JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 13, No. 9, September 2011, p. 1091 - 1094

Experimental configuration for the simultaneous study of magnetization reversal and giant magnetoresitance effects in exchange coupled spin valve structures

G. SCHINTEIE, C. KUNCSER[a*], A. KUNCSER[a], F. IOFCIU[a], I. JEPU[b], S. ANTOHE[a]
National Institute for Physics of Materials, P.O. Box MG 7, 77125, Bucharest-Magurele, Romania
[a]*University of Bucharest, Faculty of Physics, Atomistilor Street 405, P.O. Box MG-11, Bucharest-Magurele, 077125, Romania*
[b]*National Institute for Lasers, Plasma and Radiation Physics, P.O. Box MG 36, 77125, Bucharest-Magurele, Romania*

A designed experimental configuration for the simultaneous study of magnetization reversal and giant magnetoresistance effects in layered systems is reported. The suitability of the device, designed mainly for didactical purposes, to prove giant magneto-resistance effects is exemplified in case of exchange coupled spin valve structures. The multilayer structures were prepared by theromo-ionic vacuum arc methods and initially characterized by X-ray diffractometry and energy dispersive X-ray spectroscopy. According to the performed experiments, it has been clearly proven the presence of magnetoresistance maxima over ranges of applied fields inducing antiparallel magnetizations of the two ferromagnetic layers interfacing a thin conductive layer.

(Received July 19, 2011; accepted September 15, 2011)

Keywords: Spin valve structures, MOKE, GMR

---

1. Introduction

The steadily progress of magnetic recording over the last few decades was based on important achievements in decreasing the size of the bits (seen as small magnetized regions of magnetic recording media) and of the writing/reading magnetoresitive elements [1,2]. Today's magnetoresistive devices are based on either giant or tunneling magnetoresistance effects, developed by the so called spin valve structures [3]. It is worth mentioning that such devices are in fact very sensitive sensors of magnetic fields and actually the range of their technological applications has substantially overpassed the field of magnetic recording. In order to understand the functionality of a spin valve device one recalls the essence of the giant magnetoresistance phenomenon, as consisting in controlling the electron transport by spin dependent scattering processes on magnetic configurations driven by an external applied field.

The active component of a modern spin valve structure (e.g. working in conduction) consists of a stack of ferromagnetic (F), antiferromagnetic (AF) and conductive nonmagnetic (NM) thin films, building a multilayer with the sequence AF/F/NM/F. The electron transport through the conductive NM layer (e.g. a Cu film of only a few nm thickness) is controlled via the relative orientation of the spins/magnetizations of the adjacent F layers (also of only a few nm thicknesses). The switching from the parallel to the antiparallel magnetic configuration of the two F layers is realized under a very small external magnetic field (which can be generated also by the magnetic beats), in conditions that one of the F layer is coupled to an AF layer, whereas the other one is free. The F/AF interfacial coupling can have in general two different effects on the hysteresis loop of the coupled F layer (the contribution of the AF layer to the loop being negligible, due to its insignificant magnetization): (i) it may induce an increased coercivity due to an additionally induced uniaxial anisotropy or (ii) it may shift the loop by a so called exchange bias field, related to an unidirectional anisotropy [4, 5]. The two effects can manifest at different extents depending on various magnetic and geometric parameters of both interfaced F and AF layers, quality of the interface, but also on typical procedures for inducing the interfacial coupling. According to [6,7], the exchange bias field of the pined layer can be roughly expressed via the relationship $H_E=\sigma/M_rt$ with σ = the interfacial exchange energy, M_r=the remanent magnetization of the F pinned layer and t= its thickness, whereas its coercive field, higher than the coercive field of a similar free layer, can be expressed as a function of the ratio $R=K_{AF}t_{AF}/\sigma$ with K_{AF} and t_{AF} the anisotropy constant and respectively the thickness of the AF layer. Having in mind all the above mentioned aspects, it is clear that the complex multilayer structure of type AF/F1/NM/F2 has to present a complex hysteresis loop which can be decomposed into the two different loops, one belonging to the free F2 layer and the other one to the pinned F1 layer [7]. Hence, the magnetic configuration of the two ferromagnetic layers interfacing the conductive NM layer is changing and ranges from parallel to antiparallel, depending on the value of the applied magnetic field with respect to the coercivities of the two layers. According to the GMR effects, the conductivity of the NM layer is higher in the case of parallel as compared to the case of antiparallel orientations of the spins/magnetic moments of the F1 and F2 layers, due to a lower spin dependent scattering of the electrons at the F2/NM and NM/F1 interfaces [8]. Clearly, it is not a trivial task to prove experimentally the direct correlation between the conductivity of the system and the magnetic configuration of the sandwiching layers and also to make clear distinction between GMR and usual MR phenomena.

Quantitatively, the difference between the two phenomena is reflected in the much enhanced value of the GMR effect as compared to the usual MR effect and the fact that the first one becomes effective at a significantly lower (system dependent) applied magnetic field. Very sensitive GMR devices show variation of the magnetoresistence at fields of order of a few tenths of Oe and therefore, subsequent magnetoresistance and magnetometry measurements taken on the same sample but on different devices are not concluding with respect to the direct correlation of the magnetoresistence with the spin configuration of the structure. This paper reports on a designed experimental configuration for the simultaneous study of magnetization reversal and giant magnetoresistance effects in exchange coupled spin valves structure, which can offer a direct evidence for the above mentioned correlations.

2. Experimental details

A spin valve structures of the type FeMn(20nm)/FeCo(10nm)/ Cu(10nm)/FeCo(10nm) have been grown by thermo ionic vacuum arc method on Si substrates with either Ta or Cu buffer layers and with a thin Ta protective cap layer. The geometrical arrangements of the overall structures are shown in figure 1. The thermo ionic vacuum arc method is an original method for the deposition of thin films and multilayers, which can cover both the electron beam evaporation and the vacuum arc discharge regimes [9]. Complex multilayer systems involving films of simple composition as well as binary or ternary alloys can be prepared by using couples of crucibles with target materials and a corresponding number of electron guns [10,11]. In addition, the composition of the alloys (e.g. Fe-Co or Fe-Mn in our case) can be controlled by a suitable placement of the substrates with respect to the involved target materials. Practically, many substrates are placed in a bidimensional lattice type structure in front of the targets and a combinatorial like preparation with respect to the composition of certain components is obtained. The generic thickness of the film components is measured via a quartz balance (Kressington) placed at the middle of the bidimensional matrix type arrangements of the substrates (slight variations of the real thickness of the films are expected, depending on the substrate position in the matrix). Due to the particularities of the deposition conditions, the obtained structures should be carefully analysed (usually, previous calibrations on simpler structures are performed) with respect to both thickness and compositional parameters. The two samples presented in figure 1 correspond to the same position of the substrate in the matrix like arrangement and therefore, the only difference refers to the buffer characteristics.

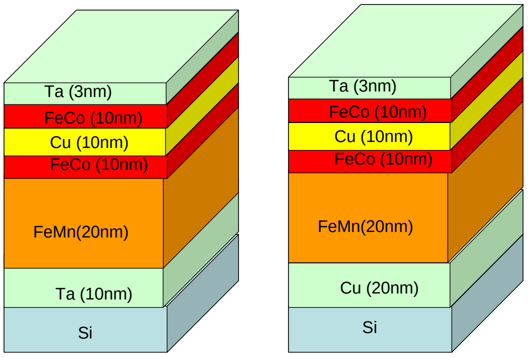

Fig. 1. The considered multilayer structures with generic thicknesses of the film components.

The elemental composition of each sample and the relative content of Fe in the Fe-Co ferromagnetic film and in the Fe-Mn antiferromagnetic film was estimated via the Energy Dispersive X-ray (EDX) technique by using incident electrons of two different energies incident at two different angles with respect to the sample surface. The structural aspects have been investigated via grazing incidence X-ray diffractometry (GIXRD) whereas thicknesses of the film components and roughness at different interfaces have been analysed via X-ray reflectometry (XRR), both performed on a Bruker type diffractometer (D8 ADVANCE) working with Cu(K_α) radiation (λ=0.154 nm).

The magnetic reversal process of the spin valve structure has been characterized by a longitudinal magneto-optic Kerr effect (MOKE) magnetometer, provided with an electromagnet with laminated sheets with essentially zero remanence and negligible hysteresis and with a laser diode emitting light with λ=640 nm. The incident light makes 45° with the sample plane and is linearly polarized perpendicular to the incidence plane (parallel to the sample plane), by a polarizer. The reflected light crosses a Faraday rod and an analyzer and finally reaches the detector which is connected to a look-in amplifier. The sample holder designed for the MOKE characterization was adapted in order to allow the measurement of the spin valve resistance by using the typical two points method. The two contacts have been done on the structure surface and the electrical measurement, performed with a Fluke multimeter, was of current in plane (CIP) type with the magnetic field applied perpendicular on the current flow. The device is schematically presented in figure 2.

The rotation of the polarization direction of the radiation reflected on the spin valve structure (the Kerr angle, θ_{Kerr}), which is proportional to the magnetization along the applied field direction, is directly recorded on the computer (by following a given algorithm) versus the value of the applied field, in pre-established steps and with a controlled time window on each step. By maximizing the time window on each step, it is possible to record simultaneously the value of the resistance averaged over a low number of applied field values, resulting finally a simultaneous field dependence of both the Kerr angle and magnetoresitance.

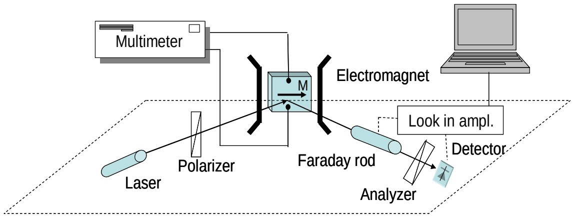

Fig. 2. Magneto optic Kerr effect device with the sample holder adapted for the simultaneous measurement of the magnetization reversal and magnetoresistance of thin films and multilayers.

3. Results and discussion

The EDX data taken at two different energies and at normal and 45° incidence of the incoming electrons have shown for the F and AF films, compositions close to $Fe_{40}Co_{60}$ and $Fe_{30}Mn_{70}$, respectively. In addition, some atomic percents of Mo have been found in both samples, with a higher relative content in the sample with Ta buffer layer, leading to the conclusion that the Ta buffer and cap layers are unpurified with Mo. Most probably this is due to the very high melting point of the Ta and the evaporation of the internal coating of its crucible.

The diffraction patterns of the sample with Cu buffer layer, are shown in figure 3. They indicate the presence of the face centered cubic (fcc) phases of Cu and Fe-Mn as well as the presence of the body centered cubic structure of the Fe-Co films. All films present a polycrystalline structure with very low structural coherence length, as suggested by the large linewidths. The inset shows the mass density profile, as deduced from XRR data, standing for a real thickness slightly under-evaluated for the Cu buffer layer and over-evaluated (some 10-20%) for the rest of the components in the Fe-Mn/Fe-Co/Cu/Fe-Co/Ta structure.

The simultaneously recorded data related to the field dependence of magnetization reversal and electrical resistance of the same spin valve structure, but grown on Ta buffer layer are shown in figure 4. Concerning the magnetization reversal, it is observed that the complex loop can be clearly decomposed (e.g. by following the procedure described in [7]) in the two components, belonging to the free F2 and the pinned F1 layers, respectively, the first loop component with a coercive field of about 60(5) Oe and the second with a coercive field of 170(5) Oe. It is worth mentioning that between the two possible types of decompositions consisting either in relatively shifted loops along the field axis (involving the presence of the unidirectional anisotropy at the F1/AF interface) or in two central loops of different coercivities (involving the presence of the uniaxial anisotropy at the F1/AF interface) has been decided by studying the magnetization reversal along different in-plane directions of the structure, on a similar sample mounted in the usual sample holder for MOKE measurements.

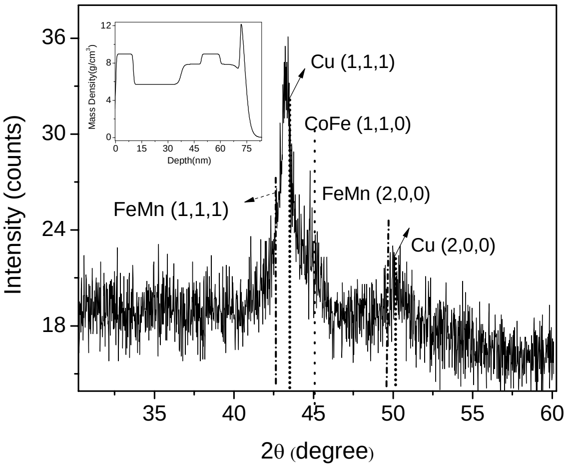

Fig. 3. GIXRD pattern taken on the spin valve structure with Cu buffer layer. The inset shows the mass density profile, as resulted from XRR data.

Based on the above mentioned decomposition, the magnetic configuration of the F1 and F2 layers can be defined for different ranges of the applied field, as follows: (i) by decreasing the field from an initial saturation, there is a parallel coupling of the F2 and F1 layers down to a negative field of -60 Oe, where the spins in the free F2 layer change the orientation, (ii) decreasing further the field, there is an antiparallel coupling of the F2 and F1 layers, down to a negative field of -170 Oe, where the spins in the pinned F1 layer change also their orientation, (iii) any further decrease of the field maintains the parallel coupling of the F2 and F1 layers, which reach again their saturation in negative field.

At increasing applied magnetic fields, the process is similar, leading to an antiparallel coupling of the F2 an F1 layers just between 60 Oe and 170 Oe, for the rest of fields the coupling being parallel. According to the GMR behavior, any antiparallel coupling of the F2 and F1 layers might lead to a maximum resistance of the conductive Cu layer sandwiched between the two ferromagnetic layers, as compared to a much lower resistance for the case of parallel coupling. Such a correlation is directly observed by figure 4 (b), where a maximum of the resistance is evidenced between -60 Oe and -170 Oe (on the decreasing branch of the field) and 60 Oe and 170 Oe (on the increasing branch of the field).

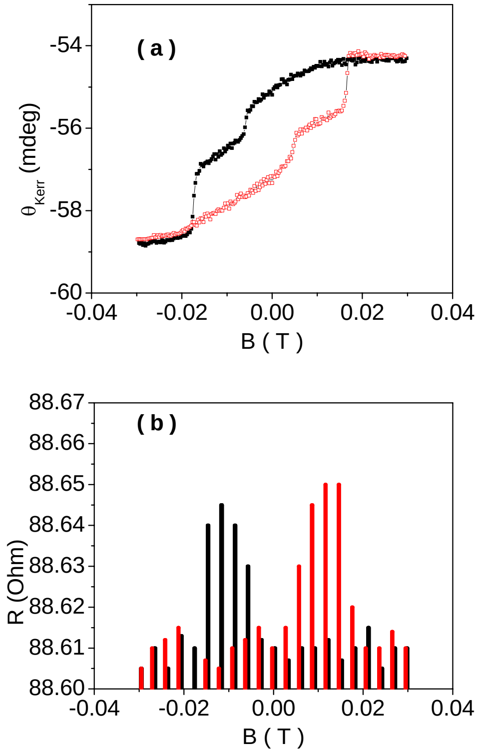

Fig. 4. The simultaneous acquisition of the field dependent magnetization reversal, through the Kerr angle, (a) and of the resistance (b), of a layered spin valve structure. The decreasing field and the increasing field regimes have been represented by different colours/intensities.

A last observation refers to the values of the magnetoresistance coefficient, which might be defined as MR(H)=(R(H)-R(∞))/R(∞). According to this definition, the maximum magnetoresistance coefficient evaluated from figure 4(b) is of order of 10^{-6}. In the present case it is clearly not a real quantitative value of the effect, due to the following reasons: (i) the two points method does not compensate the contact resistance and (ii) while the contacts are realized on the sample surface, the current does not flows just along the conductive layer but along the entire multilayer structure. Hence, the measured effect is much diminished and the assignation to a real GMR effect is realized just by the direct correlation between the spin configuration of the two ferromagnetic layers and the corresponding variation of the resistance of the structure.

4. Conclussions

An experimental configuration for proving GMR phenomena in layerd spin valve structures was reported. The mentioned configuration is based on a magneto-optic Kerr effect (MOKE) device, which sample holder was adapted for allowing the simultaneous measurement of the resistance by a simple two contacts method. Spin valve structures of type Fe-Mn/Fe-Co/Cu/Fe-Co have been prepared by the thermo-ionic vacuum arc method and subsequently characterized by X-ray diffractometry and reflectometry as well as by Energy Dispersive X-ray spectroscopy. The complex hysteresis loop of the structure, evidenced by longitudinal MOKE can be decomposed in components of different coercivities, belonging to the free and the pinned ferromagnetic Fe-Co layers, respectively. Different types of couplings between the ferromagnetic layers are induced, depending on the value of the applied magnetic field with respect to the coercivities of the two layers. It has been directly proven by using the designed experimental configuration that the resistance of the spin valve structure measured in current in plane geometry, presents maximum values just for the the antiferromagnetic coupling of the two ferromagnetic layers sandwiching the conductive Cu layer.

Acknowledgements

The financial support through the core program PN09-450103 and the doctoral fellowships by the Project POSDRU 88/I.5/5/56668 are highly acknowledged.

References

[1] J. Nogues, I K Schuller Exchange bias J.Magn.Magn.Mater **192**, 203 (1999).
[2] I R Mc Fadyen, E.E Fullerton, M J Carey, State-of-the-Art Magnetic hard Disk Drives MRS Bulletin **31**, 379 (2006).
[3] M Johnson, Magnetoelectronics Elsevier Amsterdam Cap. 2 and 3. 2004
[4] W H Maiklejohn, C P Bean, New magnetic anisotropy Phys. Rev. **105**, 904 (1957).
[5] A P Malozemoff, J. Appl. Phys. **63**(8) 3874 (1988).
[6] F. Radu, H. Zabel, Springer Tracts in Modern Physics **227**, 97 (2007).
[7] V Kuncser, W Keune, U von Horsten, G Schinteie, J. Optoelectron. Adv. Mater. **12**(6) 13852010
[8] S. Parkin Tunnel Junctions MRS Bulletin **31**, 389 (2006).
[9] I. Mustata, C. P. Lungu, A. M. Lungu, V. Zaroski, M. Blideran, V. Ciupina, Vacuum **76**, 131 (2004).
[10] V. Kuncser, M. Valeanu, G. Schinteie, G. Filoti, I. Mustata, C. P. Lungu, A. Anghel, H. Chiriac, R Vladoiu, J. Bartolome, J. Magn. Magn. Mater **320**, e226 (2008).
[11] V. Kuncser, G. Schinteie, P. Palade, I. Jepu, I. Mustata, C. P. Lungu, F. Miculescu, G. Filoti J. Alloys and Comp. **499**, 23 (2010).

---

[*] Corresponding author: kuncser@yahoo.com