ORIGINAL PAPER

CHARACTERIZATION OF THE MAGNETIC THIN MULTI-LAYERS WITH VIBRATING SAMPLE MAGNETOMETER

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Abstract. *In this paper, the magnetic hysteresis cycle of the Cu/Co multilayered pairs deposited on Sital and Si/SiO$_2$ sub-layers were investigated. A different behavior of the magneto-transport properties of the multilayer Cu/Co pairs, as a function of substrate type is shown. In addition, a magnetic characterization of the Cu/Co system by means of the vibrating sample magnetometer (VSM) is presented.*

Keywords: *hysteresis cycle, magnetic multilayer, magneto-resistive effect, magnetometer, molecular beam epithaxy.*

1. INTRODUCTION

The magneto-resistive effect is a well known physical mechanism used to measure magnetic fields [1]. Mainly, in the last 20 years the magneto-resistive effect has found a growing number of applications. The effect is applied to direct measurements of the field, such as the hard disk of computers [2-9], to playback heads, compact disks [5-11], magnetometers [10-13], compass systems [15] and so on. Position detection is another area of application. In this case, a permanent magnetization state is induced into the object which has to be detected and a sensor detects the magnetic field modification as effect of the object movement [11-17]. In other cases, a permanent magnet is fixed to the sensor. In other words, the object movement produces an interruption in the source flux which oscillates and makes the sensor modulate the magnetic field [18]. A great number of physical sizes like velocity, acceleration, force, rotation speed, generated power and so on can be correlated with several positions.

The GMR (giant magneto-resistance) effect, whose physical behavior shows many similarities with the AMR (anisotropic magneto resistance) effect, was discovered by Grunberg & co. in 1988 [19-24, 31]. They observed the resistive effect of the double magnetic layers Fe (12 nm)/Cr 1 nm/Fe (12 nm) through MBE (molecular beam epithaxy) on a sub-layer of GaAs (110) shows major modifications when is saturated ($\Delta\rho/\rho$= 1.5%) in comparison with a single Fe layer with a thickness of 25nm (0.2%). In addition, they observed that the effect does not depend on the current direction linked with the external field so that the AMR mechanism could be excluded as the possible origin of the phenomenon. From the spectrum of light dispersion through the rotation of the spin waves from these double magnetic layers, it was found that both magnetic layers are linked anti-ferromagnetic along to Cr layer [25-29]. The magnetization levels from both layers are opposite as sense in the initial

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state at field with zero value. The new magneto-resistive mechanism occurs when the magnetizations from the adjacent layers are forced to rotate from anti-parallel alignment to parallel alignment due to the field H_0.

The Fert Group from Paris [25, 30] discovered some modalities to achieve the major changes of the magneto-resistance of [Fe 30 Å/Cr 9 Å] with 60 periods deposited by MBE (molecular beam epitaxy) on GaAs (100). Thus, a ratio $\Delta\rho/\rho$ of 80% was obtained at 2 K for ρ measured in saturated state. Again, the opposite orientation of the adjacent magnetic layers in the initial state was observed. The coupling between adjacent layers was strong, so that the fields till to 20 kOe for overcoming (removing) attraction were necessary. Unfortunately, the fields with this kind of intensity for applications related to sensors are not of practical interest.

2. MAIN ISSUES

This paper studies the magnetic characteristics for highlighting the magneto-resistive response. To characterize the magnetic transport effects, a lot of experiments were performed within the laboratories from INCDIE ICPE-CA using a Hall effect system from LakeShore. This system is used for characterizing and analyzing the electronic transport in materials and thin layers. Two series of samples, some deposited on Sital sub-layer and others deposited on Si with sub-layer of SiO_2, were characterized. The Sital is a ceramic substrate which has the following composition: Si 62.5Al 14.88Mg 8.25Ca 7.99Ti 5.92As 0.46.

The first series investigated was deposited by the PLD (Pulsed Laser Deposition) method on the Sital substrate. The hysteresis cycle, curves IV, Hall mobility versus magnetic field intensity, charge carrier density on surface versus magnetic field intensity as well as ratio GMR versus magnetic field intensity were studied. Both on Sital and on Si/SiO_2, 10, 20 and 40 pairs of Cu/Co were deposited. From the depositing parameters obtained by structural investigation, the thicknesses of the Co layer at 16nm as well as, the Cu layer at 23 nm were determined. The samples were mounted on small pads, for samples having an area less than 1 cm^2, and connections were made by very thin silver wires coated with a solution of Ag using the Van der Pauw method for measuring magnetic parameters [32].

3. Cu/Co MULTILAYERS DEPOSITION BY PULSED LASER DEPOSITION METHOD

3.1. INITIAL CONDITIONS

To optimize the depositions with pulsed laser (PLD), two support materials were chosen. Firstly, the depositions were performed on a ceramic sub-layer of Sital. This material was recommended for depositions with a good quality. Secondly, the depositions on a sub-layer of Si/SiO2 were performed. The materials used for obtaining the Co/Cu multi-layers have a high purity within the order of 0.99999.

3.2. SAMPLE PREPARATION

For a good flatness of the Sital and Si/SiO_2 sub-layers, as well as for removing the oxides from the surface of Co and Cu targets, some special polishing machines for cleaning the sub-layers and targets were used as shown in Fig. 1.

a) b) c)

Fig. 1. Different types of polishing machines pads
a) Pad of polishing machine with SiC powder; b) Pad of polishing machine with diamante powder;
b) Pad of polishing machine with Al_2O_3 powder.

To observe the roughness of surface, after deposition of the Cu first layer, an atomic microscope force was used. In the first phase after microscopic analysis, it was observed that a better polishing of Sital sub-layer is recommended. The evaluation of initial roughness was highlighted very high values. This fact has determined an additional polishing of initial sub-layer.

Fig. 2 shows an AMF image for a single deposited Cu layer. More intense red colors are observed here. This explains the fact that when the Sital was not polished, the copper entered in “the unevenness” of Sital and for solving this problem of the Sital sub-layer flatness, the polishing machines were used. Another option was utilization of the Si/SiO_2 sub-layer.

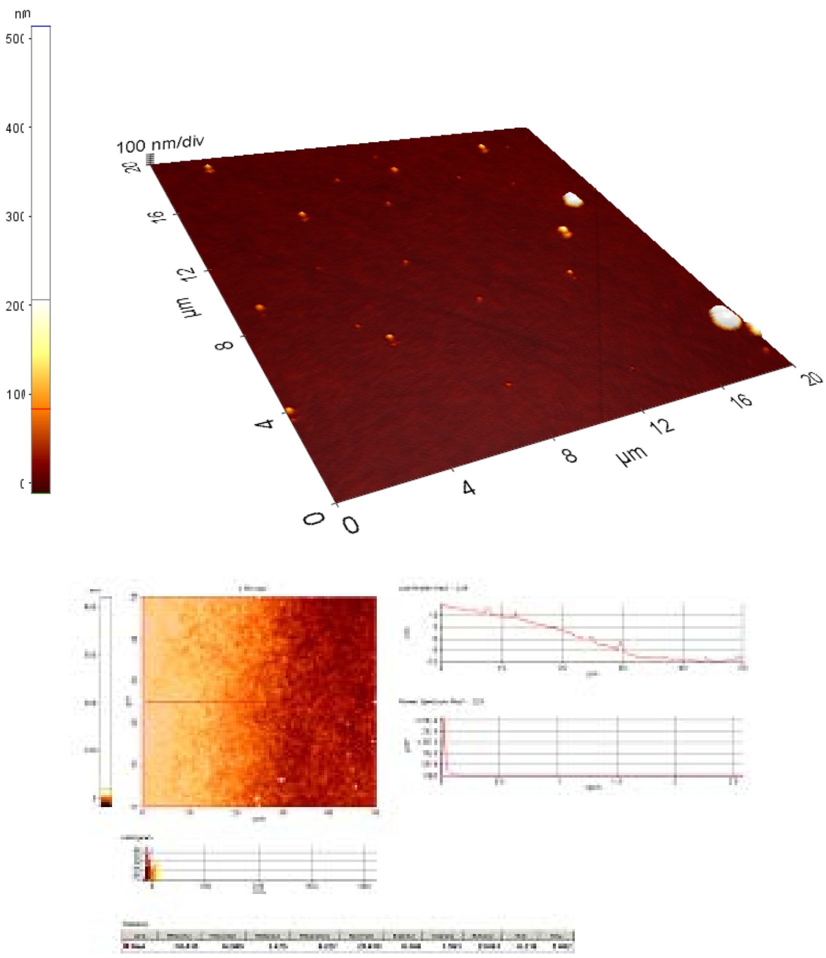

Fig. 2. AFM image for a single deposited Cu layer

Deposition of the first layers was performed in order to realize a correlation between the number of pulses and the thickness of Co and Cu layers. It is necessary to obtain continuous layers. After many experiences, our conclusion is that using the PLD method and greatly decreasing the number of pulses, there is the risk to not obtain the continuity of the layers or to obtain a Co/Cu alloy due to the used laser. The initial values used during the deposition are shown in Table 1.

Table 1. Particulars of samples deposited by PLD method

No. sample	Support	No. sequences (pairs) Co / Cu	No. of pulses / substrate
1070	Sital	10	Cu(600p)/Co(600p)/Cu(600p)…Cu(600p)
1071	Sital	20	Cu(600p)/Co(600p)/Cu(600p)…Cu(600p)
1072	Sital	40	Cu(600p)/Co(600p)/Cu(600p)…Cu(600p)
1073	Si/SiO_2	10	Cu(600p)/Co(600p)/Cu(600p)…Cu(600p)
1074	Si/SiO_2	20	Cu(600p)/Co(600p)/Cu(600p)…Cu(600p)
1075	Si/SiO_2	40	Cu(600p)/Co(600p)/Cu(600p)…Cu(600p)

During the experiments, a mechanical mask was used, which was cleaned in order to avoid the introduction of impurities in the Co/Cu film. Deposition of the Co/Cu thin layer on Sital sub-layer using the mechanical mask is shown in Fig. 3. This mask is necessary for obtaining many sensors. Among these sensors the one having the best characteristics is chosen.

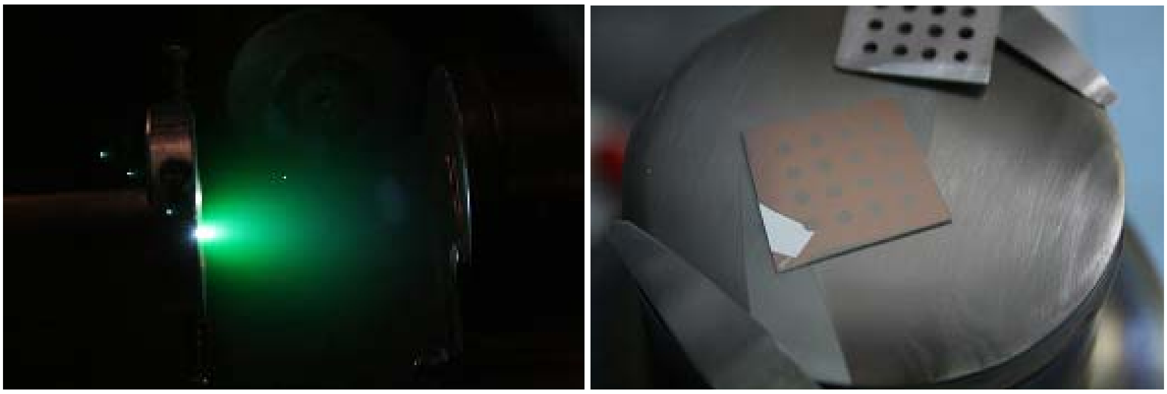

Fig. 3. Deposition of thin layers of Co / Cu on Sital sub-layer using mask.

The behavior of the thin Cu/Co magnetic layers on Sital and Si sub-layers are presented below. In this case, to compare the hysteresis cycles according to the vibrating sample magnetometer (VSM), the number of Cu/Co pairs is modified.

4. MEASUREMENTS WITH VIBRATING SAMPLE MAGNETOMETER (VSM)

Within the researches, the investigations were completed with magnetic measurements carried out by using VSM. Some of results are presented below.

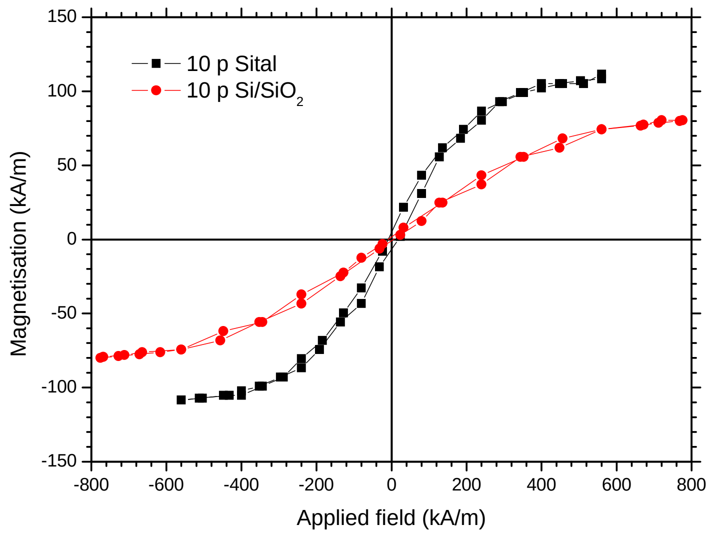

Fig. 4. Comparison of hysteresis cycles for 10 pairs of Co / Cu deposited on Sital, respectively Si/SiO$_2$.

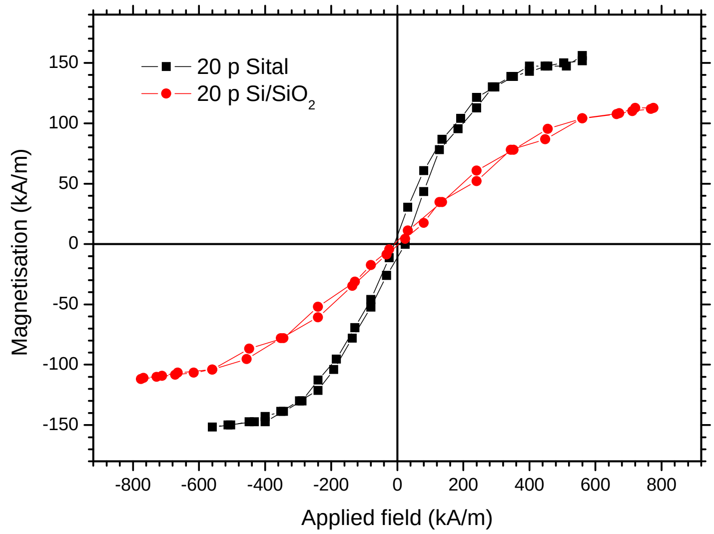

Fig. 5. Comparison of hysteresis cycles for 20 pairs of Co / Cu deposited on Sital respectively Si/SiO$_2$.

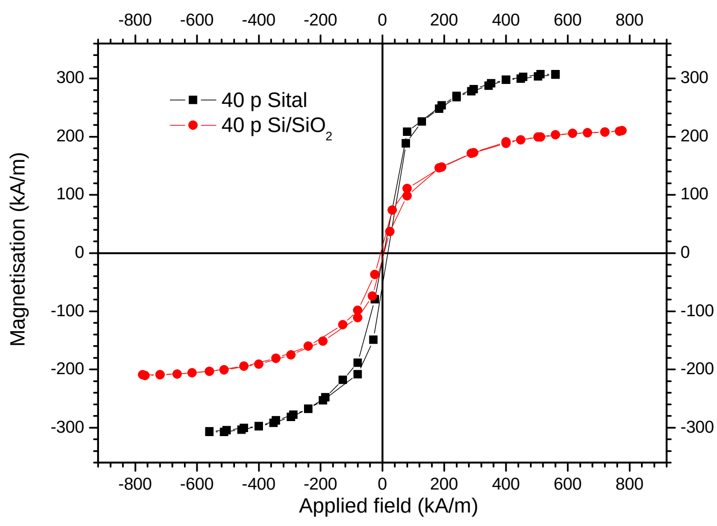

Fig. 6. Comparison of hysteresis cycles for 40 pairs of Co / Cu deposited on Sital respectively Si/SiO$_2$.

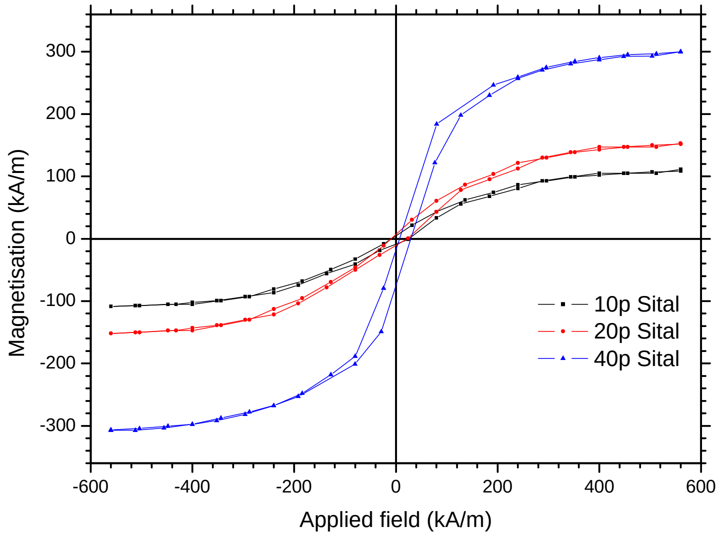

Fig. 7. Comparison of hysteresis cycles on the samples deposited on Sital.

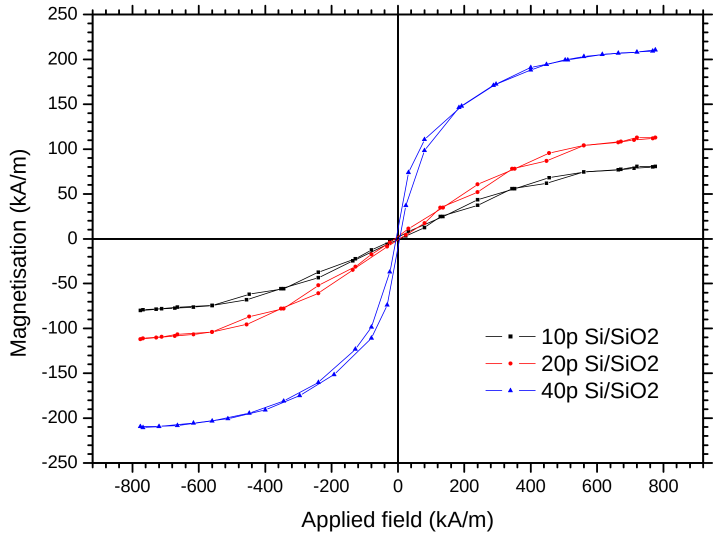

Fig. 8. Comparison of hysteresis cycles on the samples deposited on Si/SiO$_2$.

5. EXPERIMENTAL RESULTS

Our researches are focused on obtaining some magnetic properties according to many magneto-transport parameters. The experimental results are summarized in Table 2.

Table 2. Experimental results for the samples deposited on Sital and Si/SiO$_2$ sub-layers

Sample	Ms [kA/m]	Hc[kA/m]	Ms/Ms$_{max}$	Hc/Hc$_{max}$
10 p of Co/Cu deposited on Sital	109.959	17.286	0.368	1.000
20 p of Co/Cu deposited on Sital	153.563	15.797	0.514	0.914
40 p of Co/Cu deposited on Sital	298.700	11.141	1.000	0.644
10 p of Co/Cu deposited on Si/SiO$_2$	81.188	6.905	0.386	1.000
20 p of Co/Cu deposited on Si/SiO$_2$	113.809	6.905	0.541	1.000
40 p of Co/Cu deposited on Si/SiO$_2$	210.211	5.345	1.000	0.774

6. CONCLUSIONS

In this paper, the hysteresis cycle of the Cu/Co multilayered pairs deposited on Sital and Si/SiO_2 sub-layers were investigated. A different behavior of the magneto-transport properties of the multilayer Cu/Co pairs, as a function of substrate type has been shown. A magnetic characterization of the Cu/Co layers according to the vibrating sample magnetometer (VSM) has been presented. To characterize the magneto-transport properties, a lot of experiments were carried out. According to the values obtained it is observed that the saturated values increase with increasing the number of pairs and the coercivities have the same order of magnitude. In addition, at the obtained magnetic hysteresis cycle, the saturation magnetization increases with the number of Cu/Co pairs. According the evaluated samples deposited on Sital and Si/SiO_2 sub-layers, it was observed that the rate of increase is higher in the case of the samples deposited on Sital sub-layer, indicating a higher permeability.

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