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SURFACE ROUGHNESS EFFECTS ON THE COERCIVITY OF THIN FILM HEADS

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Abstract The domain wall motion coercivity, H_c, of magnetic materials arises from the dependence of the wall energy on localized changes in material parameters (magnetization, anisotropy, exchange energy densities). However, in an otherwise perfectly homogeneous material, the domain wall energy might change due to the change in the volume of the wall versus the wall position. Thus, any surface roughness contributes to the coercivity. Assuming different two-dimensional surface profiles, characterized by average wavelengths λ_x and λ_y, and relative thickness variations *dh/h*, the coercivity due to the surface roughness has been calculated. Compared to the one dimensional case, the 2D coercivity is reduced. Depending on the ratio of λ to the domain wall width, H_c has a maximum around 2, and increasing with *dh/h*. With the decreasing thickness of the thin film and GMR heads, it might be the domain factor in determining the coercivity.

I .INTRODUCTION

A very important parameter in any application of magnetic material is the coercivity. In an ideally soft infinite material without any defect, the domain walls (DW) start to move immediately with the magnetic field applied. Defects represent energy barriers to the motion of the domain walls and the field necessary to displace a DW over the large potential energy barrier is the coercive force H_c. That is the critical field for the start of the DW motion in the field of the defects. In this way H_c , as the measure of the interaction between a DW and a defect, can be chosen as a very convenient characteristic of the perfection of a material [1].

The domain wall motion coercivity of magnetic materials depends on the localized variations in material parameters. These parameters can be the magnetization, anisotropy, and exchange energy densities. However, the domain wall energy may change if the domain wall volume is changing in an absolutely homogeneous material versus the wall position. Therefore, any surface irregularity can cause a coercivity contribution. Furthermore this contribution has been shown to be an important source of coercivity of permalloy thin film head materials [2].

Most previous models of surface coercivity in ferromagnetic materials have been done with assumption that the volume of the domain walls is constant [3]. This assumption is not valid for the thin soft magentic materials in high density magnetic recording heads, where low coercivity is an important required characteristic. These films are of about 100 atomic layer thin. Therefore, a change of just a few atomic layers causes big volume variation of domain walls.

In the present paper, a model for the surface roughness effect on coercivity through is described for the case of two dimensional sinusoidal thickness modulation of a thin film.

The model assumes that the saturation magnetization M_s, the DW energy density γ_w, the anisotropy energy density K, and the exchange energy density A are constants through the material together with the DW thickness δ. The length and height of DW are L and h. The latter depends on the surface roughness, i.e. $h=h(x,y)$.

The model calculates the coercivity for 180 deg Bloch walls, with magnetization direction along the *z*-axis and H_z, the magnetic field, is directed along the *z*-axis, so that the DW is moving in the *x* direction. The model ignores the demagnetizing field. For in-plane magnetized films (magnetization and field are both along the *y* direction), the same model can be applied and in that case there is no error associated with neglecting the demagnetizing effects.

The change in the potential energy of the wall in equilibrium is equal to the change of the total wall energy $U=Lh\gamma_w$:

$$dU = 2M_s H\,dV \tag{1}$$

If the field is along the *z*-axis and that of the wall motion is *x*, then the volume variation along the *x*-axis is:

$$d(Lh\gamma_w) = 2M_s H\,dV \tag{2}$$

The wall moves if $H > H_c$, the critical field for DW motion - the coercivity:

$$H_c = \frac{d(Lh\gamma_w)}{2M_s\,dV} \tag{3}$$

$$H_c = \frac{1}{2M_s}\left(Lh\frac{d\gamma_w}{dV} + h\gamma_w\frac{dL}{dV} + L\gamma_w\frac{dh}{dV}\right) \tag{4}$$

It is assumed that γ_w=const, L=const for the material constant, and only the coercivity from the change of DW volume is calculated ; the model.

II .MODEL I

Assuming that the surface roughness is characterized by an effective wavelength, i.e. the average periodicity of the irregularity, λ and the relative thickness variation *dh/h*, and a two dimensional surface is defined by the following function, where

$k_x=2\pi/\lambda_x$, $k_y=2\pi/\lambda_y$ are the wave numbers.

$$h(x,y)=h_o-\frac{dh}{2}\cos(k_x x)-\frac{dh}{2}\cos(k_y y) \tag{5}$$

This surface profile is illustrated in fig.1

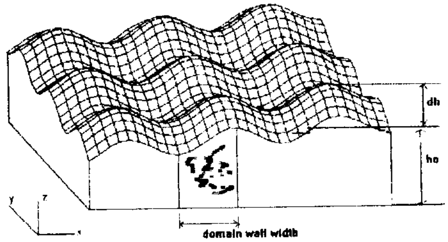

Fig. 1 Two dimensional surface for H_c calculation, as given by (5). The DW moves in the x direction and the magnetic field is applied along the z direction.

When the length of the DW along the y axis is L, the volume variation along the x axis is given by:

$$\frac{dV(x)}{dx}=Lh_o-\frac{dh}{2}L\cos(k_x x)-\frac{dh}{2}\frac{1}{k}\sin(k_y L). \tag{6}$$

If the DW energy density is γ_w, then the total wall energy is given by:

$$E(x)=\gamma_w[h_o L-\frac{dh}{2}L\cos(k_x x)-\frac{dh}{2}\frac{1}{k}\cos(k_y L)] \tag{7}$$

Differentiating Eq.(8) with respect to x, we have

$$\frac{dE(x)}{dx}=\gamma_w\frac{dh}{2}Lk\sin(k_x x) \tag{8}$$

Combining equations (3), (6), and (8), the critical magnetic field equation becomes

$$H(x)=\frac{dE(x)}{2M_s\,dV(x)} \tag{9}$$

III.MODEL II

To generate a more realistic irregular surface profile, $h(x,y)$ is described as a wave packet

$$h(x,y)=h_o-\frac{dh}{4}\cos(kx+k_1 y)-\frac{dh}{4}\cos(kx-k_2 y)-\frac{dh}{4}\cos(kx+k_3 y)-\frac{dh}{4}\cos(kx-k_4 y) \tag{10}$$

The surface profile for this case is shown in Fig. 2.

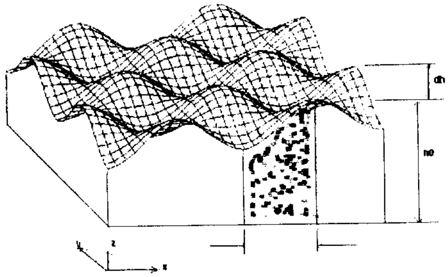

Fig .2 Surface profile according to Eq. (10)

The change of the domain wall energy is

$$\frac{E(x)}{dx}=\gamma_w(-\frac{dh}{4}(\cos(kx+k_1 L))-\cos(kx))+\frac{dh}{4}(\cos(kx-k_2 L)-\cos(kx)) \tag{11}$$

Based on equation (9) of model I, we can calculate the coercivity field.

IV.RESULT

Calculations have been performed for the case of 10nm thick permalloy head. Table I shows the parameters for the calculation. Fig.3 shows the wavelength dependance of coercivity on modeling I.

Table 1 The Permalloy parameters used in coercivity calculations.

Saturation Magnetization	800 kA/m	M_s
Exchange Energy	10 pJ/m	A
Anisotropy Energy	160 J/m^3	K
Stripe Domain Width	1 x 10^{-6} m	w_s
DW Energy Density	160 x 10^{-3} J/m	γ_w
Thickness of Film	10 x 10^{-9} m	h_o
Variation in Film Thickness	1 - 5 x 10^{-9} m	dh
DW Width	200 x 10^{-9} m	δ
Effective Wavelength of Roughness	0.2 - 1 x 10^{-6}m	λ
Width of Head	4 x 10^{-6}m	L

For the surface profile of model I, H_c is increasing linearly with the amplitude of surface roughness *dh/h*, and for any given dh/h there is a maximum coercivity, when the ratio λ/δ_w is around 1.5 to 2. Assuming dh/h=0.2, H_c=1.72 Oe at λ/δ_w= 1.5. When the roughness, dh/h=0.3 (0.5), the maximum coercivity is 2.54 (4.14) Oe, 4.14 Oe at the wavelength to DW width ratio of 1.75. As the roughness increases, the coercivity increases proportionally. However, when the wavelength of surface roughness increases, the coercivity decreases, as can be seen in Fig 3, Fig 4.

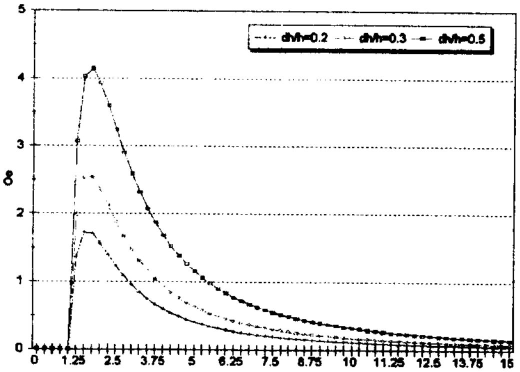

Fig.3 Coercivity of Model I depending on the relative effective roughness wavelength (λ/δ_w) for different surface roughness amplitude *dh/h*=0.2, 0.3, 0.5

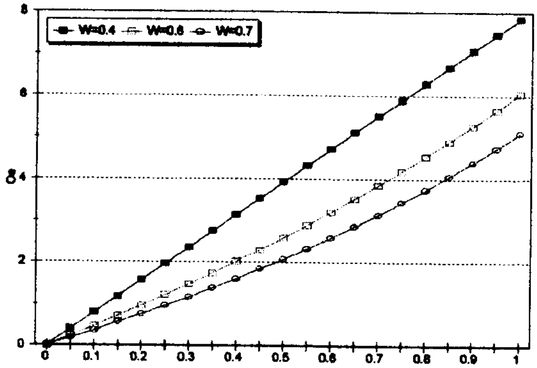

Fig.4 The coercivity in Model I, depending on surface roughness amplitude, *dh/h*, when λ=400 nm, 600 nm and 700 nm.

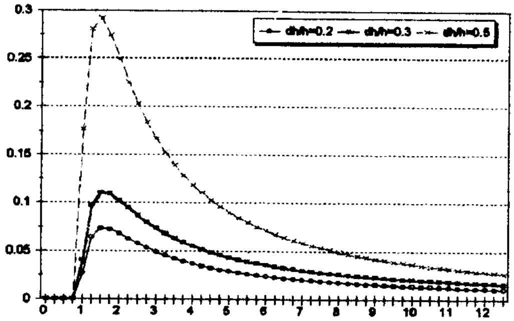

Fig.5 The coercivity in Model II depending on the effective wavelength (λ/δ_w) with the surface roughness *dh/h* as a parameter..

In Model II, the maximum coercivity is obtained, when the ratio of the effective wavelength to the DW width is around 1.5. With dh/h=0.2, M_c=0.073 Oe at λ/δ_w=1.5 . For the roughness of 0.3 and 0.5 , the coercivity is 0.11 Oe, and 0.29 Oe respectively, at the same value of wavelength to DW width ratio.

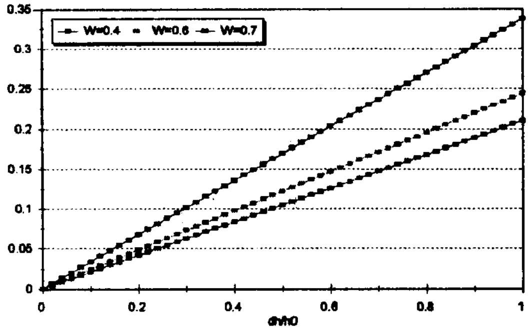

Fig.6 Dependence of coercivity in Model II on the relative thickness change for λ=400 nm, 600 nm and 700 nm.

Ⅴ.CONCLUSION

The gradient of DW energy is the origin of coercivity in magnetic materials. The source of H_c are the local charge of anisotropy and exchange energy. The surface roughness contributes to H_c due to local DW volume charges, due to surface roughness. As magnetic films (heads) are getting thinner, the same surface roughness will lead to much higher coercivity. However, the coercivity depends on both of the relative surface roughness amplitude, *dh/h*, and the rate of the effective wavelength of the surface roughness to the DW width λ/δ_w.

The coercivity has a maxium for about $\lambda/\delta_w=2$. The numerical calculations show that the surface roughness is a very important source of coercivity in soft magnetic thin films.

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