The scanning electron microscope as nanofactory - Direct-write deposition of single domain nanomagnets

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Scanning electron microscopes are known as instruments for high-resolution imaging and for chemical and crystallographic analysis. However, the energy of the electron beam can also be used for nanofabrication with a direct-write approach. In this case the focused electron beam is used to initiate a reaction on the scanned sample surface, that leads to deposition, removal or modification of material of the sample. The most prominent process is an additive direct write process called focused electron beam induced deposition (FEBID).

In this work we will present FEBID as a maskless, resistless direct write technology for assemblies of single domain nanomagnets. The injection of iron pentacarbonyl into the vacuum chamber of the SEM allows to locally decompose this precursor by the energy of the electron beam. The method is capable of the nanofabrication of sub-10 nm structures [1] as well as of complex, freestanding 3-dimensional structures [2].

With the precursor $Fe(CO)_5$ it is possible to deposit iron nanowires at room temperature (Fig. 1). Magnetic nanostructures of iron [3] and of cobalt [4,5] have been successfully deposited by FEBID. By post-processing the magnetic properties could even be tuned [6] and since then many applications of FEBID nanomagnet structures have been developed [7].

We will demonstrate the use of SEM-fabricated iron nanostructures as assembly of single-domain nanomagets for nanomagnet logic (NML). NML is a current-free, voltage-free logic processing technology that relies on information transfer and information processing via couping of magnetic fields between single-domain nanomagnets [8]. The majority gate that allows to perform AND as well as OR functions was first described in 2006 [9]. By FEBID we have deposited elongated nanowires with an iron content of up to 80%. These iron structures proved to be ferromagnetic in magnetic force microscopy (Fig. 2). Also vertically deposited nanopillars were proven to be suitable elements of NML.

The here presented FEBID of 3D nanomagnet arrays is a key technology for FNML. Especially the capability to use all 3 directions in 3D NML adds significantly to the design capability of FEBID. Am outlook on future developments and challenges ahead will be given.

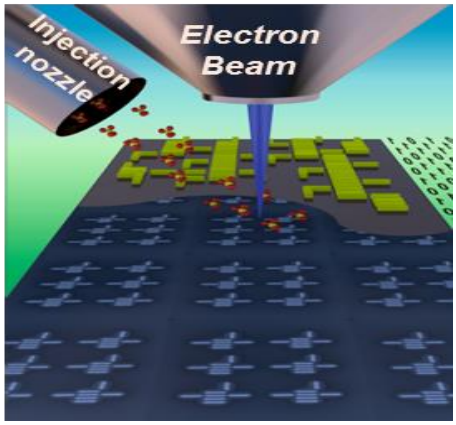

Fig. 1 Schematic illustration of additive direct write lithography of nanomagnets by focused electron beam induced deposition.

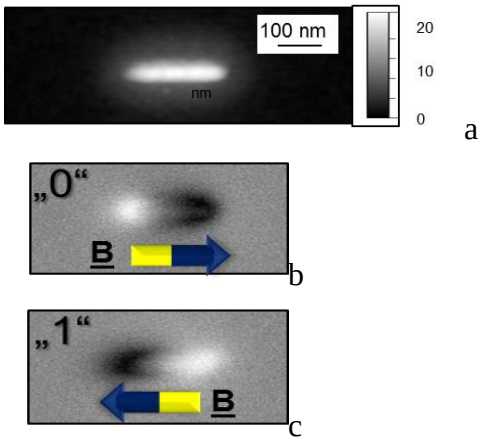

Fig. 2. Information storage in the orientation of single domain nanomagnets. MFM images of a 150 nm long iron nanowire. (a) topographic image (b,c) phase shift images revealing the characteristics of a single domain magnet

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