vortices and domain walls) at desired positions and create magnonic devices, such as phase-shifters (Fig. 1d) [WOJEWODA20].

[GLOSS13] Gloss et al, Appl. Phys. Lett. 103, 262405 (2013)

[URBANEK18] Urbanek et al, APL Materials 6, 060701 (2018)

[WOJEWODA20] Wojewoda et al. Appl. Phys. Lett. 117, 022405 (2020)

[FLAJŠMAN20] Flajšman et al. Phys. Rev. B 101, 014436 (2020)

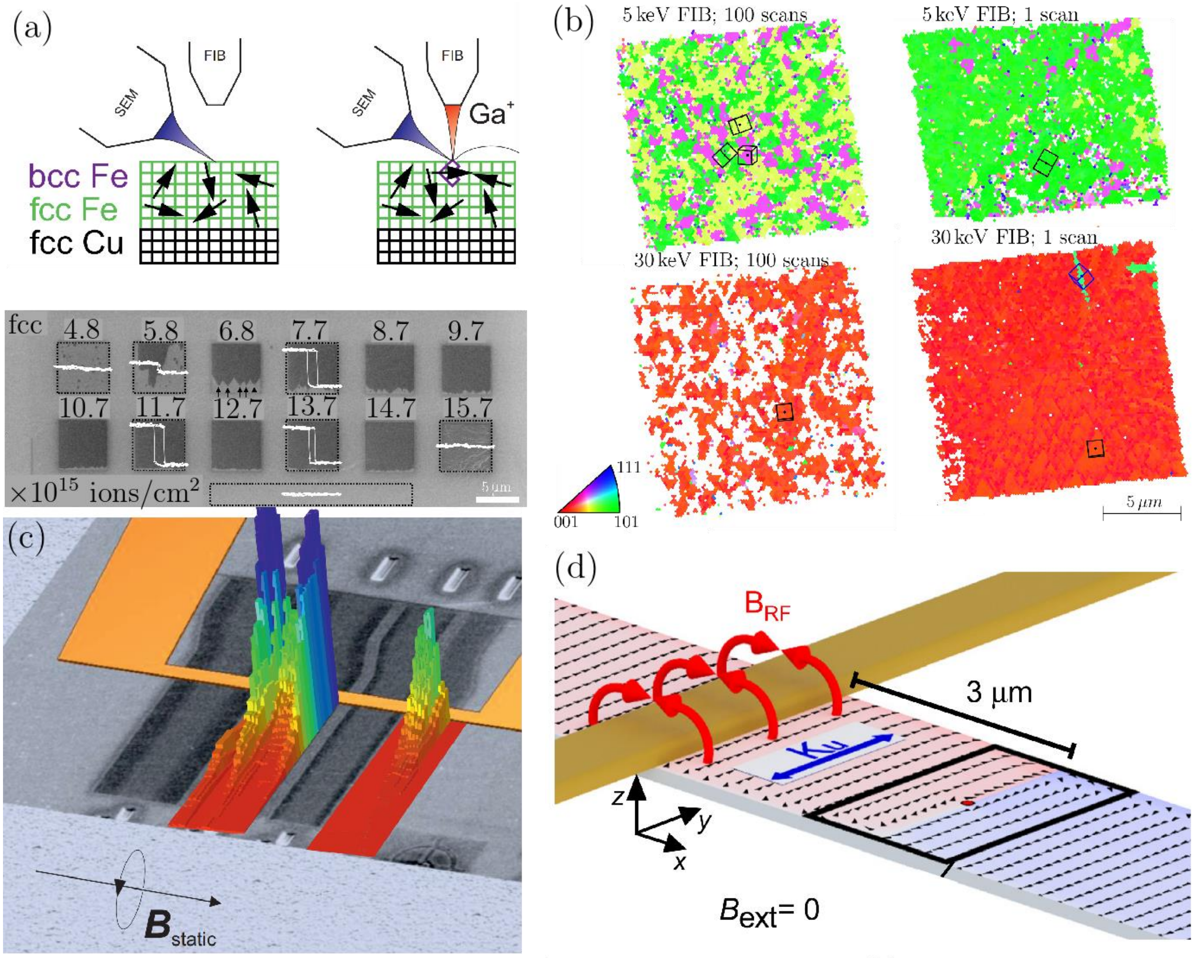

Fig. 1: System of metastable iron layer capable of FIB direct writing of magnetic microstructures. (a) The upper panel displays the scheme of the fcc-bcc transformation by FIB. The bottom panel is an SEM micrograph of dose test composed of rectangles with increasing ion dose. An evolution in SEM contrast is visible. Some of the rectangles are overlaid by hysteresis loops measured by MOKE with signals extracted from dashed black rectangles. (b) Inverse pole figure map from electron backscatter diffraction measurement. Four structures were fabricated with different combinations of ion energies and a number of scans. (c) Schematic representation of spin-wave propagation excited by the gold antenna in 2μm-wide waveguides in zero external magnetic field. (d) Micromagnetic simulation of magnetic domain wall inside the waveguides stabilized in the vicinity of the microwave antenna.