Innovation Use of Nano Technology in Magnetic Storage Devices and Nano Computers

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Abstract—The fluence of ion irradiation on polycrystalline thin films affects both anisotropy and spontaneous magnetisation M_s. The dependence of coercivity and initial susceptibility on M_s is predicted by a hysteresis model considering the balance of energy with good qualitative agreement.

1. Introduction

Demands for the continuous increase in the data storage density bring the challenge to overcome physical limits for currently used magnetic recording media [1, 2]. Ferromagnetic nano-particles of different polycrystalline thin films have been formed by heavy or light ion irradiation [2–4]. Although this modification technique may be a way to produce nano-magnetic particles, there are some critical size limits of nanomagnetic structures like the superparamagnetic limit (SPML) which faces magnetic nanotechnology. The magnetic properties of thin films are strongly influenced by their structure [5]. Small changes in the way a thin film is produced often give rise to large changes in some of the magnetic properties of the thin film [6]. This is best understood by observing how the microstructure of the film changes with processing and then correlating the microstructure directly with the properties of the thin film [6]. The behaviour of magnetic nanoparticles has fascinated materials scientists for decades [7]. Magnetic nanostructures have become a centre of great interest in the scientific community and in industry as the core technologies behind magnetic recording devices [8]. And the magnetic properties of an ultra thin multilayer can be patterned by controlled ion beam irradiation [4]. There are fundamental limits due to the atomic nature of matter which may impose ultimate physical bounds to nanofabrication and miniaturization [9]. Over the past several decades, amorphous and more recently nano-crystalline materials have been investigated for applications in magnetic devices [10]. The benefit found in the nanocrystalline alloys stem from their chemical and structural variations on a nano-scale which are important for optimizing magnetic recording devices [10].

2. Irradiation Process and Results

Several irradiation experiments carried out on the Co/Pt multi-layers samples (A1, A2, and A3 see Table 1) cause changes in the magnetic properties of the thin films [1, 4]. High aspect ratio silica masks on Co/Pt multi-layers were obtained by e-beam lithography and reactive ion etching with feature sizes down to 30 nm for lines and 20 nm for dots [3]. He+ ion irradiation of the magnetic layers through these masks was used to pattern the magnetic properties [3] (with fluences between 2.10^{14} and 2.10^{16} ions/cm^2 [4]). After mask removal, high resolution and high density, planar magnetic nano-structures were obtained [3]. The results of the irradiation show perfectly square hysteresis loops at room temperature, the coercive field decreasing progressively to zero [4]. The high perpendicular anisotropy of Pt/Co multi-layers originates from the interfaces between the layers [11]. Other experminents carried out on YCo_2 samples (thin polycrystalline film targets of polycrystalline with thicknesses of approximately $1\,\mu m$ [[12]) have shown that fluences in range of 10^{12} U ions/cm^2 cause changes in magnetic properties of the samples [1]. The result of these experiments were changes of the anisotropy perpendicular to the film plane [1], and change of spontaneous magnetisation, coercivity and initial susceptibility [13].

2.1. Equations and Calculation

The energetic model (EM) [14] is used to calculate the dependence of the shape of the hysteresis loop on M_s. The parameters of the model are calculated directly from measurements of special points of the hysteresis loop. The identification of the parameters is done at reference conditions (index 0) at a temperature $T = T_0$ without any applied mechanical stress σ, and at given M_s and N_e (N_e is the effective demagnetizing factor which is the sum of the geometric demagnetizing factor N_d and the inner demagnetizing factor N_i). The following equations show how to determine the parameter of the model from spontaneous magnetization M_s, coercivity H_c, and from the effective demagnetization factor N_e.

$$k_0 = \frac{\mu_0 M_s H_c}{1 - 2\exp(-q_0)} \tag{1}$$

k in J/m^3 related to static hysteresis loss (irreversible processes), and

$$q_0 = \frac{\mu_0 M_s^2}{k_0} \frac{1 - N_e \chi_0}{\chi_0} \tag{2}$$

q (dimensionless) is related to pinning site density (irreversible processes). Using Eqs. (1) and (2) with the approximation $\exp[-q_0] \ll 1$, we find the dependencies

$$H_c = \frac{k_0}{\mu_0 M_s} \tag{3}$$

and

$$\chi_0 = \frac{\mu_0 M_s^2}{k_0 q_0 + \mu_0 M_s^2 N_e} \tag{4}$$

which strongly affects the shape of the hysteresis. Figure 1 shows the initial magnetization curves calculated and measured major hysteresis loops in dependence of the measured value of M_s. No other change of the parameter values has been made. Table 1 shows the result of the evaluation of the equations above. Figure 2 shows the initial magnetization curves calculated with the parameters depending on M_s due to irradiation, compared to measurements.

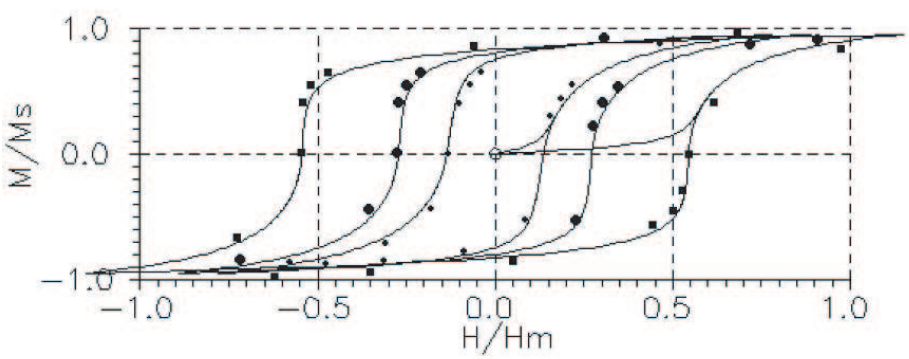

Figure 1: Calculated hysteresis loops for thin Films after different ion irradiation fluences perpendicular to the film plane and measured points. The H-values are related to the maximum field $H_m = 160\,\text{kA/m}$. The Mvalues are related to the respective saturation values of $M_s = 20\,\text{kA/m}$, $M_s = 40\,\text{kA/m}$, and $M_s = 60\,\text{kA/m}$ 1. Only these values have been changed to calculate the different major hysteresis loops.

3. Anisotropy Energy after Irradiation

The anisotropy energy k_u is essential for evaluation of the thermal stability condition on a given bit. For the three irradiated samples (A1, A2, A3), k_u was calculated (Eq. 5).

$$k_u = \frac{H_k \mu_0 M_s}{2} \tag{5}$$

4. Nano Bits Stability Factor and Its Relaxation Time Calculation

Assuming a factor f_{BS} a simple abbreviation for "bit stability factor", which represents the information stability of stored data on a given nano-bit, where: $f_{BS} = k_u V_{nano}/k_B T$, V_{nano} is the nano magnetic structure volume, $k_u V_{nano}$ is the energy barrier (ΔE), and $k_B = 1.38 \times 10^{-23}$ J/deg Boltzmann constant. The magnetic stored information on a nano dot is then stable: if only the condition ($f_{BS} > 40$) is satisfied [16]. The relaxation time (time duration of stored information) or switching time of stored information τ can be obtained from the Arrhenius relation as:

$$\tau = \frac{1}{f_0} \exp(f_{BS}) \tag{6}$$

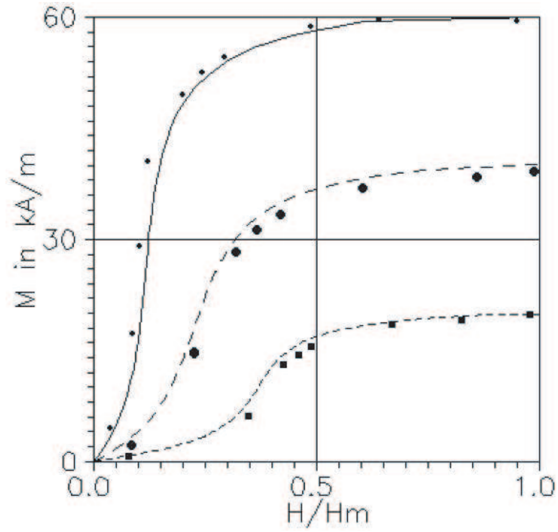

Figure 2: Calculated initial hysteresis curves loops for thin films after different ion irradiation fluences perpendicular (Tab. 1) to the film plane and measured points. The H-values are related to the maximum field $H_m = 160\,\mathrm{kA/m}$. The calculation has been done by varying the value of M_s, only.

Table 1: Macroscopic hysteresis features depending on M_s [14].

Φ	[ions/cm^2]	A1, 10^{12}	A2, $5 \cdot 10^{12}$	A3, $2 \cdot 10^{13}$
M_s	[kA/m]	20	40	60
χ_0	[1]	0.157	0.199	0.536
H_c	[kA/m]	43.6	21.8	14.5

Where f_0 is the thermal attempt frequency [17], which is usually assumed to be $10^9\ s^{-1}$. The irradiation of the samples (A1, A2, A3) with different fluences as shown in Table 1, caused changes of the calculated values of k_u for each sample. Hence different values of f_{BS} and τ were calculated (see Table 2).

Table 2: Relation between k_u, and relaxation time τ at dot-width $D_w = 22\,\mathrm{nm}$ and T=10 K, as a result of irradiation, where f_{BS} condition is satisfied.

samples	k_u [J/m^3]	τ [Years]
A_1	592.51	20.3×10^2
A_2	1017.67	23.6×10^{16}
A_3	1975.46	11.8×10^{38}

5. Conclusion

Magnetic nano-structures are subject of growing interest because of their potential applications in high density magnetic recording media and their original magnetic properties [11, 14–16]. The rapid development of magnetic recording leads to a large increase of the bit density. Multilayer thin films with perpendicular magnetic anisotropy devices may play an active role in the development and establishment of future storage technologies. Patterning magnetic media is a potential solution for ultrahigh density magnetic recording [3]. The shape of hysteresis loops depends strongly on M_s, where H_c is inversely proportional to M_s, and χ_0 is proportional to M_s^2. Thermal stability is one of the serious issues for developing high density recording, and thus much effort has been made to overcome this issue [18]. The idea to use a regular array of physically isolated grains/dots promises an improvement in thermal stability of the recorded bits [19]. The anisotropy energy k_u is essential for evaluation of the thermal stability condition on a given bit, because k_u value is used in calculation of bit stability factor f_{BS}. A given nano bit is then thermaly stable: if only the condition ($f_{BS} > 40$) is satisfied.

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