# Ultrafast Optomagnetic Bistable Effects in Magnetically–Ordered Dielectrics Cylindrical Nanoparticles

Sergei BARANOV*, Igor DOBYNDE
*Institute of Applied Physics, Academy of Science of Moldova*
baranov@phys.asm.md

***Abstract* — We present results of a study of the magnetization orientation in magnetically–ordered dielectrics cylindrical nanoparticles. We derive the hysteresis dependence of the equilibrium magnetization orientation *X* on the external parameter *p*. This hysteresis determines the region for the optical bistability observation in the opto-magnetic inverse Faraday effect.**

***Index Terms* — Magneto-optics, ultrashort laser pulse, pump-probe optical spectroscopy, opto-magnetic inverse Faraday effect, optical bistability.**

## I. INTRODUCTION

An ultrashort laser pulse (ULP) excites the spin precession in the magnetically-ordered dielectrics, as stated in [1-3]. The spin-reorientation phase transition in orthoferrites can be induced by an ULP and the rise of time of this transition is equal to a few picoseconds [1, 2].

## II. METHOD

The Landau–Lifshits equation-based description of the reorientation phase transitions dynamics was considered (see [4–7]):

$$\frac{dM}{dt} = -\gamma_0 M \times H_{eff} + \alpha M \times \frac{dM}{dt} \quad (1),$$

where $M$ is the saturation magnetisation , $\gamma_0$ is the gyromagnetic ratio, $H_{eff}$ determined as a anisotropy field (about $H_{eff}$ and the free energy , F(Ψ), see below), $\alpha$ is the Gilbert damping parameter.

The simple variant of anisotropy energy is presented in the following form:

$$F_{em} = -\frac{3}{2}\lambda\sigma\cos^2(\psi-\psi_0) \quad (2).$$

Then, for magnetic permeability, μ, taking into account the following could be obtained:

$$\mu = \left(\frac{3\lambda\sigma}{M^2} - N_\Delta\right)^{-1} \quad (3).$$

The above equation was arrived to based on the orientation phase theory transition of.

However in case where $F_{ms}$ and $F_{em}$ compensate for each other the expansion term $F_{em}$ should be considered, the latter, could be expressed noted in the following form:

$$F_2 = K_2\cos^4(\psi-\psi_0) \quad (4).$$

The form of the function $F_2$ for orientation change of phase in crystalloid magnetic depends on the type symmetry of the crystal, the equation (4) corresponds to hexagonal symmetry. The form of the above function for amorphous materials is not exactly known, therefore, further calculations a quality are only calculations free energy should also contain the $F_H$ field term and have the following form:

$$F_H = -MH\cos\psi \quad (5),$$

and

$$F = F_{ms} + F_H + F_{em} + F_2 \quad (6).$$

Equilibrium orientation of magnetization is deducted from the solution for the equation obtained from the following:

$$\frac{\partial F}{\partial\psi} = 0 \text{ on condition } \frac{\partial^2 F}{\partial^2\psi} \geq 0 \quad (7).$$

For the relative magnetization along the microwire axis, $X = \cos\psi$, a numerical solution could be obtained. For a quality assessment the equation could be simplified if to consider that:

$$F_{em} + F_{ms} = K_U\cos^2(\psi-\psi_0) \quad (8)$$

and

$$F_2 = K_2\cos^4\psi \quad (9).$$

In a case where $\psi_0 \approx \pi/2$ the equation will acquire the following form:

$$4gX^3 + 2X + P = 0 \quad (10),$$

where $g = \frac{K_2}{K_U}$ and $P = \frac{MH}{K_U}$.

The P parameter characterizes the applied field, while the g parameter characterizes the relation of the anisotropy constants, where near the “compensation” point g increases significantly due to the fact that $K_U$ tends to zero.

The generalized coordinate $\sin^2\psi$ expansion was used for the free energy representation:

$$F = F_0 + K_1(T)\sin^2\psi + K_2\sin^4\psi \quad (11).$$

The summand, which is proportional to the value of $\{H(t)M\sin\Psi\}$ and corresponds to the interreaction with the field, enters the $F_0$ term.

The parameter $\psi$ is the angle between the magnetization vector and the anisotropy axis and the external field *H(t)*.

In the elementary case, the direction of the *H(t)* vector coincides with the axis of all anisotropies; the coefficients $K_1(T)$ and $K_2$ are the scalar parameters of these anisotropies, whose changing initiates the onset of reorientation phase transitions

## III. RESULTS AND DISCUSSION

Let us consider the following expansion of the free energy:

$$F = F_0 + K_1(T)\cos^2(\psi - \psi_0) + K_2 \cos^4 \psi \qquad (12).$$

The free energy representation is due to the fact that the anisotropy axes would be probably nonparallel one another in the general case. The equilibrium magnetization orientation $X = \cos\psi$ is determined by the expression (13):

$$-16 \cdot g^2 \cdot X^8 + \left(16 \cdot g^2 - 16 \cdot p \cdot g \cdot \cos 2\psi_0\right) \cdot X^6 - 8 \cdot p \cdot g \cdot X^5 +$$
$$+\left(16 \cdot p \cdot g \cdot \cos 2\psi_0 - 4\right) \cdot X^4 + \left(8 \cdot p \cdot g - 4 \cdot p \cdot \cos 2\psi_0\right) \cdot X^3 + \left(4 - p^2\right) \cdot X^2 +$$
$$+ 4 \cdot p \cdot \cos 2\psi_0 \cdot X + p^2 - \sin^2 2\psi_0 = 0$$

where $p = MH/K_1$ , and $g = K_2/K_1$.

We derived the hysteresis dependence of the value $X$ on the external parameter $p$ from expression (13) ( see Fig.1 , and Fig. 2).

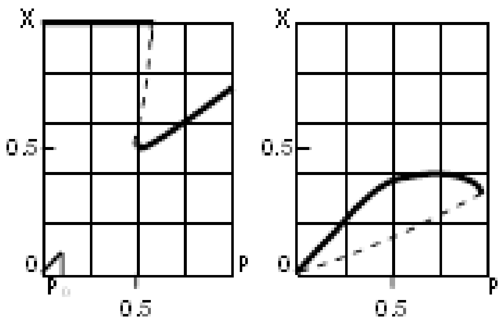


Fig.1. Examples of the numerical solutions for expression (13) (for $g$ =0.1 and $g$ = -1).

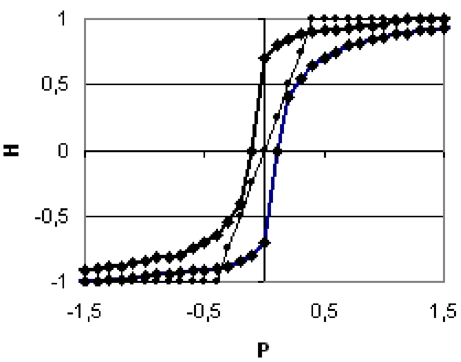


Fig. 2. Examples of the numerical solutions for expression (13) ($g$ = -1 , and <<$K_2$ >> = -100).

## IV. CONCLUSION

We derived the hysteresis dependence of the value $X$ on the external parameter $p$ from expression (13).
This hysteresis determines the region for optical bistability observation in the opto-magnetic inverse Faraday effect.

This effect may be recorded in the “pump-probe” geometry. The pump is the effective magnetic field of the high-power exciting ULP and the probe is the magnetic polarization of the weak ULP, which is transmitted through the excitation area.

Magnetically controllable bistability is useful to realize reconfigurable optical flip-flop memories.

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