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Investigation of selective realignment of the preferred magnetic direction in spin-valve layer stacks using laser radiation

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ABSTRACT

Selective realignment of the preferred magnetization direction in a laser micro structured GMR spin-valve layer system ($Ni_{81}Fe_{19}/Co_{90}Fe_{10}/Cu/Co_{90}Fe_{10}/IrMn/Ni_{81}Fe_{19}$) with a total film thickness of 23 nm was studied. For this, patterns of isolated microstructures (500 μm × 200 μm) were fabricated by laser ablation. These micropatterns were annealed using laser irradiation at a temperature above the IrMn Néel temperature. During laser annealing, the sample was subjected to an external magnetic field in order to selectively realign the magnetic direction of the reference layer. Two different laser assisted annealing techniques were investigated applying either continuous or pulsed laser systems. After laser annealing, the magnetic properties of the micropatterns were investigated using a magnetic microsensor and magneto optical Kerr effect set up.

1. Introduction

The growing need for automatization in technical fields requires high-performance sensor technologies. Particular importance can be attached to magnetic field sensors because of their frequent application in automotive, mechanical and computer technologies (read heads in modern magnetic recording). In recent years, GMR (giant magneto-resistance) sensors has increasingly established due to their high sensitivity and compact design. Hence, the GMR effect and manufacturing techniques for GMR sensors are of great interest in research and development. GMR sensors are commonly based on a spin-valve layer stack. A spin-valve consists of two ferromagnetic (FM) layers, of which one layer has a fixed magnetic direction in order to function as a reference layer and the other one acts as a sensor layer (free layer). In this regard, the exchange bias (EB) effect occurring in an antiferromagnetic/ferromagnetic bilayer system when cooled in an external magnetic field through the Néel temperature [1,2] is utilized to pin the magnetic direction of the reference FM layer. Manufacturing of GMR sensors requires not only precise layer deposition and structuring, but also the specific and local alignment of the magnetization direction of the reference layer. In this regard, laser assisted magnetic field annealing has already been demonstrated by using mask projection [3] and static continuous wave laser irradiation [4,5]. In this work, laser assisted annealing in a magnetic field is investigated by using rapidly deflected NIR laser radiation. A comparison is made between continuous and pulsed laser irradiation assisted magnetic realignment.

2. Material and experimental setup

A spin-valve layer system, Ta(3.0 nm)/Cu(0.5 nm)/Ru(0.4 nm)/$Ni_{81}Fe_{19}$(2.0 nm)/$Co_{90}Fe_{10}$(1.0 nm)/Cu(2.054 nm)/$Co_{90}Fe_{10}$(2.1 nm)/IrMn(5.0 nm)/$Ni_{81}Fe_{19}$(2.0 nm)/Ta(5.0 nm) deposited on thermally oxidized Si substrate, was investigated. During deposition, a magnetic field was applied along the film plane so as to create a preferred magnetic orientation in the reference layer. The realignment of this pinned magnetization direction is possible by heating the sample to a temperature above the Néel temperature of the antiferromagnetic layer (∼500 K) and cooling down it to room temperature in an external magnetic field. Microstructuring of the spin-valve layer stack was done by laser ablation using focused femtosecond laser irradiation. Isolated film patches with dimensions of 200 μm × 500 μm were thus fabricated (see Fig. 1).

For heating the microstructured film patches above the Néel temperature, a lamp-pumped Nd:YAG-laser with an emission

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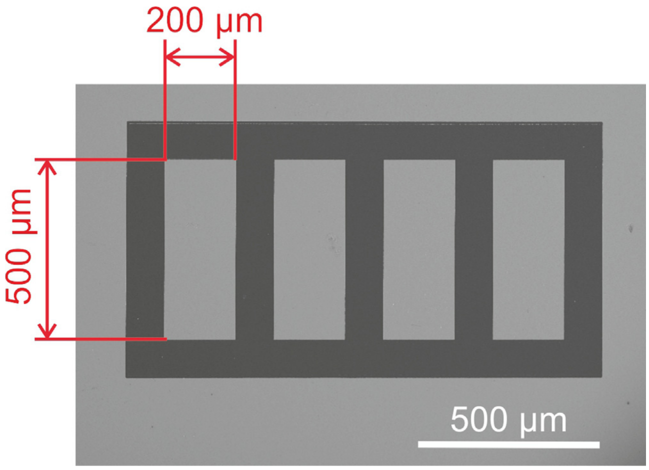

Fig. 1. Laser micro structured film patches.

wavelength of 1064 nm was used. This wavelength is well suited, since the related absorption coefficients of the main components of the layer stack (tantalum and iron) are in the range between 5×10^7 and $6 \times 10^7\ \mathrm{m}^{-1}$. The drawback of high reflectivity of the metals in this wavelength range is not substantial, since only a low energy input is required for the heating up to 500 K. The laser can operate in continuous and pulsed (q-switched) mode. An f-theta optic with a focal length of 80 mm was used to focus the laser beam to a focal radius of 13.4 µm. The laser beam was deflected by using a galvanometer scanner. During laser heating, a magnetic field was applied to the sample in a direction opposite to the initially set exchange bias direction. The magnetic flux density was higher than 100 mT, which ensured complete alignment of the magnetization of the magnetic layers towards the field direction. Fig. 2 shows a schematic of the experimental setup.

The magnetic state of the film patches after laser annealing was detected by using a magnetic micro sensor. The sensor was implemented in a scanning probe technique and thereby the magnetic stray field of the isolated film patches was detected (Fig. 3). As the magnetic flux lines at the pattern edges are aligned in the direction of sensitivity of the sensor, maxima and minima are detected at these edges. The sequence of maxima and minima provides information about the magnetization direction of the isolated film patch. The measurements with the magnetic micro sensor were further supported by the use of magneto optical Kerr effect (MOKE) measurements. This method of analysis is based on the rotation of the polarization plane of a linear polarized measuring laser beam depending on the magnetization of the reflecting sample. In this way the magnetization hysteresis loops of the sample at a certain area can be detected. The resulting exchange bias field strengths were determined from these magnetization hysteresis loops.

The laser-based realignment of the reference layer was investigated by using both continuous and pulsed laser radiation. Applying continuous laser radiation, the patches were heated by the irradiation with the fast deflected focused laser beam. The hatch distance between the scanned lines was 13.4 µm, corresponding to line overlap of 50%. During continuous laser radiation, the scan velocity and the peak intensity were varied in a range between 1000 and 4000 mm/s and 280 and 450 kW/cm^2, respectively. In contrast, in the pulsed laser process regime, heating of the patches was achieved by the irradiation with overlapping laser pulses. Two different laser pulse durations, τ_H, 62 and 167 ns, were investigated. The pulse peak intensity was varied in the range between 0.3 and 2.5 MW/cm^2.

3. Results and discussion

Fig. 4 depicts the results achieved with continuous laser radiation. For intensities between 380 kW/cm^2 (scan velocity 1000 mm/s) and 420 kW/cm^2 (scan velocity 4000 mm/s) a complete realignment of the pinned magnetization direction was achieved.

Fig. 5 shows MOKE hysteresis loops of the laser patterned spin-valve system, recorded before and after laser irradiation. The hysteresis loop reveals a two step magnetization reversal. The free ferromagnetic layer switches at low (1.2 kA/m) and the pinned ferromagnetic layer at a high magnetic field strength (80 kA/m). This shift of pinned layer reversal is denoted as exchange bias field. The realignment of the exchange bias field after magnetic field assisted laser annealing is evidenced from the shift of the pinned layer reversal from positive fields (red curve in Fig. 5) to negative magnetic fields (green curve in Fig. 5). However, for a complete alignment of magnetization, peak intensities of ~400 kW/cm^2 were required. For lower intensities only partial areas of the film patches were realigned along the field direction, as can be seen

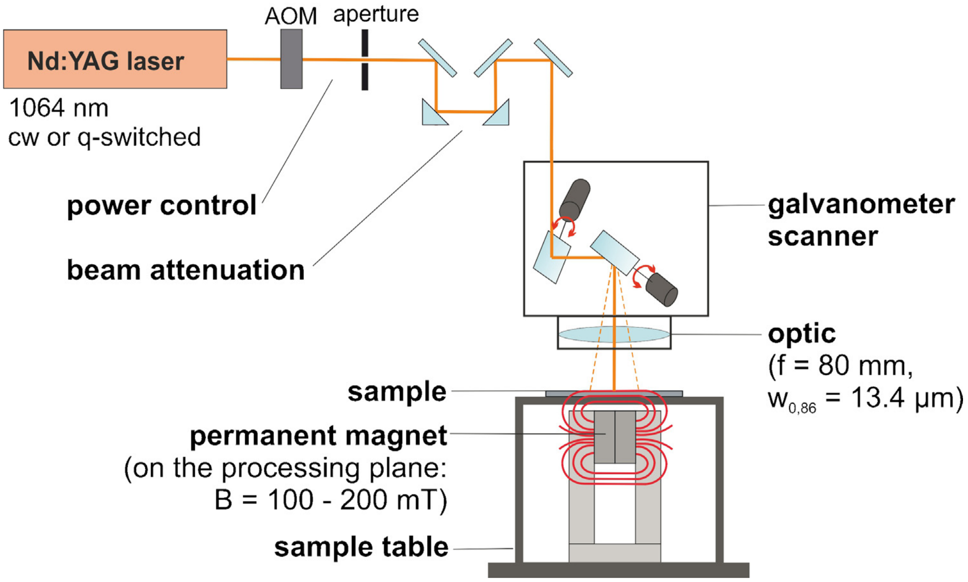

Fig. 2. Experimental setup for laser assisted annealing in a magnetic field.