Journal of Materials Physics and Chemistry, 2018, Vol. 6, No. 2, 36-38
Available online at http://pubs.sciepub.com/jmpc/6/2/1

DOI:10.12691/jmpc-6-2-1

Activation Energy Depending on the Thickness of the Ferromagnetic Layer

A. Adanlété Adjanoh[1,*], R. Belhi[2]

[1]Département de Physique, Faculté des Sciences et Techniques, Université de Kara, B.P : 404, Kara, Togo
[2]Département de Physique, Faculté des Sciences de Tunis, Université de Tunis El Manar, Tunis 1060, Tunisia
*Corresponding author: adanlete.assiongbon@gmail.com

Received August 18, 2018; Revised October 05, 2018; Accepted October 23, 2018

Abstract We present the detailed study of activation energy E_a according to the thickness of the magnetic layer ($t_{Co} = 0.7, 0.8$ and $1\ nm$). The study was carried out at room temperature by means of polar magneto-optical Kerr effect magnetometry (PMOKE) using a He–Ne laser ($\lambda = 633\ nm$). We found that the activation field $\mu_0 H_a$, the coercive field $\mu_0 H_C$ and the average activation energy E_a are weak for the sample with thickness t_{Co} = 1 nm.

Keywords: *time of demagnetization, activation field, activation energy, activation volume*

Cite This Article: A. Adanlété Adjanoh, and R. Belhi, "Activation Energy Depending on the Thickness of the Ferromagnetic Layer." *Journal of Materials Physics and Chemistry*, vol. 6, no. 2 (2018): 36-38. doi: 10.12691/jmpc-6-2-1.

1. Introduction

The miniaturization of the devices using ferromagnetic materials made grow the interest for these materials during these last decades for the researchers. Research on these materials is directed either towards the comprehension of very fundamental mechanisms or towards an important prospects for applications such as ultra-high density storage [1,2]. Indeed, the writing of the elementary bits of information is traditionally done by application of an impulsion of magnetic field. Thus the magnetization reversal dynamic plays a fundamental role in the creation of these elementary bits of information. Energy necessary to create a first reversed magnetic field is called activation energy. A perfect control of the parameters controlling the activation energy would make it possible to control the electric current necessary for the creation of the elementary bits of information. Some work has been devoted to the energy of activation [3,4,5] but these works did not discuss the effect the thickness of the magnetic layer on energy of activation.

The aim of this paper is to show that the thickness of the magnetic layer can influence the value of the activation energy.

2. Material and Methods

2.1. Sample and Structural Characterizations

Si(100) substrate is beforehand cleaned by ultrasounds in an acetone bath. After the cleaning, this substrates is thermally oxidized in a furnace at 1200°C during 2 hours. This time is sufficient for the formation of an oxide layer on the silicon surface substrate.

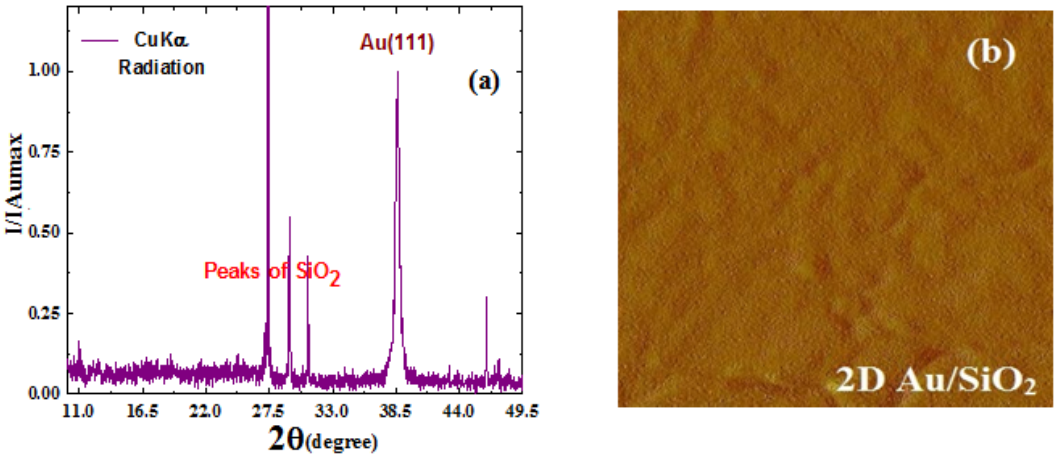

Figure 1. (a): XRD spectra of a 25 nm thick Au layers deposited on SiO_2 substrate. (b): 2D AFM image of a 25 nm thick Au buffer layer deposited on SiO_2 substrate

Au/Co/Au films were prepared by electron beam evaporation in an ultrahigh vacuum chamber, with a base pressure about of $10^{-9}\ Torr$ and approximately $10^{-8}\ Torr$ during deposition on SiO_2, at room temperature.

A first 25 nm thick Au film is deposited on the substrate at a deposition rate of 2.5 nm/min, as calibrated with a quartz microbalance, followed by annealing at 423 K during 1 h to reduce the surface roughness.

The Au film is (111) textured, as shown by X-ray diffraction (Figure 1(a)). Figure 1(b) shows the 2D AFM image of the Au buffer layer after annealing. The surface roughness (root mean square: rms) was measured to be about 0.2 nm. Using the surface corrugation obtained from 2D AFM, we estimate a lateral grain size of 40–60 nm. Cobalt layers with thicknesses (t_{Co}) equal to $1, 0.8$ and 0.7 nm are then deposited on the Au/SiO_2 at a deposition rate of 0.2 nm/min. Finally, a second Au layer with a thickness about of 5 nm is deposited on top of the cobalt layers.

The (111) texture of the Au buffer layer suggests, in each case, a possible epitaxial growth of the cobalt layer with the Hexagonal Close-Packed (0001) structure [6,7,8].

2.2. Magnetic investigations

Magnetic hysteresis loops, at a field sweep rate of $d\mu_0 H/dt = 1.2\ mT$, were recorded at room temperature (RT) by polar magneto-optical Kerr effect magnetometry (PMOKE) using a He–Ne laser ($\lambda = 633\ nm$). On the hysteresis loops we measured the coercive fields $\mu_0 H_C$ and the nucleation fields $\mu_0 H_n$. Table 1 shows magnetic quasi statistic parameters deduced from the hysteresis loops of the three samples.

Table 1. Data obtained from the quasi-static characterizations at 300 K

$t_{Co}(nm)$	0.7	0.8	1
$\mu_0 H_C(mT)$	31.60	29.20	26.50
$\mu_0 H_n(mT)$	27.4	24.9	23

2.3. Magnetization Reversal

The energy needed to reverse magnetization can be expressed in the following way [3,4]:

$$W(H) = E_a - \mu_0 M_S V_B H, \qquad (1)$$

where E_a is an activation energy at zero field i.e. thermal energy required to initiate the magnetization reversal in the absence of the field, M_S is the saturation magnetization and V_B is the Barkhausen volume (the magnetization volume that reverses during a single activation event). In this context, the time $t_{1/2}$ so that a sample is demagnetized, under the applied field $\mu_0 H$, should follow the Arrhenius-Néel law:

$$t_{1/2} = t_0 \exp\left(\frac{E_a - M_S V_B(\mu_0 H)}{K_B T}\right). \qquad (2)$$

We recorded the reduced magnetization reversal curves $m(t)$ in time. From magnetization reversal curves $m(t)$ vs t we deduced $t_{1/2}$ vs $\mu_0 H$. The fit of $t_{1/2}$ vs $\mu_0 H$ by using equation (2) allowed us to determine E_a and $M_S V_B$. On Figure 2 are represented $t_{1/2}$ vs $\mu_0 H$ and their fitting.

The experimental dots of Figure 2 show that $t_{1/2}$ evolves under the Arrhenius law. The adjustments of these experimental dots by Eq. (2) gives the values of t_0, E_a and $M_S V_B$.

3. Results and Discussions

On Figure 2, we notice in the three cases that there is an agreement between the adjustment curve and the experimental dots. In Table 2 are summarized the values of t_0, E_a and $M_S V_B$. For the three samples t_0 is $10^4\ s$, what mean that this parameter does not vary too much according to the thickness of the magnetic layer. The value of t_0 is the same magnitude order we found on $(Pt/Co)_3$ multilayers [5].

Table 2. Data obtained from the fitting by Arrhenius-Néel law

$t_{Co}(nm)$	0.7	0.8	1
$t_0(s)$	10^4	10^4	10^4
$E_a(meV)$	146.12	329.2	138.4
$M_S V_B(10^{-21}\ J/mT)$	2.15	4.05	3.35

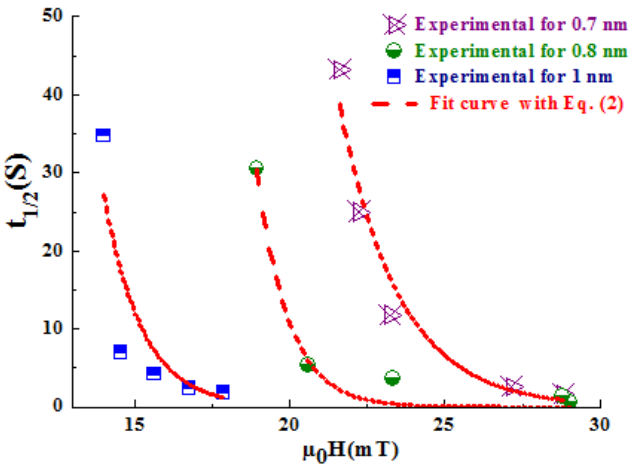

Figure 2. $t_{1/2}$ depending on $\mu_0 H$ and it fitting by Arrhenius-Néel law Eq. (2), for the three samples

The values of E_a, in Table 2, are in general weak compared to that we found on our $(Pt/Co)_3$ multilayers [5]. E_a in magnetic layer having 0.8 nm thickness is twice higher than those of the magnetic layers having thicknesses t_{Co} = 1 nm and 0.7 nm. The highest value of the activation energy found in this sample (t_{Co} = 0.8 nm) let's think that this sample would have more defects than the two others. This sample has also the highest value of $M_S V_B$. If we emit the assumption that the magnetization saturation M_S is almost of the same magnitude order for the three samples [6] then the greatest value of V_B would be in the magnetic layer of 0.8 nm thickness. This lets think that reversed initial volumes would be larger than those of the two other samples. Thus, magnetization reversal in this sample would be done by a mode different from that of the two other samples. In the samples of thickness t_{Co} = 1 nm and 0.7 nm, the weakness of the

values of activation energy E_a lets think about the magnetization reversal dynamics dominated by the magnetic domain wall motion. These deductions are in agreement with our previous works [5] where we showed that the activation volume and the activation energy are highs when magnetization reverse mainly by several nucleate centers due to the inhomogeneities.

Knowing t_0 and E_a for each sample, it is possible to estimate these times of demagnetization in zero field but under the temperature effect only at 300 K. In fact, Eq. (2) at zero field become:

$$t_{1/2}(\mu_0 H = 0) = t_0 \exp\left(\frac{E_a}{K_B T}\right). \quad (3)$$

We found respectively $t_{1/2}(\mu_0 H = 0) = 2.85 \times 10^6\ s$, $3.41 \times 10^9\ s$ and $2.11 \times 10^6\ s$ for $t_{Co} = 0.7$ nm, 0.8 nm and 1 nm.

$W(H) = 0$ for $\mu_0 H = \mu_0 H_a$, where $\mu_0 H_a$ is the activation field that cancels the energy barrier. Under these conditions the activation energy is given by:

$$E_a = \mu_0 M_S V_B H_a. \quad (4)$$

By taking into account the values of $M_S V_B$ found, in Table 2, Eq. (4) gives respectively $\mu_0 H_a$ = 10.93 mT, $\mu_0 H_a$ = 13.03 mT and $\mu_0 H_a$ = 7.43 mT for the samples with $t_{Co} = 0.7$ nm, 0.8 nm and 1 nm. In the three cases the value of $\mu_0 H_a$ is lower than that of $\mu_0 H_C$ what shows clearly that the magnetization reversal is well initiated before the sample is demagnetized. The lowest value of $\mu_0 H_a$ is found for the sample t_{Co} with = 1 nm. The lowest values of $\mu_0 H_a$ and $\mu_0 H_C$ found for this sample shows that the reversal of its magnetization would not require enough of electrical energy.

4. Conclusion

We studied ultrathin cobalt films with thickness $t_{Co} = 0.7$, 0.8 and 1 nm. We extracted for these three samples the average activation energy E_a in zero field. E_a does not vary linearly according to the thickness of the magnetic layer. We found that the activation field $\mu_0 H_a$, the coercive field $\mu_0 H_C$ and the average activation energy E_a are weak for the sample with thickness t_{Co} = 1 nm. This result shown that with this thickness one can reverse magnetization with a low electrical energy.

Acknowledgments

This work is the result of a collaboration between the LMOP laboratory (Tunisia) and the University of Kara, Togo. We acknowledge the help of LMOP in Tunisia and that of « équipe Micro et Nano-Magnétisme de l'Institut Néel à Grenoble, France ».

References

[1] J. Pommier, P. Meyer, G. Pénissard, J. Ferré, P. Bruno, and D. Renard, Magnetization reversal in ultrathin ferromagnetic films with perpendicular anisotropy: Domain observations *Phys. Rev. Lett.* 65, 2054, 1990.

[2] J. X. Shen, R. D. Kirby, Z. S. Shan, D. J. Sellmyer, and Tl Suzuki, Observation of unequal activation volumes of wall-motion and nucleation processes in Co/Pd multilayers, *J. Appl. Phys.* 73, 6418, 1993.

[3] P. Bruno, G. Bayreuther, P. Beauvillain, C. Chappert, G. Lugert, D. Renard, J.P. Renard, J. Seiden, Hysteresis properties of ultrathin ferromagnetic films, *J. Appl. Phys.* 68 (1990) 5759.

[4] M. Czapkiewicz, T. Stobiecki, S. van Dijken, Thermally activated magnetization reversal in exchange-biased [Pt/Co]$_3$/Pt/IrMn multilayers, *Phys. Rev. B* 77 (2008) 024416.

[5] R. Belhi, A. Adanlété Adjanoh, J. Vogel, Influence of Pt thickness on magnetization reversal processes in (Pt/Co)$_3$ multilayers with perpendicular anisotropy, *J. Magn. Magn. Mater.* 324 (2012) 1869-1877.

[6] C. Chappert, D. Renard, P. Beauvillain, J.P. Renard, J. Seiden, Ferromagnetism of very thin films of nickel and cobalt, *J. Magn. Magn. Mater.* 54 (1986) 795.

[7] C. H. Lee, H. He, F. Lamelas, W. Vavra, C. Uher and R. Clarke, Epitaxial Co-Au Superlattices, *Phys. Rev. Lett.* 62 (1989) 653.

[8] M. Ohtake, M. Futamoto, F. Kirino, N. Fujita, N. Inaba, Epitaxial growth of hcp/fcc Co bilayer films on Al_2O_3(0001) substrates *J. Appl. Phys.* 103 (2008) 07B522.

[9] A. Adanlété Adjanoh, R. Belhi, J. Vogel, O. Fruchart, M. Ayadi, K. Abdelmoula, Magnetization reversal dynamics in Au/Co/Au(111) ultrathin films: Effect of roughness of the buffer layer, *J. Magn. Magn. Mater.* 322 (2010) 2498.