INFLUENCE OF THE INVERSE FARADAY EFFECT ON SWITCHING AND OSCILLATIONS OF MAGNETIZATION IN SINGLE-DOMAIN NANOPARTICLES

Andrei V. Kukharev*, Alexander L. Daniluyk

Belarusian State University of Informatics and Radioelectronics,
P. Browka 6, 220013, Minsk, Belarus

ABSTRACT

We have performed a numerical simulation of magnetization switching and oscillations in a ferromagnetic single-domain particle in the disk form under the influence of nanosecond laser pulses with linearly and circularly polarization.

During the simulation of magnetization we have used the macrospin approximation with the generalized Landau-Lifshitz-Gilbert equation. In this model the interaction of laser with ferromagnetic metal leads to following processes: a change in energy magnetic crystallographicanisotropy and in a value of saturation magnetization, a generation of the spin-polarized current by photon pressure, an occurrence of the magnetic field induced by the magnetoopticalinverse Faraday effect in the case of circularly polarized laser.

The analysis has shown that the interaction of laser pulses with a ferromagnetic nanodisk leads to change in the direction of its magnetization. This process is accompanied by magnetization oscillations with duration from units to tens of nanoseconds. As it follows from the obtained results, the main cause of magnetization switching is the reduction of magnetic anisotropy energy at heating of the structure by laser. The field of the inverse Faraday effect can lead to an increase in frequency and amplitude of this oscillations.

Key words: magnetization oscillations, ferromagnetic nanoparticles, magnetoopticalinverse Faraday effect

INTRODUCTION

An important practical application of single-domain ferromagnetic nanoparticlesis the development of non-volatile magnetic memory. The speed of such memory depends on the duration ofmagnetization reversal. It's necessary to use single-domain nanoparticleswith a large value of the coercive force$H_c$in order to increase the storage density. However, modern writing/reading systems using external magnetic field aren't capable to switch of the magnetization of nanoparticles with a large $H_c$value. The perspective way of the local decrease

* e-mail: kuharev-sp@mail.ru, tel: (+375)292187885, tel: (+375)172938869

ofthe H_c value is heating by laser. Moreover, the interaction of laser with a ferromagnetic particle leads to the creation of additional magnetic field induced by the magnetoopticalinverse Faraday effect in the case of circularly polarized radiation.If a magnetic nanoparticle is included in a structure ferromagnetic / nonmagnetic metal / ferromagnetic, then in this structure the spin-polarized currentis induced by photon pressure [1]. This current influences on magnetization of the particle by the Slonczewski-Berger mechanism of the spin transfer torque [2]. In this case the stable magnetization oscillations in this structure may be excited. This effect can be used for development of microwave nanogenerators. However, the main problem here is the request of large current density.

Recent experimental investigations have shown that it is possible to switch locally magnetization in magnetic thin films by nano- and picoseconds laser pulses. Depending on conditions the reason of such magnetization reversal includes various factors. It is the decrease of the coercive force due to heating of the sample, the influence of the magnetoopticalinverse Faraday effect and the influence of spin-polarized current. However, the transient process and magnetization oscillations during the moment of switching is not completely studied.

The purpose of this work is to clarify the role of the inverse Faraday effect in switching process and magnetization oscillations in a ferromagnetic single-domain particle of hexagonal cobalt under the influence of nanosecond laser pulses at zero magnetic field.

MODEL

We consider a magnetic nanoparticle of hexagonal cobalt in the disk (nanodisk) with following parameters: the saturation magnetization at zero temperature $M_0 = 1.432 \cdot 10^6$ A/m, the Curie temperature T_C= 1394 K, the Gilbert damping parameter $\alpha = 0.02$. The aspect ratio of the disk $\varepsilon = L/D$, where the diameter $D$is ranging from 10 to 18 nm, the height L is ranging from 5 to 20 nm. The disk of such size has a single-domain state. In the chosen coordinate system the z axis is perpendicular to the plane of the nanodisk. The nanodisk is irradiated by laser beam with power of 5 – 100 MW/cm^2 and duration of 0.1 – 2 ns.

The dependence of saturation magnetization from temperature T is approximated by expression $M(T)=M_0[1 - (T/T_C)^2]^{1/2}$. We use the Landau-Lifshitz-Gilbert equation for description of magnetization dynamics:

$$d\mathbf{m} / d\tau = -\left[\mathbf{m}\times\mathbf{h}\right] - \alpha\left[\mathbf{m}\times\left[\mathbf{m}\times\mathbf{h}\right]\right] \tag{1}$$

Wherem = M/$M(T)$, |m| = 1is the unit vector of magnetizationM, h = H/M_0 is the effective field, $\tau = \gamma M_0 t/(1+\alpha^2)^2$, t is the time, γ isthe gyromagnetic factor.Theeffectivefieldhincludesthe field of magnetic crystallographicanisotropyh$_a$,the demagnetization field h$_d$,the field of the inverse Faraday effect h$_{mo}$ and the field of thermal fluctuationh$_T$.

RESULTS AND DISCUSSION

The influence of the inverse Faraday effect is the most significant for thin and thick disk, when the [0001] crystallographic direction is parallel to the planes of the disk.

Thindisk. Let's consider a thin nanodisk with height of 5 nm, diameter of 18 nm. If this disk is heated from 300 to 610 K by a linearly polarized laser pulse with peak intensity I_{1m} = 95 MW/cm^2 and duration of 0.1 ns, its magnetization is switched from the *x*direction to the *y*direction (*fig. 1a*). This switching is accompanied by magnetization oscillation with average frequency of 8.5 GHz. If laser beam hasleft circularly polarization, the magnetization vector deviates towards the negative direction of *z*axis and rotates around this axis during the moment of action of a laser pulse. Then it moves to the position parallel to the *y*axis (*fig. 1b*).

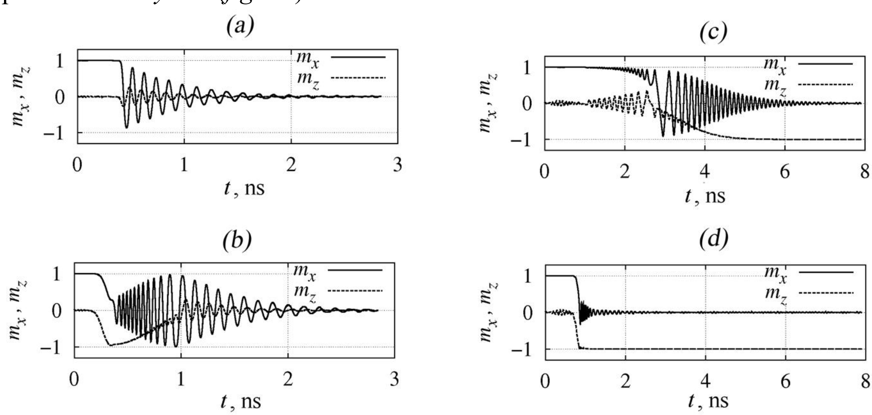

Fig. 1–The oscillation of magnetization in cobalt nanodisk under the influence of a laser pulse: *a* –the thin disk and the linearly polarization of laser; *b* – the thin disk and the left circularly polarization of laser; *c* – the thick disk and the linearly polarization of laser; *d* – the thick disk and the left circularly polarization of laser

*Thickdisk.*The thick nanodiskis characterized by height of 20 nm and diameter of 10 nm. A laser pulse with peak intensity I_{1m} = 60 MW/cm^2 and duration of 0.15 ns heats this disk fromT_0 = 300 KtoT_1 = 590 K. For such a disk at temperature $T_0$the steady magnetic state is parallel to the *x*axis, while at temperature T_1 it is parallel to the *z* axis.

If the laser has linearly polarization, the inverse Faraday effect is absent. In this case after heating the disk by laser the magnetizationis switched from the *x* direction to the positive or negative direction of the *z* axis with equal probability due to thermal fluctuations (*fig. 1c*). The frequency of accompanied magnetization oscillation is ranging from 3 to 10 GHz.

If the laser has right circularly polarization, the magnetizationis switched only to the positive direction of the *z* axis. In the case of the left circularly polarization, the magnetizationis switched only to the negative direction of the *z* axis (*fig. 1d*). Thus, in this thick disk for any polarization of laser beam the magnetization is switched from the planar state to the one of perpendicular states, but the specific direction depends on the laser polarization.

CONCLUSIONS

It is shown the process of magnetization switching of cobalt single-domain nanoparticles in the disk form under the influence of laser nanosecond-pulsesis accompanied by magnetization oscillations.Thefrequencies and duration of these oscillations for different thickness of the disk and crystallographic orientation are defined. The influence of the magnetoopticalinverse Faraday effect on the switching and oscillation of magnetization has been investigated.

Two cases have been considered when the inverse Faradayeffect has essential influence: thin and thick disks with the [0001] crystallographic direction in the plane of the disk. For the thin disk the influence of inverse Faraday effectleads to the deviation of the magnetization vector along the axis of the disk only during the moment of action of a laser pulse.For the thick disk the direction of laser polarization (right circularly or left circularly) determines the direction of magnetization switching: along the positive or negative direction of the *z* axis.

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