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L-Short paper

Modeling of magnetic properties (Cr/NiO/Ni) based multi-layers deposited by magnetron sputtering using Preisach model

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Abstract : In the present work, thin films of Cr/NiO/Ni are deposited on glass substrates using RF magnetron sputtering technique. The uniformity and homogeneity of the prepared films were controlled by varying the power of the source, the target-substrate distance and the pressure of the plasma gas which is argon. In order to test the Preisach Model, we carried out measurements according to two directions: parallel and perpendicular to the substrate plane using a Vibrating Sample Magnetometer at room temperature. Good agreement has been obtained by comparing the experimental hysteresis loops to the ones determined using Preisach model. We conclude that this model is powerful in predicting the magnetic properties of multilayer systems.

Keywords : Cr/NiO/Ni, MAGNETRON SPUTTERING, PREISACH MODEL, MAGNETIC HYSTERESIS.

Introduction

The exchange coupling between a ferromagnetic material (F) and an antiferromagnetic material (AF) is one of the important physical phenomena during the recent decades. It is mainly operated in the case of magnetic thin layers [1].

The choice of nickel oxide (NiO), as part of this work, is justified by the alternative it offers in terms of both antiferromagnetic layer and insulation. Moreover, it has a very strong corrosion resistance [2]. This choice also finds its origin in the exchange interaction, but in this case, the atomic arrangement is such that this interaction promotes antiparallel spin ordering [3]. As for the ferromagnetic material, we have chosen nickel which is of considerable importance because of its advantageous properties such as the spontaneous magnetization in the absence of magnetic field at room temperature [4-6] and also its total magnetic energy is minimum [3].

It is worth noting that Chromium as thin films with thickness in the range 10 – 20 nm are widely used to make Hard disk drives. The deposited films are composed of crystalline grains which are physically isolated through the segregation of intergranular non-magnetic Chromium to the grain boundaries. It is also importatnt to point out that prior to 2006, all HDDs used so-called longitudinal media where the Co c-axis lay in the media plane. Hence the easy-axis anisotropy direction and magnetization were also in the film plane [7].

The recording layers are deposited on the substrate using sputtering which is the most suitable deposition technique for preparing this kind of films. To achieve a film with adequate magnetic properties, it is important to well set the process parameters which are: composition, thickness and structure of the layer. The magnetic properties of the deposited film also depend on the structure of the chromium underlayer. The deposition parameters for both layers, such as substrate temperature, bias voltage and surface texture, are also very important. It is essential to deposit the recording layers on a chromium underlayer in order to obtain the necessary in-plane orientation [8].

Another option for the recording layers is to include a very thin layer of an antiferromagnetic spacer material which has the advantage of orienting the magnetization of the high and low materials, antiparallel for a magnetically more stable configuration. The spacer could be achieved by either depositing a very thin layer of material such as chromium or by oxidizing surface made of Ni thus forming NiO [9]. However, when one generally makes a ferromagnetic material (F) in contact with an antiferromagnetic material (AF), there is an interface of the two materials, which will induce an additional anisotropy in the system called exchange anisotropy [10] which is unidirectional and depends on the used materials and their geometry [3], their crystallinity, texture, interface roughness, distribution, and many other parameters such layer thickness or temperature where the real role is not yet understood [11].

Multilayer structures made of Cr/NiO/Ni are widely used in several magnetic and electronic fields such as digital storage, magnetic sensor technology [12-13], magnetic recording media [14-15] or domain stabilizers in recording heads based on anisotropic magnetoresistance [16]. The general deposition techniques used to prepare magnetic layers are spray [17], e-beam [18], pulsed laser deposition [19], chemical bath deposition [20], ion bombardment [21] and molecular beam epitaxy [22].

In the present work, the studied multilayers were deposited on glass substrates using DC and RF magnetron sputtering techniques.

Experimental protocol

Thin films of Cr/NiO/Ni are deposited on glass substrates the sizes of which are 5mmx5mmx1mm using DC and RF magnetron sputtering techniques carried out on a sputter type MOORFIELD MiniLab 060.

Firstly, the substrates were ultrasonically cleaned in detergent, ethanol and acetone. Each cleaning step was carried out during 20 min with, between each two consecutive steps, a thorough rinsing in deionized water heated at 90°C. The substrates were finally dried in a flowing nitrogen gas.

High quality of Cr, NiO and Ni targets are used for deposition with purity ranging between 99.94% and 99.99%. The targets were pre-sprayed for 5 min to remove any surface contamination with the shutter in place to prevent the substrates to be exposed. The substrate holder was rotatably held during spraying in order to obtain a homogeneous and uniform growth on the substrate surface.

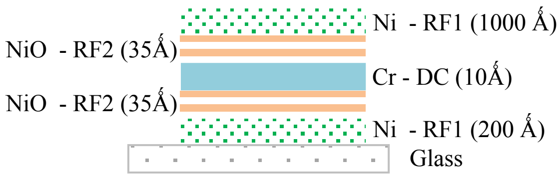

Figure. 1: thin films (Cr/NiO/Ni) deposited on glass (Substrate)

Preisach model

Mathematical modified formulation

We obtained through the Preisach model and the modified Lorentz function the following expression:

$$M(t) = M_{i-1}(t) \pm 2 \iint_D \frac{K\,a^2}{\left[a+\left(\frac{\alpha}{H_C}-b\right)^2\right]\left[a+\left(\frac{\beta}{H_C}+b\right)^2\right]}\,d\alpha\,d\beta$$

This formulation makes calculation easier.

Experimental results

Measurements of magnetic properties were carried out on a VSM EV9 from Digital Measurement System with a maximum strength field of 2.6 Tesla parallel and perpendicular to the substrate plane. Figure. 2. shows the hysteresis loops for both parallel and perpendicular cases. As it can be seen, the loop is very slim. Hence, we conclude that the losses are very small.

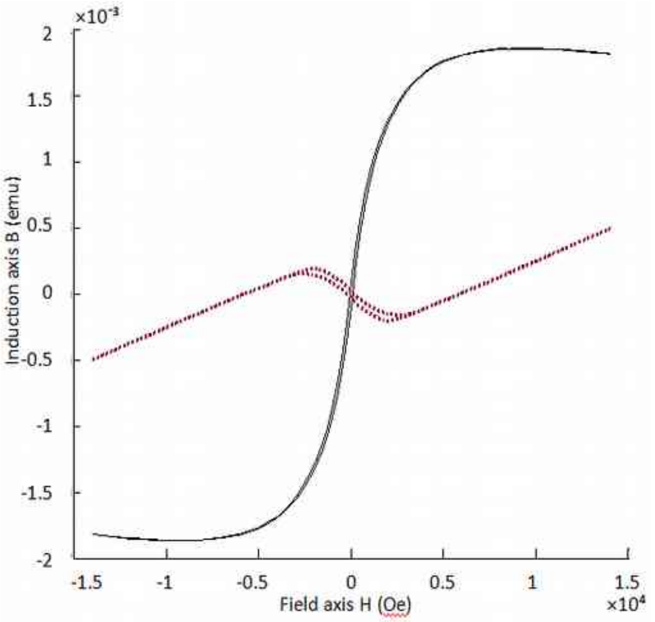

Figure. 2: Hysteresis loops thin layers based on (Cr/NiO/Ni)

Magnetic fields applied Parallel to the substrate

Magnetic fields applied Perpendicular to the substrate

It is worth noting that when Ni is deposited on NiO, the exchange coupling takes place. However, the effects is still relatively lower because of the reduction of contact surface with the AF layer. Furthermore, the offset field is lower with NiO, which is consistent with the interfacial coupling energies reported in literature.

The reversal of the magnetization is a basic principle of magnetic recording. Magnetization in a material can be reversed by applying a large enough field allowing the material to reach the saturation regime in a direction parallel to the field. The two different states of plus and minus magnetization are the basic idea for digital information storage. The two principal methods for reversing the magnetization are rotation and domain-wall motion and the predominant mechanism depends on the material and its dimensions. Both modes can be examined in terms of energy considerations.

Validation of the Experimental model of Preisach

The identification of the model parameters is conducted by minimizing the deviation of measured and simulated results by an optimization method.

In order to test the Preisach Model, we carried out tests according to two directions: parallel and perpendicular to the substrate plane by comparing the experimental hysteresis loops and those obtained by the model.

A result for a typical example is depicted in Figure. 3.

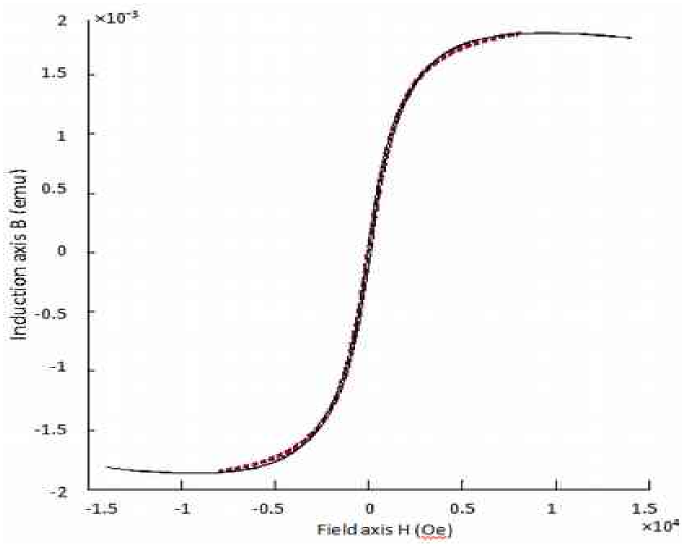

Figure. 3: Parallel magnetic field

Experimental (Measurement)

Theoretical (Preisach model) Simulation

Conclusion

We have determined the magnetic properties of antiferromagnet/ferromagnet multilayers of the system Cr/Ni/NiO, using DC and RF magnetron sputtering. Magnetic hysteresis loops measured at room temperature for the prepared films revealed that the magnetization is parallel to the substrate plane.

A Preisach model based on the rotation operator has been presented. The results provided by this model are very satisfactory and are in good agreement with the experimental results.

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