Journal of Magnetism and Magnetic Materials 458 (2018) 292–300

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Research articles

Free and forced Barkhausen noises in magnetic thin film based cross-junctions

Amir Elzwawy [a,b], Artem Talantsev [a,c,d,*], CheolGi Kim [a,*]

[a] Department of Emerging Materials Science, DGIST, Daegu 42988, Republic of Korea
[b] Ceramics Department, National Research Centre, 12622 El-Bohouth Str., Cairo, Egypt
[c] Institute of Problems of Chemical Physics, 142432, Chernogolovka, Moscow, Russia
[d] Tambov State Technical University, 392000 Tambov, Russia

ARTICLE INFO

Article history:
Received 6 February 2018
Received in revised form 10 March 2018
Accepted 17 March 2018
Available online 19 March 2018

Keywords:
Magnetic thin films
Magnetization switching
Anisotropic magnetoresistance
Planar Hall effect
Barkhausen noise

ABSTRACT

Barkhausen noise, driven by thermal fluctuations in stationary magnetic field, and Barkhausen jumps, driven by sweeping magnetic field, are demonstrated to be effects of different orders of magnitude. The critical magnetic field for domain walls depinning, followed by avalanched and irreversible magnetization jumps, is determined. Magnetoresistive response of NiFe/M/NiFe (M = Au, Ta, Ag) trilayers to stationary and sweeping magnetic field is studied by means of anisotropic magnetoresistance (AMR) and planar Hall effect (PHE) measurements. Thermal fluctuations result in local and reversible changes of magnetization of the layers in thin film magnetic junctions, while the sweeping magnetic field results in reversible and irreversible avalanched domain motion, dependently on the ratio between the values of sweeping magnetic field and domain wall depinning field. The correlation between AMR and PHE responses to Barkhausen jumps is studied. The value of this correlation is found to be dependent on the α angle between the directions of magnetic field and current path.

1. Introduction

Magnetic thin films are widely used in magnetoresistive devices for magnetic field detection [1–4]. Wide operating temperature ranges and competitive sensitivities to low magnetic fields make magnetoresistive sensors gain new and new areas of application in magnetic field detection and magnetic nanoparticles detection in biotechnology [2,3]. Generally, single domain state of these films is required for detection of low magnetic fields. However, magnetic films with stable multi-domain states still remain objects of interest, especially in magnetic nanoparticles detection. The stray fields of magnetic particles, deposited on the surface of multi-domain thin film, cause local magnetization reversals in these films. The spatial distribution of these local reversals partially replicates the distribution of nanoparticles on the surface of the film. However, spontaneous domain wall displacement in magnetic films may result in significant difference between the domain distribution inside the film and magnetic particles distribution on the surface of the film. The domain wall motion can be suppressed in different ways, from the biasing by adjacent antiferromagnetic layers [5,6] to the biasing by shape anisotropy of the junctions [7,8]. However, most of these ways result in single domain state of the sensing layer [5–8]. In this work we will demonstrate, that the magnetic field sensitivity of junctions, based on multi-domain magnetic films, is comparable with sensitivities of single domain ones, if the magnetic energy of the film in applied magnetic field is less than energy barrier of domain wall depinning.

Direct measurements of sample magnetization allow us to judge about key magnetic parameters of magnetoresistive junction. However, magnetic hysteresis loops of each magnetic layer in the junction, separately, can be recorded only if these loops are separated from each other by exchange bias magnetic fields [9–13]. In case of no exchange bias, or weak bias and partial separation of magnetic hysteresis loops of the top and bottom layers, direct measurements of magnetization give us just general information about magnetization reversal in the entire sample, without any respect to the layer, where this reversal occurs.

Instead of direct magnetic measurements, the planar Hall effect (PHE) output voltage is sensitive to mutual magnetization directions of layers, because of the contribution of giant magnetoresistance (GMR) effect [10]. For example, if there is ferromagnetic coupling between top and bottom ferromagnetic (FM) layers, separated by a nonmagnetic interlayer (NM), the reversal nuclei in bottom layer will be directly under reversal nuclei in the top layer

---

* Corresponding authors at: Department of Emerging Materials Science, DGIST, Daegu 42988, Republic of Korea (A. Talantsev).

E-mail addresses: adt@dgist.ac.kr (A. Talantsev), cgkim@dgist.ac.kr (C. Kim).

https://doi.org/10.1016/j.jmmm.2018.03.042
0304-8853/

(nuclei occupy same areas in the top and bottom layers). In that case, the top and bottom layers will have identical domain structures, and the magnetizations of correspondent areas in the top and bottom layers are of same orientations. The last will result in absence of GMR contribution to magnetoresistance vs magnetic field curve. In case of no coupling between FM layers, the reversal nuclei will form in different areas of the top and bottom layers. As a result, the bilayer structure will contain some areas with opposite magnetization directions in the top and bottom layers. These areas introduce additional contribution to magnetoresistance of the sample, due to the GMR effect. In this work we have studied this contribution in detail, by means of comparison of PHE output voltage of the magnetoresistive junction with its anisotropic magnetoresistance (AMR). The aim of our work is to find magnetic field range and direction of magnetic field in respect to applied current path, under which the Barkhausen noise in multi-domain magnetoresistive junctions is minimized, and determine signal-to-noise ratio of the PHE response of these junctions, if they are used as magnetic field sensors.

2. Experimental methods

Three structures were investigated in our work: Ta(5)/$Ni_{80}Fe_{20}$(10)/**Ta**(1)/$Ni_{80}Fe_{20}$(10)/Ta(5), Ta(5)/$Ni_{80}Fe_{20}$(10)/**Au**(1)/$Ni_{80}Fe_{20}$(10)/Ta(5) and Ta(5)/$Ni_{80}Fe_{20}$(10)/**Ag**(1)/$Ni_{80}Fe_{20}$(10)/Ta(5), thicknesses are in nanometers – denoted as samples **I**, **II** and **III**, respectively. Each sample has been made in two configurations: thin films and cross-type junctions. Thin films of square shape and 0.5 cm × 0.5 cm size were deposited directly on Si/SiO_2 substrates of the same size, by the DC magnetron sputtering under a vacuum of around 1.8×10^{-6} Torr. The scheme of the sequence of layers in the sample is presented in Fig. 1. Targets of 99.99% purity (Kojundo Chem. Lab. Ltd., Japan) were used for deposition of samples. Prior to deposition, the targets deposition rates were examined by means of X-ray reflectivity (XRR) and they were 0.05 nm/s, 0.012 nm/s, 0.16 nm/s, 0.058 nm/s, for $Ni_{80}Fe_{20}$, Ta, Au and Ag, respectively. The Si/SiO_2 substrate was covered by 5 nm Ta buffer layer, then the junction structure itself was grown, and the Ta capping layer is grown to prevent oxidation and corrosion of the sensing layers of the structures. The substrate rotation was kept constant at 10 rpm during the samples deposition to adhere more homogenous and uniformed layers. The Ar working gas pressure was 3 mTorr and the flow rate was 30 cm^3/min during the deposition. The role of 5 nm Ta buffer layer was to enhance surface adhesion and decrease its roughness. A magnetic field was not applied for all stages of the sample growth.

The cross-type junctions were deposited on patterns of cross shape, obtained by a combination of photolithography and lift-off process. The branches of crosses were of the same size (50 μm × 750 μm) and mutually perpendicular, as shown in the Fig. 1(a) and (b). The central area of the junctions was of 50 μm × 50 μm size. The preparation of junctions consisted of four steps: cross-type pattern preparation, thin film deposition on the pattern, electrode pattern preparation and electrode deposition. At first step, Si/SiO_2 substrates were cleaned by ultra-sonication in acetone for 1 h followed by methanol sonication and dried by air gun. The substrates were put on a (Spin-1200D) spin coater, covered with (AZ5214E) photoresist and rotated by 4000 RPM for 30 s followed by soft baking on (AS ONE TH900) triple hotplate at 120°C for 60 seconds. Afterwards the samples were exposed to UV light using (MIDAS MDA 400 s aligner) to transfer the 50 μm × 50 μm cross junction from mask to substrates, then it was immersed in (AZ-500MIF) developer for 60 s with slight shaking followed by deionized water for another 60 s.

On the second step, the stack of junction's layers is grown on the pattern at the sputtering conditions same with ones used for films deposition. The sputtering of the thin film was performed together with the junction-type sample, in the same chamber. The sputtered materials were deposited on two different substrates, 1.8 cm × 1.8 cm for junction's junction and 0.5 cm × 0.5 cm for thin films, mounted in the holder, side by side. After the sputtering, the samples were immersed in acetone to remove the material, deposited outside the pattern. One the third step, the pattern for electrodes deposition was prepared by the same procedure, which was used at the first step. The mask for electrodes was used instead of the mask of the cross junction. Finally, on the fourth step Ta (5)/Au (1 0 0) layers were sputtered on the pattern and lift off procedure in acetone was done again to remove the material, sputtered outside the pattern.

The thin films were used for magnetic moment characterization, the cross-type junctions – for AMR and PHE characterization. Magnetic hysteresis loop measurements were performed on plate-shaped samples by VSM technique on the LakeShore 7407 vibrating sample magnetometer. The samples magnetization values were calculated by normalization of VSM magnetic moment value to the NiFe volume (2×10 nm × 0.5 cm × 0.5 cm = 5×10^{-7} cm^3) in thin films. Magnetoresistance measurements were performed in both AMR and PHE geometries. The AMR was measured by two-point measurement technique. The sensing current of 1 mA was applied by Keithley 2400 Source-meter. The U_{AMR} voltage was measured in two-point geometry. The U_{PHE} voltage was detected by Keithley 2182 Nanovoltmeter. The PHE voltage noise was recorded in slow rate mode (10 points per second), during 20 min. Fourier filtering with 0.1 Hz–10 Hz frequency window was performed to subtract long-time drift component from the results of PHE noise measurements. The magnetic field was produced by two pairs of Helmholtz

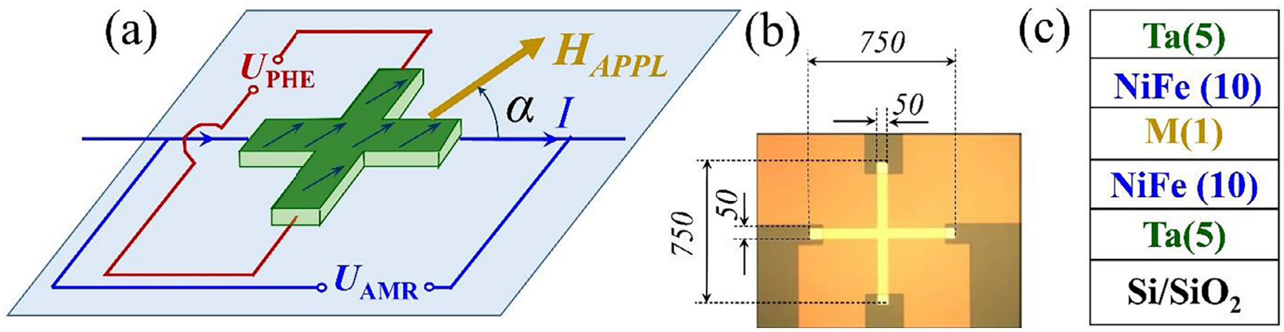

Fig. 1. (a) The scheme of connection of the cross-type junction for AMR and PHE measurements; α – angle between applied magnetic field H_{APPL} and current I directions, U_{PHE} – planar Hall voltage response, U_{AMR} – the voltage response to anisotropic magnetoresistance, measured by two-point measurement technique; the arrows on the cross correspond to the magnetization direction. (b) The microphotograph of the junction; dimensions are given in microns; (c) the layer constitution of the cross-type junction.