Direct-writing of nanomagnets for logic circuitry

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Nanomagnet logic (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 [1]. The majority gate that allows to perform AND as well as OR functions was first described in 2006 [2]. The first nanomagnet logic circuits were realized by conventional lithography and deposition of magnetic layers. This allowed only planar NML circuits with magnetic elements of identical thickness.

In order to overcome the limitations of resist-based lithography as an alternative focused electron beam induced deposition (FEBID) was developed as a maskless, resistless direct write technology. 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].

In this work a finely focused electron beam was used to induce the chemical vapour deposition of $Fe(CO)_5$ to deposit iron nanowires at room temperature (Fig. 1). Elongated nanowires with an iron content of up to 80% were deposited an proved to be ferromagnetic in magnetic force microscopy (Fig. 2). Custom-designed arrangement of the magnetic nanowires allowed to design complex logic circuitry such as an XOR gate shown in Fig. 3. Also vertically deposited nanopillars were proven to be suitable elements of NML. Magnetic in-plane nanowires and out-of-plane nanopillars were directly written by FEBID to assemble 3D NML circuitry. We report on (i) custom-designed 3-dimensional nanomagnet arrays, (ii) coercitivity design of each nanomagnet and (iii) successful operation of magnetologic "AND" and "OR" gates.

For NML several circuit models have been developed [8] and also complex circuitry such as a full adder [9] has been realized. The here presented FEBID of 3D nanomagnet arrays is a key technology for FEBID and 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.

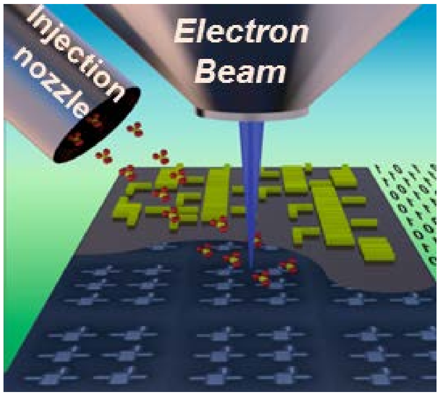

Fig. 1 Schematic illustration of additive direct write lithography of nanomagnets by focused electron beam induced deposition.

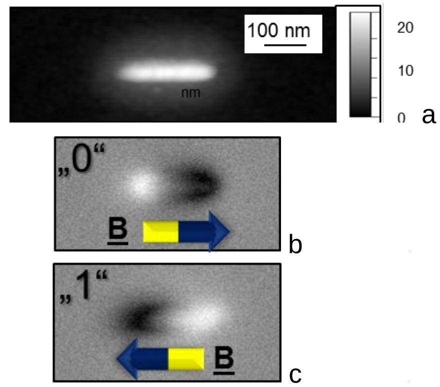

Fig. 2. Information storage in the orientation of single domain nanomagnets. MFM images of a 150 nm long iron nanowire. (a) topographic image (b,c) phase shift images revealing the characteristics of a single domain magnet

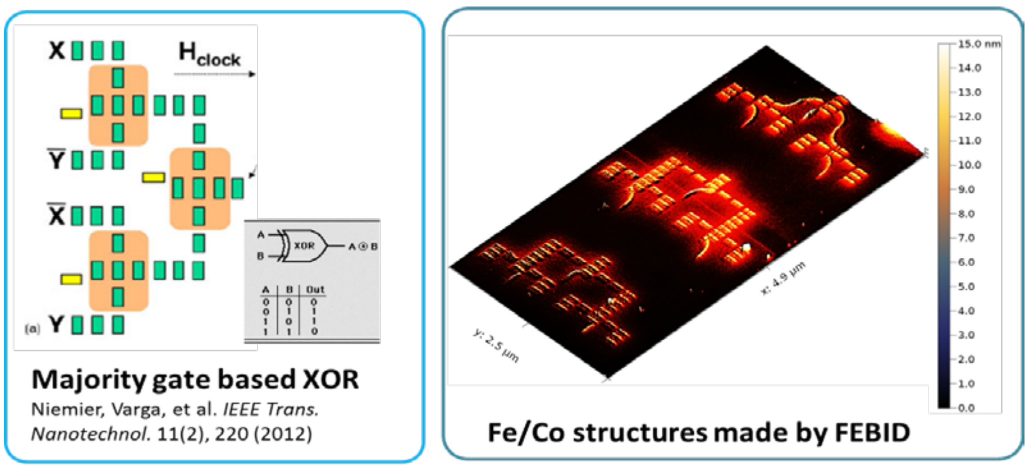

Fig. 3 A majority gate based XOR logic gate fabricated by focused electron beam induced deposition of iron structures. (left) schematic illustration of a nanomagnet logic XOR gate as proposed by Niemier, Varga et al. and (right) AFM images of iron nanostructures as deposited by FEBID of iron; not the curved structures, that combine driver and input for reducing coupling errors between nanomagnets.

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