Magneto-optical and X-ray microscopy of nanomagnetic logic components with shape-induced biaxial anisotropy

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Nanomagnetic logic devices are built from nanoscale ferromagnetic bits arranged such that the information encoded in their magnetic states is processed via nearest-neighbor dipole interactions [1]. The energy scales of these interactions are on the order of the thermal energy and many orders of magnitude lower than CMOS-based microprocessors, making nanomagnetic logic attractive for computing applications that demand very high energy efficiency. Here we investigate the application of nanomagnets with concave geometries to nanomagnetic logic using magneto-optical and X-ray microscopy techniques. We show that lithographically-defined concavities in rectangular nanomagnets have a dramatic impact on their biaxial anisotropy properties, which in turn impacts the dynamic behavior of nanomagnetic logic devices. Most significantly, the model that describes signal propagation changes from a thermally-driven random walk to a magnetic field-driven cascade, which results in significantly faster and more reliable computation [2]. Experimental approaches for implementing biaxial anisotropy in nanomagnetic logic had not been successful to date as they required the use of crystalline nanomagnets, presenting a number of fabrication challenges compared to the more commonly used polycrystalline magnetic material permalloy (NiFe). We solve this problem by using shape-induced biaxial anisotropy rather than crystallinity-induced anisotropy. The nanomagnet geometry proposed and investigated is the concave rectangle shown in the top of figure 1 (a).

In our investigation, magneto-optical Kerr effect (MOKE) magnetometry is used to characterize the anisotropy properties of large arrays of identical nanomagnets. Our apparatus measures the average anisotropy strength versus magnetization angle of the nanomagnets when polarized light is focused onto the array. Magnetic hysteresis loops are also measured. Our plotted results in figure 1 (a) verify that strong biaxial anisotropy is induced in the shape-engineered concave nanomagnets in comparison with ellipses of the same dimensions. The additional stability is a result of configurational anisotropy [3], and its strength is widely tunable by adjusting the depth of the concavity. Next, we carried out X-ray photoelectron emission microscopy (PEEM) experiments at the Advanced Light Source, Lawrence Berkeley National Laboratory to investigate the effect of biaxial anisotropy nanomagnetic logic chains. Evidence of deterministic cascade dynamics was obtained by varying the dimensions and temperature of the nanomagnets (figure 1 (c-d)). These results are the first experimental demonstration of biaxial anisotropy in nanomagnetic logic and pave the way for future improvements to the reliability and speed of nanomagnetic logic devices.

References:

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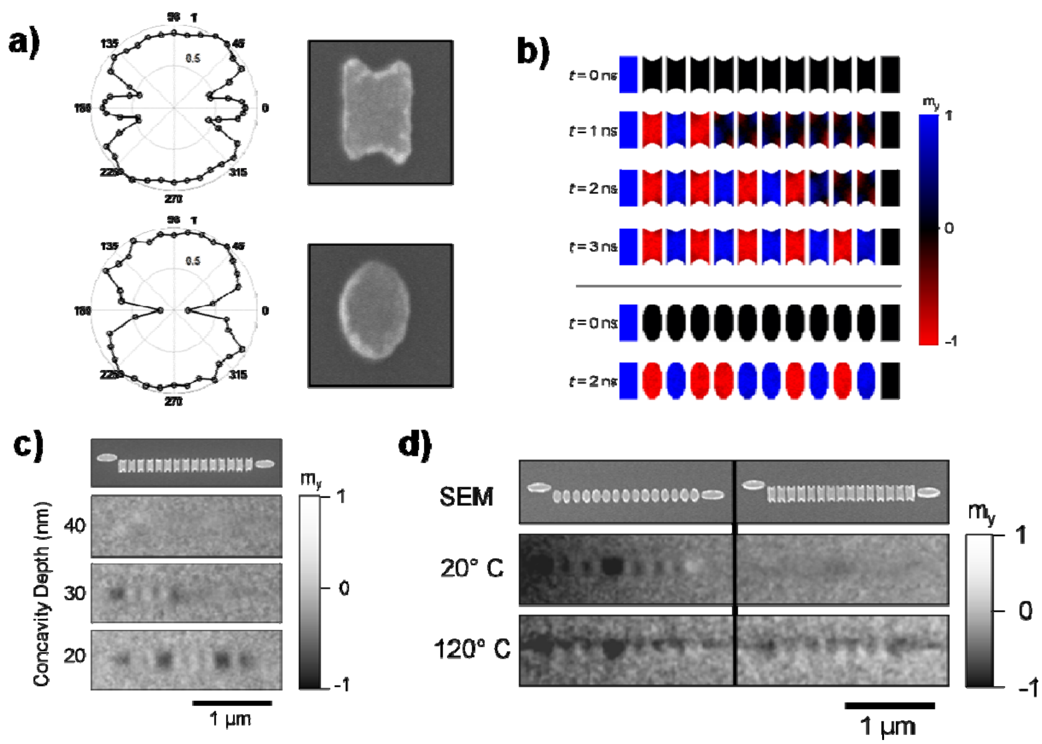

Figure 1: (a) Anisotropy profile (anisotropy strength as a function of magnetization angle) of concave and ellipsoidal nanomagnets obtained by MOKE microscopy. (b) Micromagnetic simulation showing distinct dynamic behaviors in concave and ellipsoidal nanomagnetic logic chains. (c) Effect of dimensional variation and (d) effect of temperature variation on concave nanomagnetic logic chains measured using PEEM microscopy.