Thermal relaxation and energy barriers near vortex nucleation field in circular permalloy dot arrays

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Patterned nanomagnetic structures (dots) currently have great perspectives to be implemented as magnetic field and spin polarized current controlled devices. The magnetic properties of such dot arrays are determined by shape, size and materials parameters of the individual dots as well as interdot interactions. One of the central problems closely related to applications is magnetization reversal of the dots in an external magnetic field. Thermal stability of the given magnetization distribution is especially important for the magnetic recording and memory applications.

Typical remanent magnetization distribution of submicrom magnetic dots is vortex state. Applying in-plane field the vortex can be expelled from the dot at a critical annihilation field (H_{an}) and dot transits to a saturated state. Decreasing the field starting from the dot saturated state a magnetic vortex nucleates at the dot edge at a critical nucleation field (H_n) and propagates to the dot center. *I.e*., the magnetization reversal process can be represented as a vortex motion through the dot. The dependences of H_{an}, H_n on the field sweep rate were measured in Ref. [1] for permalloy (FeNi alloy) dots. That allowed estimating energy barriers for the vortex annihilation and nucleation processes.

In this paper we present measurements of long time magnetization dynamics of square permalloy circular dot arrays at different temperatures and magnetic fields close to the vortex nucleation by Vibrating Sample Magnetometer. The temperature range was 100 – 400 K. The dot radii R were varied from 250 nm to 750 nm, the dot thickness was 40 nm. The interdot separation edge-to-edge in the prepared dot arrays was equal 2R to exclude interdot magnetostatic interactions. I.e., the time dependent magnetic properties of an ensemble of the isolated dots were measured and interpreted by the energy barrier and relaxation time language. The nucleation process in each dot is independent and corresponds to a different value of the energy barrier and probability to nucleate the vortex core within the dot. In our case, the resulting detected signal is an average over an ensemble of ~4×10^6 dots. The thermal relaxation from the saturated state to equilibrium vortex state (the vortex nucleation at fixed H and T) consists of two steps having different time scales. The first step is a continuous transition from the single-domain state to intermediate quasi-uniform C- or S-state. This transition occurs relatively fast, during time of ~50 s, and is not subject of consideration of the present paper. We concentrated here on the second, long-time relaxation step (~ 1 hour), which is related to the energy barrier overcoming. The thermally induced long-time magnetization dynamics of the dot array assuming an uniform statistical distribution of the energy barriers within the interval [0, E_m] can be described by the equation:

$$\mu(t) = \mu(t_0) - S\ln(t/t_0), \qquad (1)$$

where μ is the magnetic moment of the dot array, and S is the magnetic viscosity. This equation was used to find the magnetic viscosity (see Fig. 1) from the fitting the experimental $\mu(t)$ time-dependences measured at different temperatures. Then, the maximum energy barrier value E_m was extracted from the field dependent viscosity [2].

The effect of the dot sizes, magnetic field and temperature in the vortex nucleation in 2D dot arrays is explored. Time decay of the magnetization of the arrays of permalloy circular dots of different sizes was measured on a long time scale (hours) near the vortex nucleation field [2]. A considerable influence of the magnetic field and temperature on the slow magnetization dynamics was detected. The observed effects are explained by overcoming the field and dot size dependent energy barriers in the process of vortex nucleation. The obtained results can serve as a basis for understanding of the magnetization reversal and thermal stability in the vortex state magnetic dot arrays.

References

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[2] G. N. Kakazei et al., Appl. Phys. Lett., **99**, (2011) 052512.

Figures

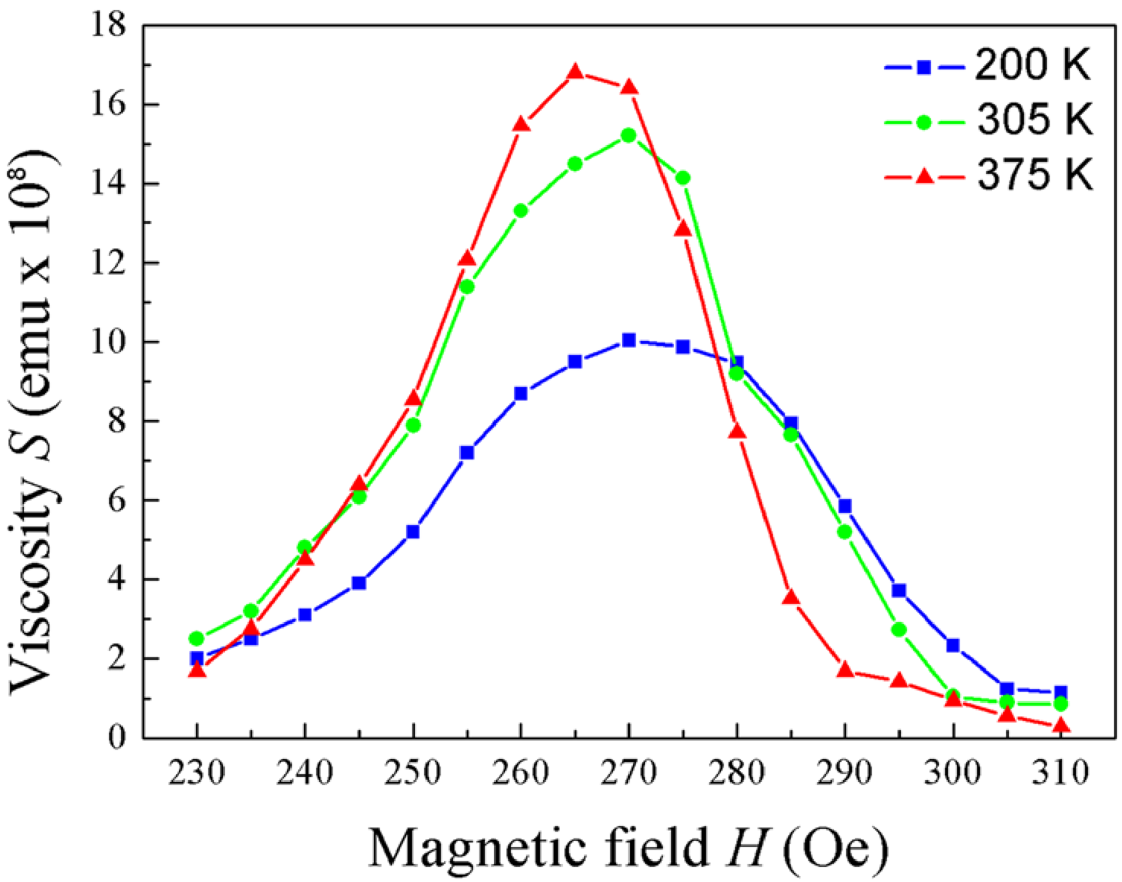

Fig. 1. Magnetic viscosity of the permalloy dot array vs. in-plane magnetic field extracted from the magnetization decay experiments by using Eq. (1): black squares (T=200 K), red circles (T=305 K) and green triangles (T=375 K). The dot radius is R = 250 nm and thickness is L=40 nm.