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Tailoring magnetic nanostructures with neon in the ion microscope

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Helium Ion Microscopy (HIM) (Hlawacek et al., 2014) is well known for its high resolution imaging and nano fabrication capabilities. The latter is usually employed to create structures on the nanoscale by either locally removing material by sputtering or by ion beam induced deposition from precursor gases. In gas field ion source (GFIS) based microscopes both process are often performed with neon due to the higher sputter yield compared to helium. In particular for material removal high ion fluencies are needed as the efficiency of the sputter process is low even when neon is used. However, as we will show, certain specific material properties like magnetism can be changed with fluencies much lower than the ones required for classical additive or destructive nano—machining. This will be exploited for the creation of magnetic patterns on the nanoscale.

We will present a number of results that have in common that the nanosized beam available in the GFIS microscope has been used to tailor the magnetic properties of various nanoscale objects. The flexibility of the tool allows rapid prototyping of free form shapes who's exact geometry and irradiation parameters can be optimized in a tight feedback loop with magnetic characterization techniques. In particular TEM holography, Kerr microscopy and magnetic force microscopy (MFM) have been used to understand the results.

In fig. 1 a cross sectional HIM image of a thin $Fe_{60}Al_{40}$ film on a Si_3N_4 membrane is presented. The $Fe_{60}Al_{40}$ films can be prepared with two different crystal structures (see fig. 2). While the so called B2 structure is paramagnetic the very similar A2 structure is ferromagnetic. Energetic ions with suitable mass such as neon can be used to induce disorder in the B2 structure and thereby increase the number of Fe-Fe nearest neighbors (Bali et al., 2014). This makes the irradiated areas ferromagnetic. Thanks to the 2 nm neon beam available in the Orion NanoFab the achievable resolution is only limited by the straggling of the ions in the film and not by the instruments resolution. We demonstrate the fabrication of spin valve structures with critical design dimensions of 20 nm. The results have been checked by Kerr microscopy and electrical transport measurements and TEM holography. Ion energy, fluence and film thickness have been optimized. In fig. 4 the results of the TEM investigation are shown (Röder et al., 2015). The field lines around two nanomagnets which are separated by a tiny paramagnetic spacer with a length of less than 20 nm are visible. The deviation between the designed pattern (grey area) and the realized magnetization is a result of the lateral ion straggling in the $Fe_{60}Al_{40}$ film.

However, the nanopatterning capabilities of the ion microscope allow arbitrary shapes to be patterned. Such patterns are presented in fig. 3. The image has been recorded using scanning x-ray transmission microscopy. In addition ambient magnetic force microscopy has been applied to characterize these nanostructures. Furthermore, the HIM can be used to pin the vortex position in such nanomagnets by creating a local defect inside the magnetic nanostructure.

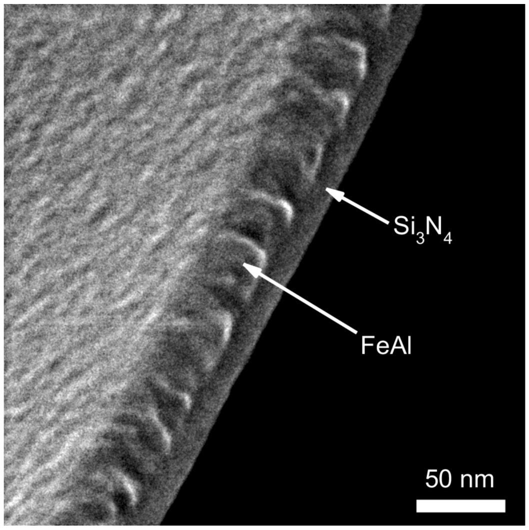

Figure 1: Cross sectional HIM image of a 40 nm thin $Fe_{60}Al_{40}$ film on a Si_3N_4 membrane.

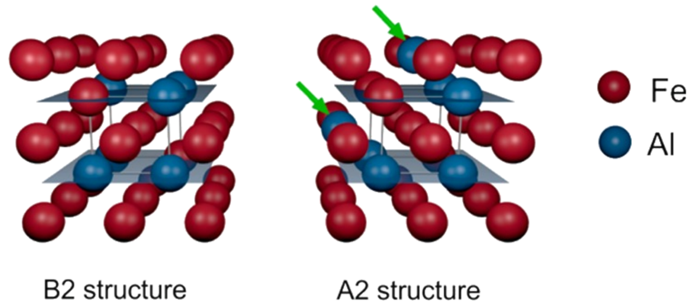

Figure 2: Paramagnetic B2 and ferromagnetic A2 structure of $Fe_{60}Al_{40}$. The ferromagnetism is related to the higher number of Fe-Fe nearest neighbors in the A2 structure (Bali et al., 2014).

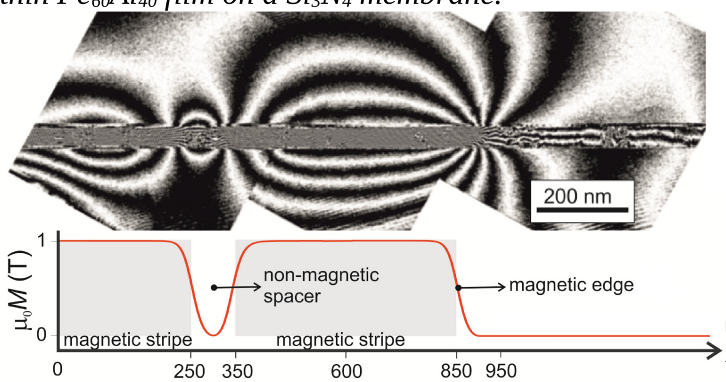

Figure 4: TEM Holography of two ferromagnetic nano magnets separated by a paramagnetic spacer. The designed (grey area) and realized magnetization (red line) are sketched below the data (Röder et al., 2015).

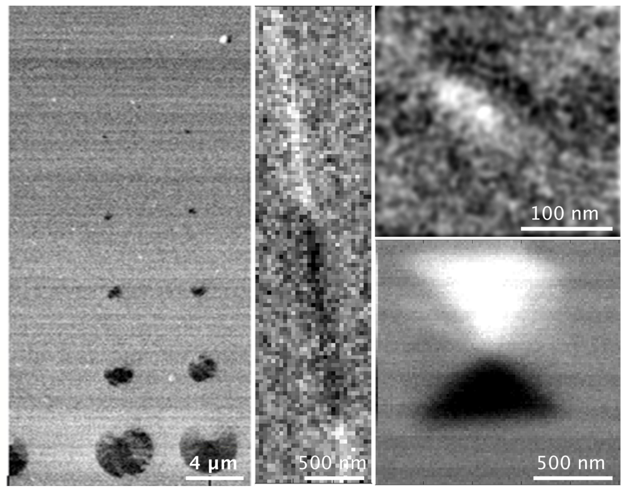

Figure 3: Nanomagnets with various shapes created by a 2 nm neon beam. Images have been recorded using STXM.

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