The influence of demagnetization on the magnetic after-effect of Co-Cr micro structures.

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Abstract—The influence of the demagnetizing field on the magnetic after-effect of Co-Cr media is discussed. The demagnetizing field of as-sputtered Co-Cr was changed into block-shaped micro structures by lithographic processes. This process does affect the shearing of the perpendicular hysteresis curve but not the intrinsic magnetic properties. A linear relation was obtained between the coefficient of magnetic viscosity and the slope of the hysteresis curve.

I. INTRODUCTION.

The after-effect of magnetic storage media is of practical interest in long term stability and high frequency writing [1]. The long term stability is determined by the decay in remanence which in general obeys the relation:

\[ M(t) = M(t = 0) + S \ln(t) \]

where \( M \) is the perpendicular magnetization at time \( t \), or at the start of the measurement \( t = 0 \). \( S \) is the coefficient of viscosity and is known to depend on for example the magnetic switching volume \( v \), temperature \( T \), saturation magnetization \( M_s \), anisotropy \( K \), and the magnetic field \( H \). For Co-Cr recording media with a perpendicular magnetic anisotropy the remanent magnetization is found to decay quasi-logarithmic with time [2-4], and that the viscosity \( S \) depends on the bit density. Lottis et al. [2] measured the decay in read back signal of a bit pattern and attributed the smaller decrease of the signal in time to a decrease in demagnetizing field because of decreasing bit size. However the relation with the demagnetizing field was not quantified experimentally. An attempt of Lottis et al. [4] to do so theoretically, resulted in a useful model which makes the influence of demagnetization on the time dependence more clear. The comparison of theory and experiment resulted nevertheless in large discrepancies.

In this paper the magnetic after-effect of as-sputtered and patterned Co-Cr is discussed. The patterned Co-Cr has a structure as the bit size used in ref. 2 (see fig. 1), and exhibits a demagnetization factor \( N_g \) smaller than one. In this way the demagnetizing field was manipulated whereas the intrinsic properties like \( M_s \), \( K \), and \( v \) were unaffected.

In section III the experimental conditions will be described in more detail. The results of the demagnetizing influence on the magnetic after-effect will be presented in section IV. But we first start with a mesoscopic consideration of the magnetic after-effect in perpendicular media.

II. MAGNETIC AFTER-EFFECT.

The magnetic after-effect of perpendicular media is often regarded as qualitatively different from in-plane (particular) media, because of the presence of a strong internal and time dependent demagnetizing field [5]. As a result some distinct characteristics arise. For example a). the relaxation process is quasi-logarithmic because with a decay in magnetization also the internal field changes considerably. And b). the coefficient of viscosity is nearly independent of the external field over a range of several 100 kA/m [2,4], whereas in-plane (particulate) media exhibit a magnetization time decay which is sharply peaked around the coercive field [1]. The magnetic after-effect of perpendicular media however must be based on the same general principal, i.e. that each system tries to reach its equilibrium state. Thus after a sudden change in applied field, certain magnetic entities c.q. domains will be in a metastable state. But because of thermal fluctuation fields these entities can hop over the energy barrier to more stable orientations of their magnetization vector c.q. a more stable domain width or period. On a macroscopic level, the energy barrier will be connected to the coercivity. And the change in magnetization, due to a rotation of the magnetization vector,
will be connected to the irreversible susceptibility $\chi_{irr}$. The magnetic relaxation thus most probably will agree with the well known relationship [6]:

$$S = \chi_{irr} H_f$$

(2)

where $H_f$ is the fluctuation field, and was found to be related to the coercivity in so-called Barbier plots [6].

This simple approach enables us to understand the broad field dependence of the coefficient of viscosity because the perpendicular hysteresis curve exhibits a shearing due to demagnetization, and thus the susceptibility spreads out.

This shearing $T$ depends on the demagnetization factor $N_z$ and can be approximated, at coercive field, by [7]:

$$T^{-1} = N_z - 1.20 \frac{\lambda}{h}$$

(3)

where $h$ is the thickness and $\lambda$ is the material length. Note that this relation is derived for thin films exhibiting a stripe domain structure. Which is, in the case of Co-Cr, only true for low values of $H_c$ over $H_K$ [8]. In that case eq. 3 gives an indirect relation between $N_z$ and the coefficient of viscosity.

The decay in read back signal of a written bit pattern [2] can be understood in the same terms, thus having metastable instead of equilibrium dimensions. A bit pattern with dimensions approaching the equilibrium value will probably have a coefficient of viscosity which tends to zero. Moreover a bit pattern with even smaller dimensions will presumably exhibits a coefficient of viscosity unequal to zero because it contains a surplus of bit transition energy. This inspite of the lower demagnetizing field within the bit.

III. EXPERIMENTAL.

Co-Cr was RF sputtered under optimized conditions [9]. The pattern was obtained by ion-beam etching, leaving the intrinsic magnetic properties unaffected. However the demagnetization difference influences the shearing of the hysteresis curve (fig. 2; eq.3). The demagnetization factor was obtained from VSM and torque measurements according to the method as described in [9].

IV. RESULTS.

In figure 3 two examples are shown of the after-effect of the normalized remanent magnetization for two different patterned films. As can be seen do both curves differ in absolute values because the value of the remanence is affected by $N_z$ (see shearing in fig. 2, and [9]). The time dependent curves can be fitted to a log function (dotted line) which indicates a distribution in energy barriers. For sample 120291-5 a quasi-logarithmic phenomenon can be observed in this time window. This slight decrease in the viscosity with time could be observed in several samples, however no relation with parameters as field or $N_z$ could be found.

In figure 4 the magnetic viscosity $S$ is given as a function of the applied field. The as-sputtered sample shows an almost constant behaviour (open squares). The patterned sample (filled squares) slowly decreases towards the value of the open squares. Note that there is no maximum value of $S$ near coercivity, as is observed for in-plane media [1].
TABLE 1.
MAGNETIC PROPERTIES OF THE INVESTIGATED SAMPLES.

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In the same figure the slope as calculated by eq. 3 is depicted proving the validity of eq. 3 for these films.

V. CONCLUSION.

The magnetic after-effect of Co-Cr is found to agree with the theory as obtained for in-plane magnetic materials, i.e. the coefficient of viscosity exhibits a linear relationship with the susceptibility. The time dependence however looks different because the susceptibility is influenced by a strong demagnetizing field. A relationship (eq. 3) describing this influence was experimentally verified for these films.

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REFERENCES.