Expanding nanomagnetic logic into the third dimension New pathways via FEBID

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Nanomagnet logic (NML) is a spin based computation technology using elongated single-domain nanomagnets for encoding the Boolean values “0” and “1”. Logic operations are performed via dipolar magnetic coupling between adjacent nanomagnets. The International Technology Roadmap for Semiconductors (ITRS) [1] ranks NML among the most prospective emerging research devices as NML features a strongly reduced power consumption compared to conventional CMOS technology. The conventional fabrication approach for such NML devices is based on a blanket deposition of magnetic thin films followed by lithographic structuring of these thin material layers. Currently, shape control of nanosized single-domain magnets is the major challenge [2].

In this work we introduce gas-mediated, focused electron beam induced deposition (FEBID) from iron carbonyl as a one-step method for direct-write deposition of magnetic nanodevices. Magnetic nanowires have been fabricated by FEBID [3]. In this work we have used $Fe(CO)5$ as precursor to fabricate magnetic nanostructures with a remarkably high iron content ($Fe > 80\%$) for high vacuum EBID process. It will be shown how the geometry of the deposited nanostructures influences the number of magnetic domains and how the individual tailoring of the height of a magnetic nanowire influences its coercivity. The impact for tailoring NML devices will be discussed.

Utilizing the magnetic coupling between neighboring nanowires we have fabricated 2 dimensional NML arrays with specific digital logic functions including majority gates and fan outs. We will present advanced 2nd generation magnetologic gates with reduced coupling errors, where neighboring elements were merged into a single curved magnetic elements (Fig. 3).

Ultimately, we have expanded NML into the third dimension. 3-dimensional arrays that combine in plane (IP) Fe-nanowires and out of plane (OP) Fe-nanopillars have been synthesized (Fig. 4). By extending the in-plane structures by vertical OP nanopillars ads another level of control to the NML gate. This extra magnetic degree of freedom will allow to separate digital processing from input/output functionality. Future development trends will be presented.

[1] ITRS Roadmap for Semiconductors, Emerging Research Devices, http://www.itrs.net/ (2013)
[2] Niemier, M. T., G. H. Bernstein, G. Csaba, et al., J. Phys. Condens. Matter 23 (49) (2011)
[3] Fernández-Pacheco, A.; Serrano-Ramón, L.; Michalik, J. M.; Ibarra, M. R.; De Teresa, J. M.; O’Brien, L.; Petit, D.; Lee, J.; Cowburn, R. P. Sci. Rep. 3, 1492 (2013)

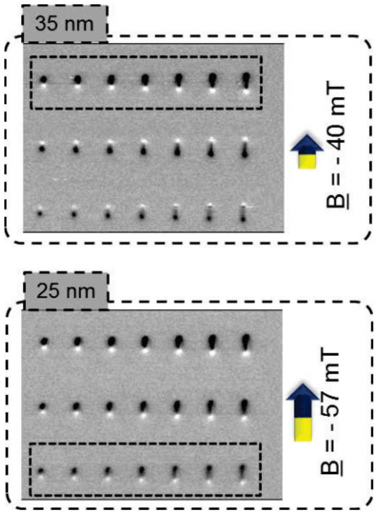

Fig. 1: Effect of thickness on coercivity. With increasing thickness of the FEBID iron nanowires the coercivity decreases.

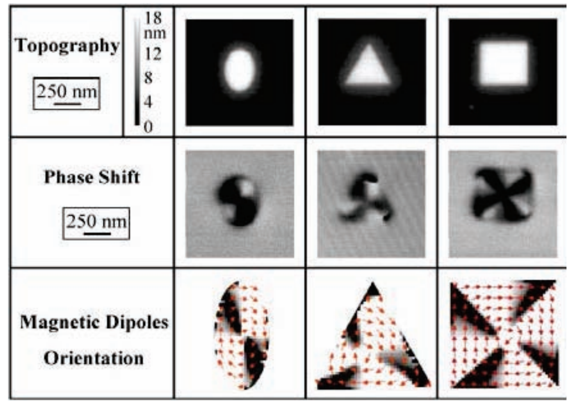

Fig. 2: Geometry influences the number of domains. MFM investigation of the main iron nanostructures obtained by FEBID. The orientation of the magnetic dipoles for each geometry is represented.

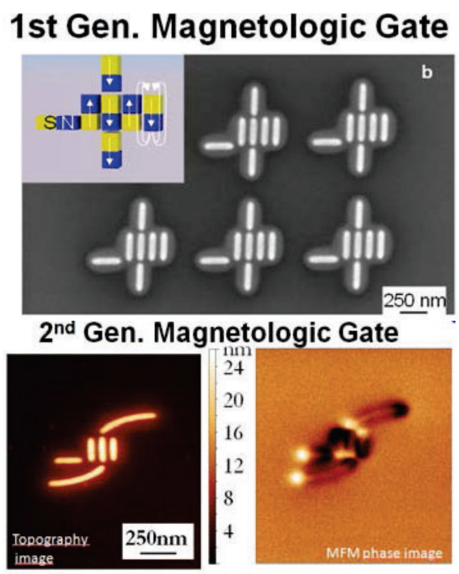

Figure 3. Magnetologic majority gate structures fabricated by FEBID (Top:) SEM micrograph of iron nanowires interacting through magnetic dipolar coupling (inlay) (Bottom:) an advanced gate structure with connected helper and inputs

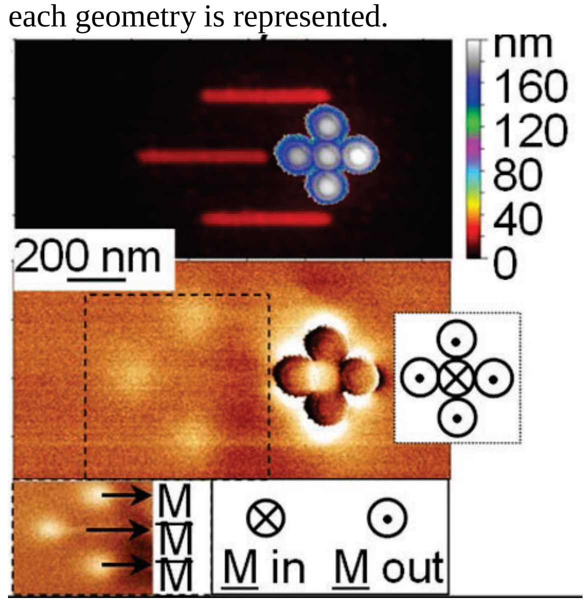

Figure 4. A 3 dimensional majority gate deposited by FEBID. MFM analysis of the structure where M indicates the magnetization vector inside the nanostructures