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TWO–DOMAIN MODEL OF MAGNETIZATION IN THIN DISCS WITH UNIAXIAL MAGNETIC ANISOTROPY

IVAN ANTONOV, JERZY M. MUCHA*, LYUDMIL VATSKITCHEV and MARIA VATSKITCHEVA

Faculty of Physics, Sofia University, 1126 Sofia, Bulgaria
**Institute of Physics, Jagellonian University, Krakow, Poland*

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The influence of the domain structure on the magnetization processes in thin magnetic discs with uniaxial anisotropy is investigated. The critical magnetic fields of transformation from multi–domain to one–domain structure in the sample are calculated. The theoretical results are verified experimentally by the torque moment measurements.

1. *Introduction*

The domain structure with 180°–domain walls is observed in thin magnetic discs with uniaxial magnetic anisotropy [1-3]. In an external magnetic field the magnetization process takes place through the domain wall motion and the rotation of magnetization vectors. When two magnetic domains with antiparallel magnetizations are observed in the sample, this magnetic structure transforms into a one–domain structure. The conditions of this transformation are discussed in the present paper. The values of the critical magnetic fields H_{cr} and the angles Θ_{cr} have been derived theoretically and we obtained a good agreement with the experimental results obtained by torque measurements.

2. Theoretical background

In a thin magnetic disc, the changes of magnetization are due to internal magnetic field $\vec{H}_i$ which is a sum of the external field $\vec{H}$ and the demagnetization $\vec{H}_d$. In the initial state of the sample, two antiparallel domain magnetizations along the easy axis of magnetic anisotropy can be observed. When the applied field H increases at $\Theta =$ const., the sample magnetization changes by the domain wall motion and the rotation of the domain magnetization $\vec{M}_1$ and $\vec{M}_2$ inclined at angles φ_1 and φ_2, respectively, with respect to the domain wall (Fig. 1).

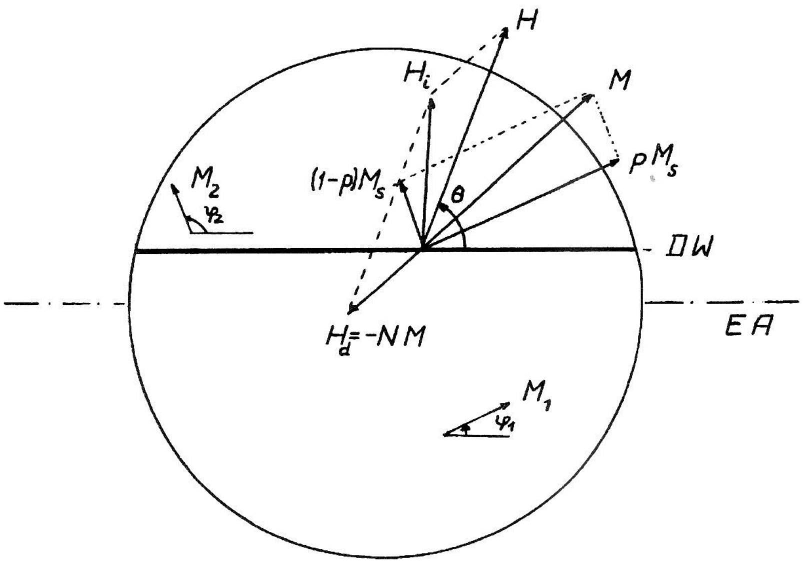

Fig. 1. Magnetizations of a two–domains and magnetic fields in the disc sample with uniaxial magnetic anisotropy. EA and DW are the easy axis and domain wall, respectively.

2.1. Free energy of the two–domain sample

We denote the relative volume of the first domain (with a magnetization M_1) by p. The magnetic free energy E of the sample can be calculated as a sum of the anisotropy energy E_a and the energy of interaction E_i between the internal field and the magnetization:

$$E = E_a + E_i = E_a + E_H + E_d = pK \sin^2 \varphi_1 + (1-p)K \sin^2 \varphi_2$$

$$-pHM_s \cos(\Theta - \varphi_1) - (1-p)HM_s \cos(\Theta - \varphi_2) + E_d, \qquad (1)$$

where K is the anisotropy constant and M_s is the saturation magnetization.

We calculated the interaction energy E_d between the demagnetizing magnetic field $\vec{H}_d$ and the magnetization $\vec{M}$ of the sample by presenting the demagnetizing field as $\vec{H}_d = \hat{N}\vec{M}$, where $\hat{N}$ is the diagonal tensor with components $N_{xx} = N_{yy} = N$ and $N_{zz} = Z$ for a thin disc. Then

$$E_d = \frac{1}{2}NM_S^2\left[p^2 + (1-p)^2 + 2p(1-p)\cos(\varphi_2 - \varphi_1)\right]. \tag{2}$$

Therefore, the free energy is a function of the angles φ_1 and φ_2 and of the relative volume p at fixed H and Θ. The domain configuration of the sample is determined from the minimum of the free energy

$$0 = \frac{\partial E}{\partial p} = \frac{K}{2M_S}\sin(\varphi_1+\varphi_2)\sin(\varphi_1-\varphi_2)$$

$$+H\sin\left(\frac{\varphi_1+\varphi_2}{2} - \Theta\right)\sin\frac{\varphi_1-\varphi_2}{2} + NM_S\left(\frac{1}{2} - p\right)(\cos(\varphi_2-\varphi_1) - 1), \tag{3}$$

$$0 = \frac{\partial E}{\partial \varphi_2} = \frac{p}{2}\left(\frac{K}{M_S}\sin 2\varphi_1 + H\sin(\varphi_1 - \Theta) + NM_S(1-p)\sin(\varphi_2-\varphi_1)\right), \tag{4}$$

$$0 = \frac{\partial E}{\partial \varphi_1} = \frac{1-p}{2}\left(\frac{K}{M_S}\sin 2\varphi_2 + H\sin(\varphi_2 - \Theta) + NM_S p\sin(\varphi_2-\varphi_1)\right). \tag{5}$$

2.2. Critical fields

The two–domain structure of the sample transforms to the one–domain at the critical value of the external magnetic field, H_{cr}, which depends on the field direction (the angle Θ). If $\Theta = 0$, then $\varphi_1 = 0$ and $\varphi_2 = \pi$. From Eq. (3) we can calculate $H_{cr} = NM_S = H_{ds}$ at $p = 1$. Therefore, the sample will pass into one–domain state if strenght of the applied field H is equal to the demagnetization field H_{ds} at magnetic saturation of the sample.

We can obtain a similar result if the external magnetic field is perpendicular to the easy–axis direction ($\Theta = \pi/2$). Then $H_{cr} = 2K/M_S + NM_S = H_a + H_{ds}$ and the external applied field $H \geq H_{cr}$ must overcome the anisotropy field H_a and the demagnetization field H_{ds} at a magnetic saturation.

In the general case ($\Theta \neq 0,\ \pi/2$ and $\varphi_1 + \varphi_2 = \pi$) we obtained

$$p = \frac{1}{2}\left[1 + \frac{1}{\dfrac{H_{ds}}{H_x}\left(1 - \dfrac{H_y^2}{(H_a + H_{ds})^2}\right)^{1/2}}\right], \tag{6}$$

where $H_x = H\cos\Theta$ and $H_y = H\sin\Theta$ are the components of the external field. The critical value (at $p = 1$) is given by

$$H_{cr} = \frac{1}{\left(\dfrac{\cos^2\Theta}{H_{ds}^2} + \dfrac{\sin^2\Theta}{(H_a + H_{ds})^2}\right)^{1/2}}. \tag{7}$$

2.3. Torque moment

If the sample is placed in the external magnetic field, the torque moment $L = -\partial E/\partial\Theta$ acts on the magnetic disc. The torque moment increases with H^2 and reaches the maximum for $\Theta = \pi/4$:

$$L = -HM_S\sin(\Theta - \varphi) = -\frac{H^2}{2}\frac{H_a M_S}{H_{ds}(H_a + H_{ds})}\sin 2\Theta. \tag{8}$$

This formula is valid in the presence of a domain structure in the magnetic fields $H < H_{ds}$. The maximum value of L is expected in the magnetic field:

$$H_{cr_1} = \sqrt{\frac{2}{\dfrac{1}{H_{ds}^2} + \dfrac{1}{(H_a + H_{ds})^2}}}. \tag{9}$$

If $H > H_{cr_1}$, the maximum torque moment is expected at $\Theta > \pi/4$ and the new value of the critical magnetic field is:

$$H_{cr_2} = \sqrt{\frac{(H_a + H_{ds})^2 + H_{ds}^2}{2}}. \tag{10}$$

In this field the two domain structure transforms into the one–domain structure. At $H > H_a + H_{ds}$ one observes one–domain structure for every value of Θ.

3. *Experimental results*

The torque moment L on a thin disc of laminated iron with uniaxial magnetic anisotropy was measured as a function of the angle Θ for different values of the external magnetic field H by torque magnetometer [4]. The critical values of H and Θ were calculated theoretically and they were compared with the experimental ones (Fig. 2).

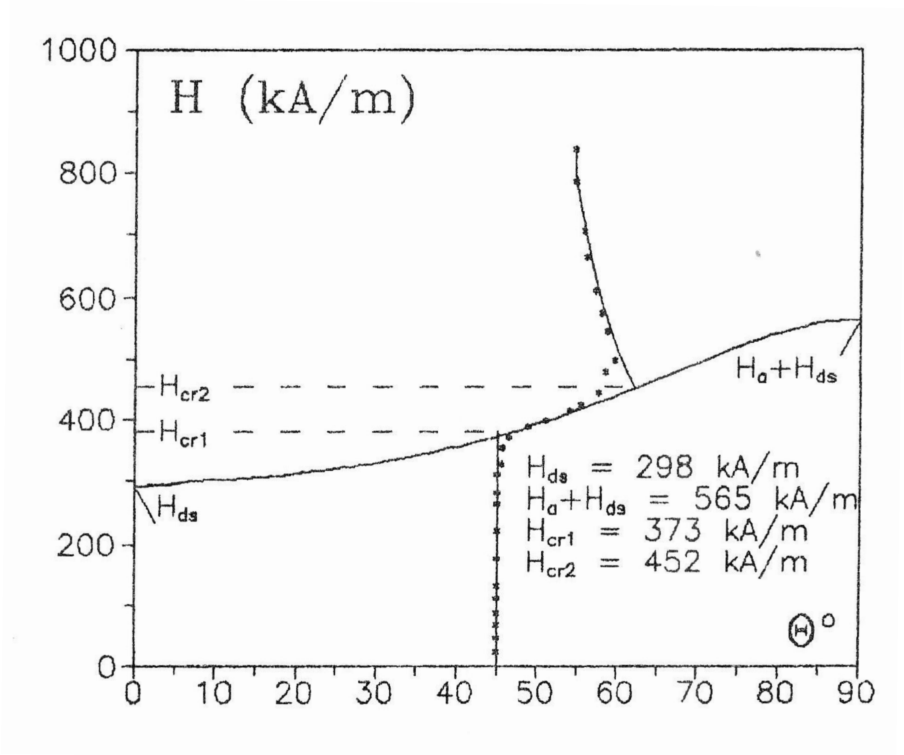

Fig. 2. The critical values of the external field H and its direction (the angle Θ) calculated theoretically (—) and measured experimentally ($_{***}$) in a thin magnetic disc. H_a and H_{ds} are the anisotropy field and demagnetization, respectively, at magnetic saturation; H_{cr1} and H_{cr2} are the critical fields calculated from the expressions (9) and (10).

The dependence of the maximum torque L from the applied field H is shown in three cases (Fig. 3):
i) theoretical curve for one domain state (Stoner–Wohlfarth model [5]),
ii) theoretical curve in this two domain model, and
iii) experimental points, measured for our sample.

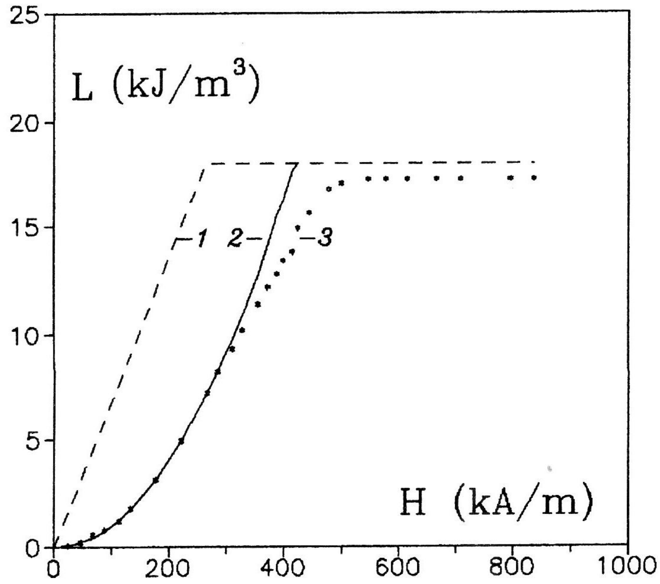

Fig. 3. The maximum torque moment, as a function of the applied field H (1 and 2 – theoretical curves for the one– and two–domain models, respectively, 3 – experimental values).

4. Conclusions

The two–domain model gives the possibility to describe the magnetization process in a sample with uniaxial magnetic anisotropy. The calculated critical magnetic parameters of the domain structure transformation closely describe the experimental values. The good agreement between the theoretical curve for L_{max} for the two–domain model and the experimental results shows that this model is more adequate to describe the magnetic structure than the one–domain model. The real domain structure of the sample appears to be similar to the expectation.

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DVODOMENSKI MODEL MAGNETIZACIJE U TANKIM DISKOVIMA S JEDNOOSNOM MAGNETSKOM ANIZOTROPIJOM

IVAN ANTONOV, JERZY M. MUCHA*, LYUDMIL VATSKITCHEV i MARIA VATSKITCHEVA

Faculty of Physics, Sofia University, 1126 Sofia, Bugarska
Institute of Physics, Jagellonian University, Krakow, Poljska

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Proučava se utjecaj domenske strukture na procese magnetiziranja tankih magnetskih diskova s jednoosnom anizotropijom. Izračunate su vrijednosti kritičnih magnetskih polja pri kojima se višedomenska struktura transformira u jednodomensku. Teorijski su rezultati eksperimentalno provjereni mjerenjem momenta sile na diskove.