Patterned Epitaxial Nanomagnets for Novel Logic Devices

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Novel logic architectures that dissipate significantly less power than conventional CMOS are of tremendous research interest. One such idea, ensembles of patterned nano-scale elliptical magnetic elements (nanomagnets), where logic is driven by dipolar interactions between the nanomagnets and the state variable is their magnetization direction, has demonstrated basic logic operations and holds promise for more sophisticated computations[1]. Logic is initiated by coercing each magnetization to lie along the short or magnetically hard axis by application of a large external magnetic field. When the external field is removed dipole interactions mediate the ensuing cascade of their magnetizations into easy axis alignment in a predictable way.

Success of this cascade is contingent upon each hard axis magnetization remaining metastable for the duration of the cascade transient. Previous research on such ensembles has demonstrated that logic gates and interconnects, assembled from ellipsoidal nanomagnets that are patterned from polycrystalline magnetic films, are not reliably stable and often suffer from erroneous cascade nucleation points. A proposed solution to this problem is to enhance the stability of each nanomagnet by introducing a biaxial anisotropy term to the overall magnetic energy. The most straightforward way of introducing biaxial anisotropy is through a magnetocrystalline term, requiring that the elliptical nanomagnets be patterned from a biaxial (i.e. epitaxially cubic) magnetic thin film.

Epitaxial thin magnetic films can be deposited by various physical vapor deposition methods (e.g. molecular beam epitaxy or pulsed laser deposition). However, these methods employ high temperature anneals before, during, and/or after deposition, making photoresist liftoff patterning impossible. As the dipolar coupling between nanomagnets is very short-ranged, spacing between the nanomagnets must typically be sub-20 nm. This poses considerable challenges on the etch definition process as sidewall re-deposition and adventitious shadowing from neighboring nanomagnets from ion beam etching will be problematic.

We report on the status of our research to fabricate such nanomagnetic ensembles, where we explore various epitaxial magnetic systems and patterning procedures. We also demonstrate, through temperature dependent micromagnetic simulations, that by tuning the two anisotropy terms it is possible to create a stable magnetic transmission line of arbitrary length at room temperature.

1 A. Imre, G. Csaba, L. Ji, A. Orlov, G. H. Bernstein, and W. Porod, Science **311**, 205 (2006).

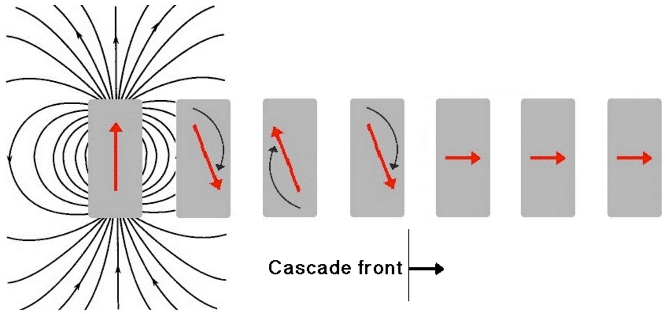

Figure 1. Cartoon of a line of nanomagnets or "magnetic wire" propagating the logic signal (i.e. magnetization relaxation to the easy axis) as a cascade front from left to right. Dipolar interactions between nanomagnets drive the signal propagation. Nanomagnet that are ahead of the cascade front (shown explicitly) must remain stable until the signal reaches them.

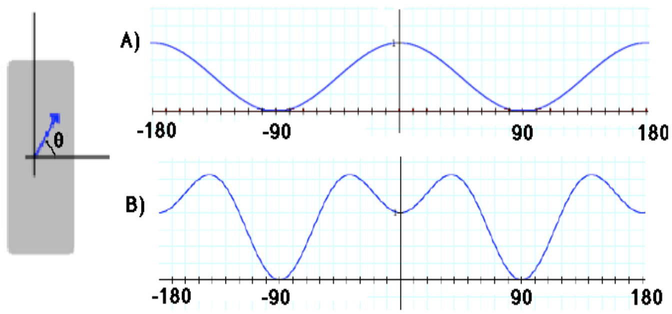

Figure 2. Energy landscape U(θ) for (A) uniaxial and (B) uniaxial + biaxial anisotropy terms. No Zeeman energy (magnetic field) terms are included. The addition of the biaxial anisotropy term creates a point of metastability along the previously unstable uniaxial hard axis to allow for the correct propagation of the magnetic signal.

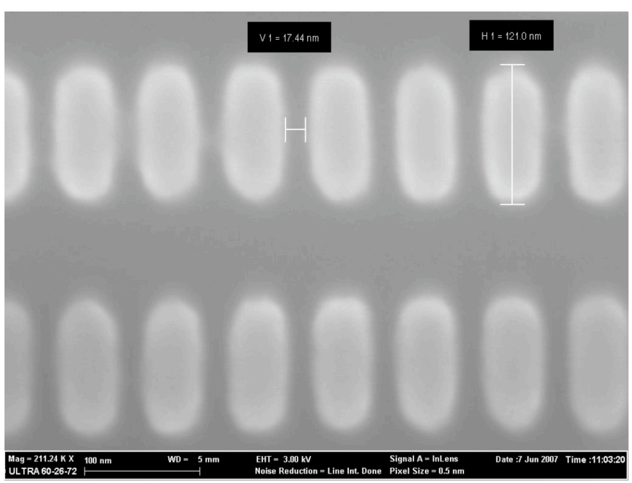

Figure 3. SEM micrographs of e-beam lithography-defined hydrogen silsequioxane (HSQ) masks on Cu with dimensions 121nm x 50nm and 17nm spacing. These HSQ masks will be used as ion beam etch masks to pattern epitaxial Co(100) which lies beneath the Cu cap.