LASER-INDUCED MAGNETO-RESISTANCE EFFECT IN MAGNETIC TUNNEL JUNCTIONS WITH PrO BARRIER

M. Krupa, A. Korostil

Institute of Magnetism NAS of Ukraine, Kyiv, 03 142
Ukraine (Tel: 8044-424-1020; e-mail: amand@ rambler.ru).

Abstract: We have studied mechanisms of the laser-induced magnetic switching and a magneto-resistance effect in the magnetic tunnel junctions consisting from nanolayers on the base of NiCoFe compounds with perpendicular magnetic anisotropy and the tunnel barrier on the base of the PrO compound. On the basis of magneto-optical measurements we have shown that magnetic swathing in the considered magnetic junction is caused by the direct magneto-optical effect via internal effective magnetic fields related with the inverse magneto-optical Faraday effect and internal magnetic effective fields related to s-d interaction of the laser-induced spin current with a lattice magnetization and the indirect laser-induced effect of thermal demagnetization. It is shown that a complex action of the mentioned mechanisms provides well the enough magnitude of the laser-induced magnetoresistance effect.

Keywords**:** polarized laser pulses, magnetic tunnel junctions, magnetic and resistance switching

1. INTRODUCTION

Spintronics belongs to one of the most quickly developing area of science and technology, which is based on the control by processes of transfer of a spin current between the elements of electronic devices. Researches of a spin dependent transport and spin relaxation in solids, the search of new materials with the high degree of an electron spin polarization and development of methods for active control of spin states in solid-state circuits constitute the main directions of the spintronics.

The spin current control assumes the presence of effective spin current injectors, control means of electron spin orientation and elements for a spin current filtration. Magnetic materials with the high degree of spin polarization are used as the effective injectors of the spin current. The high degree of the spin polarization at a room temperature is provided in magnetic semimetals, some magnetic Haussler alloys and magnetic semiconductors.

Heterogeneous magnetic nanostructures constitute the most perspective materials for spintronics. The study of such nanostructures allowed to get a high magnetoresistance effect, basic regularities concerning influence of the electronic structure and magnetic characteristics of spatially inhomogeneous materials on the spin-polarized current (see Žutić and et al. (2004), Yuasa and Djayaprawira (2007)), and also to reveal the effect of spin current-induced non-equilibrium magnetization of nonmagnetic nanolayers [5,7].

For creation of high-frequency elements of spintronics it is necessary high-speed control systems of a spatially localized magnetization. Solution of this problem with the help of conventional magnetic systems is overspecified. Interesting possibility of the magnetization control in heterogeneous magnetic nanostructures can be realized via spin current (see Žutić et al. (2004), Gulyaev et al. (2005)). The promising method for excitation of such spin current in multi-layered magnetic nanostructures constitutes in their irradiation by nano- and picosecond polarized laser pulses (see Kimel, Kirillyuk and Hansteen, et al (2007)). Such short laser pulses allow to get a large spin current along the laser beam and induce the effective internal magnetic field of the inverse magneto-optical Faraday effect (see Vahaplar, Kalashnikova and Kimel et al. (2009)). It provides ultrafast switching in the magnetic nanostructures. At powerful enough laser pulses reversal times can do not exceed a few picoseconds.

The problem of magnetization reversal in tunnel magnetic junctions, which has better matched to the requirements of semiconductor technology presenting essential interest is studied in our work. The laser-induced magnetic switching represents the perspective direction for solving of the problem of the fundamental and practical limit of increasing the speed and density of magnetic writing and reading of information (see Kimel, Kirillyuk and Hansteen, et al (2007)).

In the presented work we have researched mechanisms of the laser-induced reversal magnetization and magnetoresistance effect in the magnetic junctions with amorphous nanolayers on the basis of the compounds TbCoF with a perpendicular magnetic anisotropy and the tunnel barrier on the basis the PrO compounds. It is shown the role of the laser-induced spin current in magnetic transformation in the magnetic nanolayers and possibility of fast magnetic reversal in these nanostructures under ultra-short polarized laser pulses that can be used in novel spintronics devices.

2. RESULTS AND ANALYSIS

In our experiment the amorphous ferrimagnetic junction on the basis TbCoFe compounds with perpendicular anisotropy were excited by circularly polarized pulses of the Nd-YAG laser with a central wavelength at $\lambda_0 = 1060$ nm and $\lambda_0 = 355$ nm. The linearly polarized probe pulses of the He-Ne laser ($\lambda_0 = 632,8$ nm) were used for ultrafast image of the magnetization dynamics of the magnetic junctions by means of the magneto-optical Kerr and Faraday effects.

The considered magnetic tunnel junction $Al_2O_3/Tb_{22}Co_5Fe_{73}/Pr_6O_{11}/Tb_{19}Co_5Fe_{76}/Al_2O_3$For under the external reversal magnetic field exhsibits the conventional tunnel magnetoresistance (TMR) effect. In this case resistance switching occurs in result of the magnetic switching of the nanolayers $Tb_{22}Co_5Fe_{73}$ and $Tb_{19}Co_5Fe_{76}$ (under the external magnetic field H) between states with parallel and antiparallel magnetizations. The size of this effect is measured by the fractional change in resistance $TMR = \frac{R_{AP}}{R_P}$, where R_{AP} and R_P are the resistances at antiparallel and parallel nanolayer magnetizations. For our tunnel microcontacts TMR is large enough. As it is visible from the results of measurements in Fig. 1, TMR constitutes 70 % and 200 % at temperatures T = 300 K and 77 K, respectively.

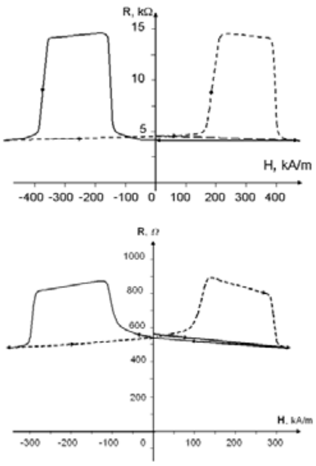

Fig. 1. The dependence of the resistance R of the tunnel magnetic nanostructure $Al_2O_3/Tb_{22}Co_5Fe_{73}/Pr_6O_{11}/Tb_{19}Co_5Fe_{76}/Al_2O_3$ on the external magnetic field at different temperatures: T=77 K, (upwardly), T=300 K (below).

The considered magnetic tunnel junction under nano- and picosecond polarized pulsed laser radiation perpendicular to magnetic nanolayers also exhibits the TMR effect. However, in this case the resistance switching occurs in result of special laser-induced internal effective magnetic fields remagnitizating magnetic nanolayers. Such magnetic switching is caused by the laser-induced thermomagnetic and opto-magnetic impact. The special role belong to the effective magnetic H_F of the inverse magneto-optical Faraday effect and effective magnetic field H_{s-d}, which is related to the exchange s-d interaction between the laser-injected spin-polarized electrons and the magnetic lattice. See Kimel, Kirillyuk and Hansteen, et al (2007) and Gulyaev et al. (2005). Such effective magnetic fields are generated powerful enough polarized picosecond pulsed laser irradiation.

This laser-induced magnetoresistance effect in the magnetic tunnel junction $Al_2O_3/Tb_{22}Co_5Fe_{73}/Pr_6O_{11}/Tb_{19}Co_5Fe_{76}/Al_2O_3$ under the circularly picosecond polarized pulses of the Nd-YAG laser is represented in Fig. 2.

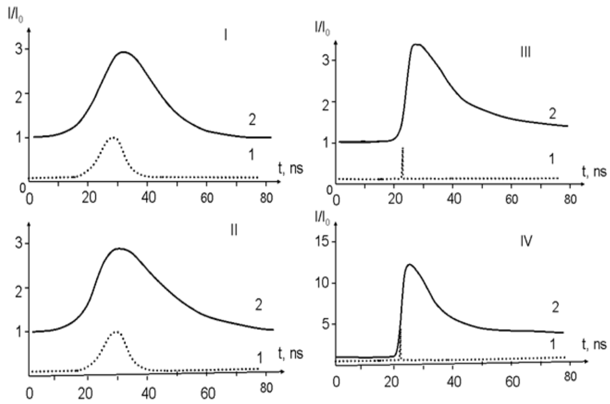

Fig. 2. The time dynamics of the tunnel current through the microcontact $Tb_{22}Co_5Fe_{73}/Pr_6O_{11}/Tb_{19}Co_5Fe_{76}$ under pulses of the Nd-YAG laser with circularly polarized radiation and different pulse times (τ_i = 15 ns – l, ll) and (τ_i = 80 ns – lll, lV): l – the microcontact $\uparrow Tb_{22}Co_5Fe_{73}/Pr_6O_{11}/\uparrow Tb_{19}Co_5Fe_{76}$ with equally magnetized layers with laser intencity I_i =1 MW/cm^2 ; ll-lV – the microcontact with oppositely magnetized layers: ll– I_i =1 MW/cm^2; lll – the circularly polarization: I_i =1 GW/cm^2 , T=300 K; lV– I_i =1 GW/cm^2, T=77 K; 1 – the laser-induced current pulse, 2 – the laser pulse.

As it is visible in Fig.2, the magnetic switching of the tunnel junction under circularly polarized laser pulses can occur together with laser-induced thermal demagnetization, so the internal effective magnetic field of the inverse Faraday effect becomes sufficient for remagnetization of magnetic nanolayers. The remagnetization in the tunnel junction under linearly polarizer laser pulses can be also caused by the internal effective magnetic field of the s-d interaction of the laser-induced spin current which is injected through the tunnel barrier.

Really, the laser-induced magnetic switching in the film $Al_2O_3/Tb_{22}Co_5Fe_{73}\uparrow/Pr_6O_{11}/Tb_{19}Co_5Fe_{76}\downarrow/Al_2O_3$ with antiparallel magnetized nanollayers depends not only pulse duration and polarization but from the incidence direction of laser pulses with respect to the film. The magnetic switching the low-coercive nanolayer $Tb_{19}Co_5Fe_{76}\downarrow$ under laser radiation from the side of the highly coercive nanolayer $Tb_{22}Co_5Fe_{73}\uparrow$ can occurs even for linearly polarized nanosecond pulses without magnetic switching the nanolayer $Tb_{22}Co_5Fe_{73}$. In this case the magnetic switching into the state $Tb_{22}Co_5Fe_{73}\uparrow/Pr_6O_{11}/Tb_{19}Co_5Fe_{76}\uparrow$ occurs in the film areas subjected to the irradiation by the Nd-YAG laser.

The pulsed laser impact on the magnetic system of the magnetic tunnel junction occurs via the laser-induced demagnetization (both direct opto-magnetic and indirect thermal impacts) and reversal magnetization by laser-induced effective internal magnetic fields. The lasts contain the effective magnetic field of the inverse magneto-optic Faraday effect pointing along the direction of laser circular polarization and the effective internal magnetic fields related to the exchange s-d interactions between a laser-induced spin current and lattice magnetization.

The speed and density of the pulsed laser impact on magnetic systems is determined by the intensity, duration, polarization and spatial localization of the laser pulses that can reaches record values. The power of such laser pulses should be large enough for forming strong internal magnetic fields causing the magnetization reversal.

Decreasing of pulse duration from nanosecond to picoseconds interval for circularly polarized laser radiation results in the direct opto-magnetic magnetization and magnetic switching related to the laser-induced heating demagnetization with successive magnetization by strong enough laser-induced internal magnetic fields.

The laser-induced magnetic dynamics and magnetization reversal with the temperature demagnetization are described in the framework of the Landau-Lifshitz-Bloch (LLB) equation in which the temperature dependence of the anisotropy constant is introduced in this equation via the temperature dependence of the transverse susceptibility. Temperature dependence parameters are determined via Langevin dynamics and the Landau-Lifshits-Gilbert equation taking into account both the laser-induced spin torque effect and nonequilibrium spin injection.

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