Influence of the rough interface CoZr/Cu on the magnetoresistance in spin-valve sandwich CoZr/Cu/Co

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The magnetoresistance (MR) of the sandwich CoZr/Cu/Co at 300K has been investigated. The MR behaviour versus the thickness of the CoZr magnetic layer exhibits a maximum (≈ 3,6%) at $t_{CoZr} = 30$ Å, over which a significant decrease is observed. The representation of the interface CoZr/Cu by a mixed zone in the Johnson-Camley semi-classical model reproduces well the experimental results, showing up the important role of the interface quality on the electronic transport properties.

I. INTRODUCTION

Since the discovery of the giant magnetoresistance (GMR) in (Fe/Cr)[1-3], considerable attention both scientifically and technically (recording support, MR read-out heads and memory...) has been paid to magnetic multilayers composed of alternating non magnetic metal and ferromagnetic layers such as (Co/Ru)[4] and (Co/Cu)[5,6] multilayers. To improve more their sensitivity $\left(S = \Delta R / R\Delta H\right)$, a particular interest has been focused in sandwiches composed from soft magnetic layers such as NiFe[7], NiFeCo[8] and FeCoB[9,10].

Amorphous CoZr alloy presents ultra-soft properties compared to NiFe[11], can be alternative material for spin-valve device. The spin antiparallel configuration realized in low external field and the MR are induced by the difference of coercivities between the two magnetic layers, which depends not only on the thickness of non magnetic interlayer but it is also related to some physical properties such as microstructure and quality of interfaces and the MR is enhanced by the spin dependent scattering. Indeed, theoretical investigations[12] showed that the effects of spin-dependent scattering at the interfaces and in the bulk are responsible for the GMR phenomenon.

In the present work, we describe and analyse the dependence of the MR ratio on the thickness of CoZr magnetic layer using the Johnson-Camley[13] semi-classical model, which is based on the resolution of the Boltzmann transport equation. The correlation between the MR and the main electrical properties (resistivity, mean free path) has also been discussed.

II. EXPERIMENTAL

CoZr/Cu/Co sandwiches has been deposited onto corning 7059 glass substrates, submitted to in-plane dc magnetic field to induce well defined uniaxial anisotropy. A base pressure lower than 4.10^{-7} mbar was obtained prior to the deposition in a Z550 Leybold RF diode sputtering system. 300W RF power was applied on 10cm diameter Cu and Co target under the constant argon pressure expected for deposition of the Cu layers. The CoZr layer was obtained from Co disk target covered by Zr chips (Zr composition was ranged from 2 to 5 at%). The layer thickness and CoZr compositions were determined from a Tencor-1 profilometer and chemical composition of the CoZr layer was obtained from Electron Probe Microanalyser (EPMA) respectively. MR measurements were made using four-point probe method with the current flowing in the film plane and along the induced easy-axis direction. A vibrating sample magnetometer (VSM) was used for magnetic parameter characterization. Amorphous structure of thick CoZr films was confirmed by X-Ray diffraction for $x_{Zr} = 5\%$. The top Co layer was partially oxidized. The thickness of oxidized layer was estimated from magnetization measurements compared between glass/Cu/Co, glass/Co/Cu/Co and glass/Co/Cu samples deposited at the same thicknesses and under the same sputtering parameters without breaking vacuum of the deposition chamber.

III. RESULTS

Figure 1 shows the dependence of the measured MR ratio versus the CoZr layer thickness in the CoZr/Cu/Co sandwich at room temperature. The main features of this evolution show that the MR increases with increasing the CoZr thickness and exhibits a maximum of 3,6% comparable to the other sandwiches[14,15].

The MR ratio then gradually decreases as the CoZr layer thickness increases further, becoming almost 0% for 100Å thick CoZr. Furthermore the decrease of the MR with decreasing t_{CoZr} below $t_{max}^{MR} = 30$ Å, may be attributed to the decrease in the coercivity contrast between the two magnetic layers, while the decrease of the MR with increasing CoZr thickness above t_{max}^{MR}, also observed for many sandwiches[14,15] as M/Cu/NiFe, (where M=Co, NiFe or Ni), has been explained by the shunt effect of the

magnetic thicker layers when the spin-dependent scattering is essentially of the bulk nature.

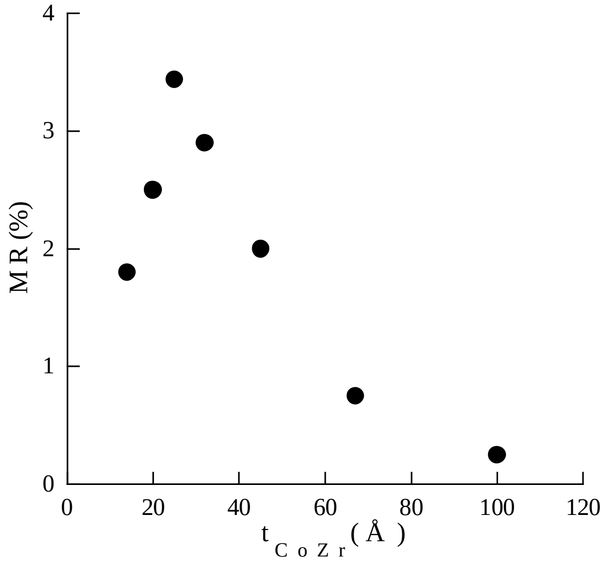

FIG. 1: Dependence of the measured MR ratio at room temperature on the CoZr layer thickness for $[Co_{98}Zr_2(t_{CoZr}(Å))/Cu(28Å)/Co(25Å)]$ sandwich.

However, in the range of the used magnetic layer thickness, the rapid decrease observed in our sandwich CoZr/Cu/Co may be due to the reducing of the mean free path (MFP) for electrons across the CoZr/Cu interface, due to the increasing disorder and interfacial roughness.

The dependence of the resistivity on the CoZr layer thickness shows an increase for $t_{CoZr} > 30$ Å.

IV. DISCUSSION

To make a best understanding of the apparent brutal fall of the $MR = f(t_{CoZr})$ observed notably for $t_{CoZr} > 30$ Å, we have supposed both an interdiffusion of the Cu in CoZr and in Co within the two mixed zones. Indeed, the formation of such solid solutions in the interface between CoZr and Cu layers that we suggest forming a "CoZrCu alloy", seems to be a characteristic generally admit for this type of multilayers (the insertion of the Al and the Mn in (Fe/Cr)[16] interfaces, the Co in (NiFe/Cu) and the NiFe in (Co/Cu)[17], the Co in (CoZr/Cu) and the CoZr in (Co/Cu)[18],...). The MFP of electrons and the spin-dependent scattering asymmetry (SDSA) coefficient are strongly dependent on the nature of the considered interface. Consequently, if λ^0_{mx} and α^0_{mx} represent respectively the MFP and the SDSA coefficient at the interface Co/Cu, when a very small concentration of Zr is introduced in the Co magnetic layer, these quantities become:

$$\lambda_{mx} = \frac{g_2(\rho_2^\uparrow + \rho_2^\downarrow)}{g_2(\rho_2^\uparrow + \rho_2^\downarrow) + g_1(\rho_1^\uparrow + \rho_1^\downarrow)}\lambda^0_{mx} \qquad (1)$$

$$\alpha_{mx} = \frac{g_1\rho_1^\uparrow + g_2\rho_2^\uparrow}{g_1\rho_1^\downarrow + g_2\rho_2^\downarrow}$$

$$= \left[\frac{g_1}{\alpha_1(g_1 + g_2 K)} + \frac{g_2}{\alpha_2(g_2 + g_1\frac{1}{K})}\right]^{-1} \qquad (2)$$

where $g_1 + g_2 = t_{mx}$ and $K = \dfrac{\rho_2^\downarrow}{\rho_1^\uparrow}$.

t_{mx} represents the thickness of the mixed layer; g_i, $\rho_i^{\uparrow(\downarrow)}$ and $\alpha_i = \dfrac{\rho_i^\downarrow}{\rho_i^\uparrow}$ are respectively the geometric weighting factors, the resistivities for spin $\uparrow(\downarrow)$ electrons and the SDSA coefficients of the "CoZrCu alloy" (i=1) and Cu (i=2) in the CoZr. t_{mx} is estimated to 6 Å in agreement with those proposed by other authors[13] (i.e: $t_{mx} = 5$ Å for (Fe/Cr) multilayers).

The disordered phase "CoZrCu" in the interface increases with increasing CoZr thickness. For a weak considered Zr concentrations and assuming, at first approximation, that the weighting factor g_1 is directly related to t_{CoZr} as $g_1 \approx At_{CoZr}$ (where A is an adjusting parameter), the resolution of the Boltzmann transport equation in the framework of the Johnson-Camley[13] semi-classical model, allowed us to well reproduce the behaviour of the MR as well as of the saturation resistivity (ρ_{sat}).

Then we have introduced these obtained g_1 values in the previous expression of λ_{mx}. The qualitative behaviour of the obtained MFP versus the disordered phase proportion in the mixed zone shows as presented in figure 3 a rapid decrease with increasing C_{Alloy}.

It appears that this MFP exhibit an exponential decay behaviour as:

$$\lambda_{mx} = \lambda^0 \exp(-C_{Alloy} / C_{Crit}) \qquad (3)$$

where the deduced $\lambda^0 = 9{,}45\,\text{Å}$ is comparable to $\lambda^0_{mx} = 10\,\text{Å}$ of the MFP in the interfacial layer between Cu and Co.

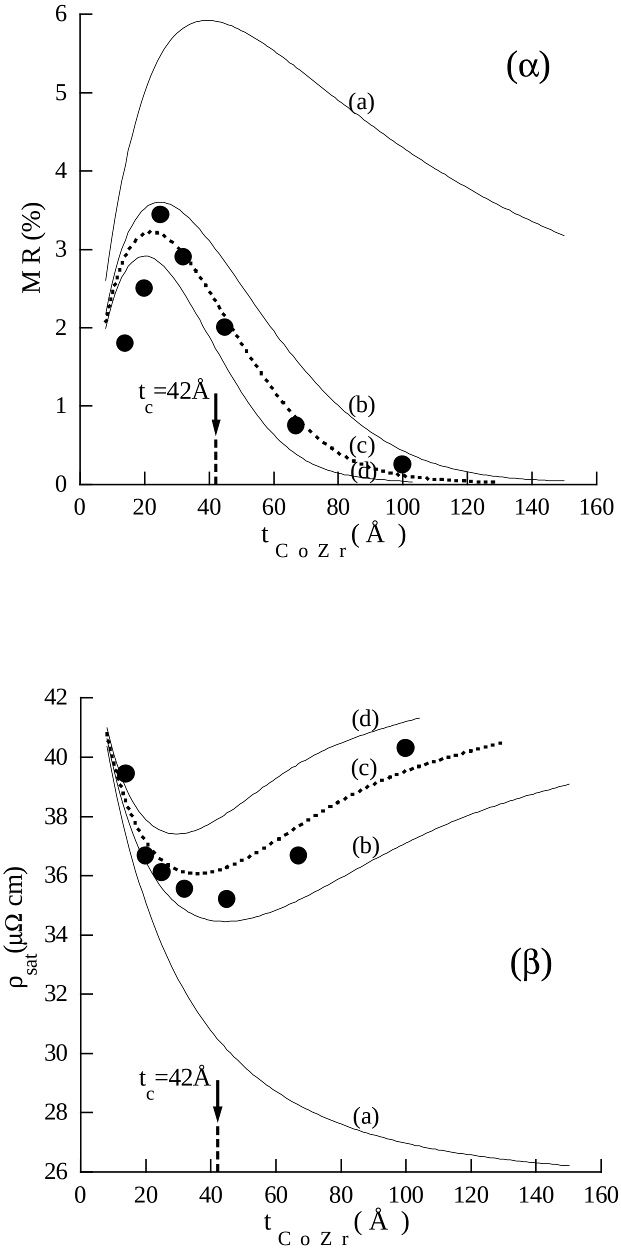

FIG. 2: Variation of the MR (α) and ρ_{sat} (β) as a function of the CoZr layer thickness.
•: Experimental results at T=300K.
—: The set of fits for experimental data of MR and ρ_{sat} for different values of the parameter A. (a): A=0; (b): A=0,03; (c): A=0,04; (d): A=0,05.

The exponential part may reflect physical behaviour of the CoZr/Cu interface. The constant $C_{Crit} = 28{,}3\,\%$ will be representing a "critical concentration" of the "CoZrCu alloy", corresponding to a CoZr magnetic layer thickness ($t_c = 42$ Å) beyond which important modifications in the MR and ρ_{sat} behaviour can be expected. This is in accordance with experimentally observed results. Indeed, figure 2(β) shows that from this thickness ($t > t_c$), the ρ_{sat} behaviour changes notably: (i) it decreases strictly for $t < t_c$, (ii) it's a minimum for $t \approx t_c$ and (iii) it increases strictly for $t > t_c$. Similarly, figure 2(α) shows also that this thickness t_c marks an inflexion point in the MR decrease becoming more swift for $t > t_c$. Thus, it would seem that beyond this magnetic layer thickness, the disordered phase "CoZrCu" clusters number extend more rapidly in the mixed zone implying a speedy distroying interfaces quality.

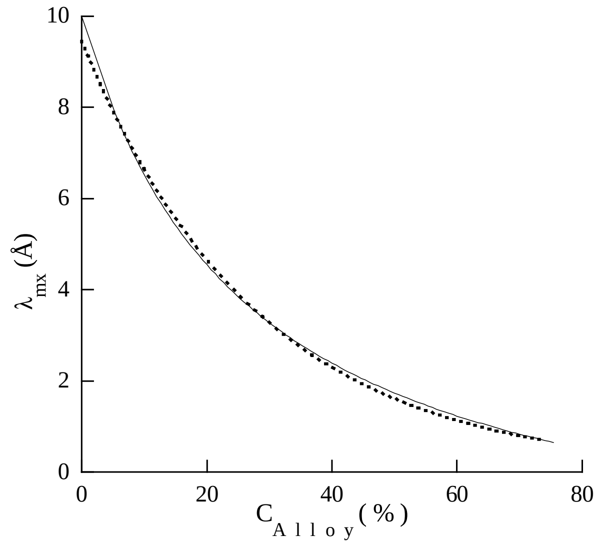

FIG. 3: The MFP evolution with the "CoZrCu alloy" concentration in the mixed zone between CoZr and Cu layers.
—: The $\lambda_{mx} = f(C_{Alloy})$ curve for A=0,04
…: Exponential decay fit for $\lambda_{mx} = f(C_{Alloy})$ curve.

V. CONCLUSION

A brutal fall of the measured MR versus CoZr magnetic layer thickness and the increase of ρ_{sat} for the larger thickness were observed and interpreted considering the existence of an "alloying phase" at the interface CoZr/Cu which affect both the MFP and the SDSA coefficient. This suggested "alloying phase" leads to an interface inhomogeneity, giving rise to the appearing spin-dependent diffuser centers and to a strongly electronic braking and consequently to the lowering electronic flux across the CoZr/Cu interface.

[1] M. N. Baibich, J. M. Broto, A. Fert, Nguyen Van Dau, F. Petroff, P. Etienne, G. Creuzet, A. Friederich and J. Chazelas, *Phys. Rev. Lett.* **61** (1988) 2472.
[2] G. Binash, P. Grünberg, F. Saurenbach and W. Zinn, *Phys. Rev. B.* **39** (1989) 4828.
[3] J. J. Krebs, P. Lubitz, A. Charïken and G. A. Prinz, *Phys. Rev. Lett.* **63** (1989) 4828.
[4] S. S. P. Parkin, N. More and K. P. Roche, *Phys. Rev. Lett.* **64** (1990) 2304.
[5] S. S. P. Parkin, R. Bhadra and K. P. Roche, *Phys. Rev. Lett.* **66** (1991) 2152.
[6] D. H. Mosca, F. Petroff, A. Fert, P. A. Schroder, W. P. Pratt, R. Laloee and S. Lequien, *J. Magn. Magn. Mater.* **94** (1991) L1.
[7] T. Shinjo and H. Yamamoto, *J. Phys. Soc. Jpn.* **59** (1990) 3061.
[8] M. Jimbo, T. Kanda, S. Goto, S. Tsunashima and S. Uchiyama, *J. Magn. Magn. Mater.* **126** (1993) 422.
[9] S. Gangopadhyay, S. Hossain, J. Yang, J. A. Barnard, M. T. Kief, H. Fujiwara and M. R. Parker , *J. Appl. Phys.* **76** (1994) 6522.
[10] M. Jimbo, K. Komiyama, H. Matsue, S. Tsunashima and S. Uchiyama, *J. Appl. Phys.* **34** (1995) L112.
[11] M. A. Akhter, Y. Q. Matan and D. J. Mapps. MMM, *Conf. Atlanta* Nov (1996) BR-11.
[12] B. Dieny, *J. Phys. Cond. Matter.* **4** (1992) 8009.
[13] B. L. Johnson and R. E. Camley, *Phys. Rev. B.* **44** (1991) 9997.
[14] B. Dieny, P. Humbert, V. S. Speriosu, S. Metin, B. A. Gurney, P. Baumgart and H. Lefakis, *Phys. Rev. B.* **45** (1992) 806.
[15] B. Dieny, V. S. Speriosu, S. Metin, S. S. P. Parkin, B. A. Gurney, P. Baumgart and D. R. Wilhoit, *J. Appl. Phys.* **69** (1991) 4774.
[16] P. Baumgart, B. Gürney, D. Wilhoit, T. Nguyen, B. Dieny and V. Speriosu, *J. Appl. Phys.* **69** (1991) 4792.
[17] Y. Hosoe, K. Hoshino, S. Tsunashima, S. Uchiyama and R. Imura, *IEEE. Trans. Magn.* **28** (1992) 2665.
[18] K. Bouziane, J. Ben Youssef, M. El Harfaoui, O. Koshkina, H. Le Gall, J. M. Desvignes, M. El Yamani, and A. Fert, *J. Magn. Magn. Mater.* **165** (1997) 284.