2009 toifur

by Irip123 Mpfis

GIANT MAGNETORESONANCE EFFECT OF NiFe/Ag/ NiFe MULTILAYERS PREPARED WITH DC SPUTTERING TECHNIQUE ON Ag DEPOSITION TIME

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ABSTRACT

A study on the Giant Magnetoresonance (GMR) effect of NiFe/Ag/NiFe multilayers on Ag deposition time (t_{Ag}) ranging from 1 to 3 minutes has been performed. The study was intended to obtain the most suitable Ag deposition time to give the largest GMR ratio by using 150 G deposition field in transverse direction of anode-chathde and $200°$C substrate temperature during deposition. Several characterizations have been performed including morphological sample cross section, microstructure, magnetic properties of the layer, and GMR ratio in an external magnetic field ranging from -20 up to 20 gauss. The results show that multilayers with $t_{ag} = 2$ minutes displays the largest GMR ratio of 54.87%. The layer has a high level of atomic structure ordering, a large grain size, the highest remanence and the smallest coercive power. The situation is close to Pool's estimation that the GMR ratio for trilayers of approximately 50%.

Keywords: GMR ratio, deposition time, remanence, and coercive.

I. INTRODUCTION

An effort to discover the more sensitive magnetic field sensor material is still continuously done. The Giant Magnetoresonance (GMR) effect is one of goodness parameters of magnetic field sensor material. Miniaturization of layers is one of methods for raising the GMR effect (Lehnert et al., 1999). Miniaturization include regulating the thickness of magnetic layer, thickness of spacer layer, the number of layer (de Jonge, 1997), application of buffer and pinning layers.

In miniaturization type supperlattice, magnetic films are sandwich coupled with non magnetic film. In making multilayers type superlattice NiFe/Ag/NiFe, the thickness of Ag layer (as a spacer layer) between the two flanked NiFe layers has a very important role to induce the antiferromagnetic coupling between the two ferromagnetic NiFe layers. The thinner the layer of Ag the greater the coupling interaction produced. Nesbet (1999) argued that antiferromagnetic coupling will happen if the minimum distance between two atoms is 1.5 times the size of atoms. However, as stated by Gagorowska et. al. (2009) the thikcness of ferromagnetic layer obtain the antiferromagnetic fraction. The thinner ferromagnetic layer the larger antiferromagnetic fraction.

Therefore, the thickness of Ag layer determines the thickness of interface between the first and the second NiFe layers. In the normal situation of sputtering machine we hope the thickness for single layer of Ag and NiFe depends linearly on the deposition time, but in practice due to diffusion effects from Ag to NiFe the thickness of the formed layers differ from its normal state.

Kim and Sanders (1995) have achieved the additional activity on NiFe/Ag/NiFe multilayers i.e. the annealing at post deposition with temperature ranging from 300 up to $400°$C. The result is Ag layer break up to NiFe layer due to diffusion effect so the NiFe layer surface that is a continues layer at initially stage to be a discontinues one at later in the form of columnar grains. It is caused by the surface free energy of Ag (1.2 J/m^2) is lower than surface energy of Ni (1.9 J/m^2). Thus depending on amount of diffused atoms it will affect the strength of antiferromagnetic coupling between the two NiFe layers. The thinner interface the weaker coupling interaction, and vice versa. While Parkin et. aI in Christides et al. (1996) made [NiFe/Ag]$_{20}$ on $40°$ C substrate temperature.

In this research we made NiFe/Ag/ NiFe multilayers prepared with dc sputtering technique on variation of Ag deposition time ranging from 1 up to 3 minutes. Deposition was assisted with deposition field of 150 G in the transvers direction of anode-chatode, together with supplying $200°$C substrate temperature during deposition.

We use deposition field for many utilities, i.e. (1) for deviating secunder electrons produced by Ar ions colliding target, then only deposit particles that till to substrate, (2) for rising sputtering densities due to the rising of plasma density, (3) to facilitate parallel alignment of electron spins when achieve to surface of substrate, so the produced film was have anysotropy axis.

Supplying the substrate temperature during deposition process is like an annealing at the time deposition. This is actually is a supply of thermal activation energy on substrate atoms, then the atoms vibrate and form interstitials. With this situation deposit particles should easily enter to substrate surface, and adhere it. Characterization of samples include cross section morphology of layer done by SEM, magnetic properties of layers using VSM, and GMR effect using four point probes in CIP mode.

II. EXPERIMENTAL PROCEDURE

Deposition process for making NiFe/Ag/NiFe multilayers includes three stages, namely the deposition layer NiFe (1), the Ag layer deposition and the latest deposition of NiFe (2) layer. Deposition procedure initially is installing the target Ag or NiFe on the negative electrode (cathode) in sputtering chamber which has been connected with a target cooler and putting the target substrate on the positive electrode (anode) one. Then sputtering system, the cooling target, heating the substrate, turbo pump are operated, and the pressure of sputtering chamber is vacuumed until 10^{-6} torr. Argon as gas sputtering is streamed into the reactor tube so that the gas pressure in the tube rise to 1.6 x 10^{-1} torr or the gas pressure is set according to the desired pressure. Turning on the dc high voltage system and regulate it on the desired working voltage up to 30 watts of power. In this condition, we will look at the formation of plasma in the reactor, which means that the deposition process is underway. In NiFe deposition, to assist the formation of spin-spin electrons in parallel direction deposition process is equipped with an external magnetic field of 150 gauss perpendicular to the anoda-cathoda direction. Substrate temperature is set on 200 °C. Direction of the external magnetic field in formation process of NiFe(1) layer is opposite to the direction of external magnetic field in formation process of NiFe(2) layer. Deposition time for formation of NiFe(1) and NiFe(2) layers was set on 30 minutes, meanwhile the deposition time of Ag layer was varied from 1 up to 3 minutes. After completion of deposition, dc high voltage is reduced down to 0 volts and then turned off. Similarly, the gas flow, the current of external magnetic field, substrate heater, target cooler, and the vacuum pump and latest the engine sputtering are turned off. After 30 minutes the substrate removed from the deposition chamber.

III. RESULTS AND DISCUSSION

a. Observing Multilayer Cross Sections of NiFe/Ag/NiFe

Figure 1 shows a part of SEM photographs of multilayer cross sections of NiFe/Ag/NiFe taken by SEM, namely for deposition time of Ag (or t_{Ag}) 1 and 2 minutes. It appears that the deposition time of Ag affects to the thickness of layer either Ag or NiFe layers. In Figure 1 (a) the NiFe (1) layer blurred and thin (like adhere on the glass substrate), NiFe(2) layer appear more clearly visible, while the Ag layer is seem sharp and thick. Surface of the interface between the Ag and NiFe layers as well as the outer surface of NiFe(2) appears to smooth. Analytically, as mentioned in introduction the thicker of Ag the more difficult formation of antiferromagnetic coupling between the two NiFe.
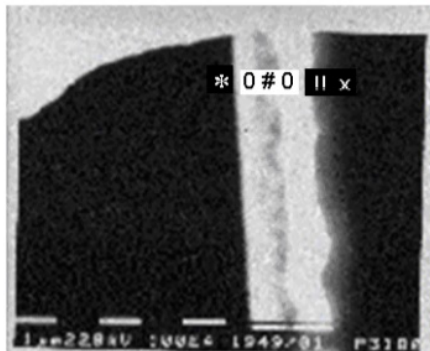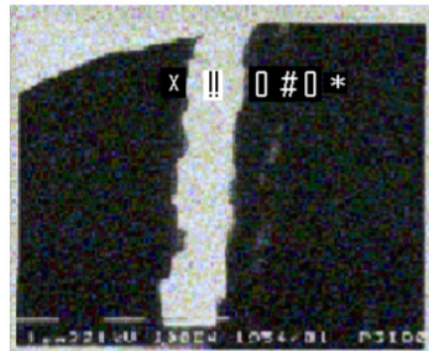
(a) t_{Ag}=1 minute   (b) t_{Ag}=2 minutes

Figure 1. Photograph of cross section of NiFe/Ag/NiFe multilayers taken by SEM, for t_{Ag}=1 minute (a), and t_{Ag}=2 minutes (b). The marks (*) substrate, (0) NiFe, (#) Ag, (!!) gold, and (x) power glue.

In Figure 1 (b) it is seem that NiFe(2) materials penetrate the Ag layer reach the NiFe(1) layer, a part of Ag layer is covered by NiFe material. However, the Ag layer is still seemed although very thin. The thinner of Ag as spacer layer the more potential to generate antiferromagnetic coupling between two NiFe magnetic layers. Furthermore, we will to analyze the fact with another characterization. In Figure 2 it is showed the estimated thickness of NiFe(1) and NiFe(2) on various deposition time of Ag. The thickness is measured from the length of scale viewed in the VSM photographs.
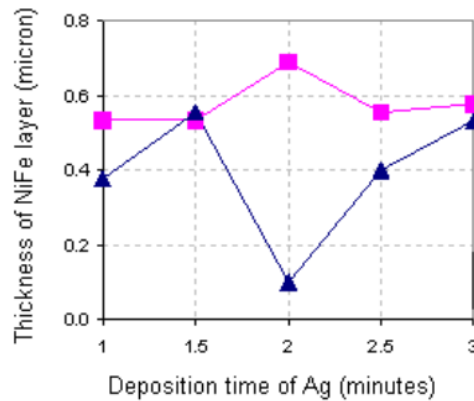

Figure 2. Thick layers of NiFe(1) (mark □) and NiFe(2) (mark □) in the variation deposition time of Ag

The most difference between the two NiFe layers is according to the sample with the t_{ag} = 2 minutes. The thickness of NiFe(1) and NiFe(2) layers are 0.1 and 0.69 microns respectively. Meanwhile the sample with t_{Ag} = 1.5 minutes is almost the same thickness layers of NiFe(1) and NiFe(2) layers, namely 0.56 and 0.53 microns.

b. Observing Microstructure of NiFe/Ag/NiFe Film
Furthermore, the graph shown in Figure 3 XRD spectra of the NiFe/Ag/ NiFe multilayers with variation deposition time of Ag.
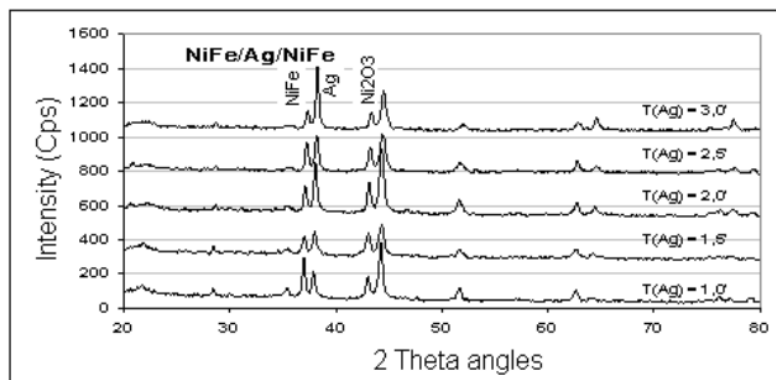

Figure 3. XRD spectra of the NiFe/Ag/NiFe multilayers with variation deposition time of Ag.

From these images it is appear that the films have crystalline structure with position of diffraction peaks around the corner of 37.2°, 38.1°, 42.8° and 44.2°. By comparing with Table Powder Diffraction Data (Morris et al.,

1997) the corner is accordance with NiO, Ag, NiFe and Fe_2O_3 and their Miller index are [111], [111], [111] and [110] respectively.

The existence of Ni and Fe oxides is probably due to the target contains oxygen and chemically react among them, so it is not probable to remove it during sputtering process although in the low vacuum. During bombardment of target by Ar ions these oxides are ejected directly toward the substrate and form film which a part contain the NiO and Ni_2O_3. Or during bombardment of target, at the first the oxide bond are separated into Ni, Fe and O_2 and then ejected together toward to the substrate and substrate reacts with Ni and with Fe to form NiO or Ni_2O_3. Another alternative is the reaction between Ni and Fe with oxygen in substrate because the glass substrate is made from silicates (SiO_3). Because the sputtered atoms are high-energy particles the energies was able to release oxygen from substrate SiO_3, then continuing the process to form NiO or Ni_2O_3.

Variations of time depositon of Ag affect the degree of ordering structure of atom in film. It can be seen from the change of the diffraction peak intensity of each phase as the raising deposition time of Ag. In Figure 4, it is shown intensity and grain size of the phase's calculated using Scherrer formula (Tan *et al.*, 1996) as a function of t_{Ag}.
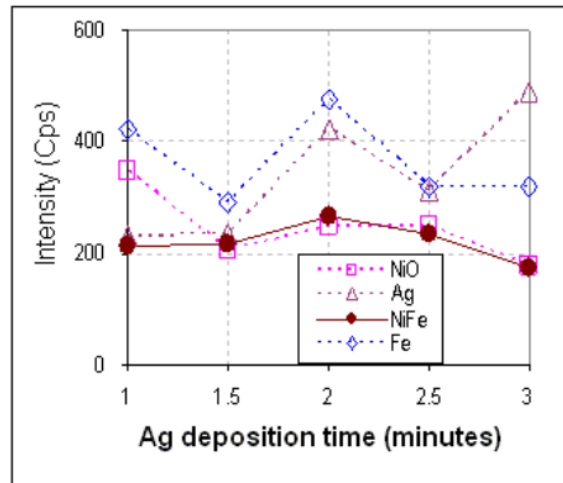
(a)
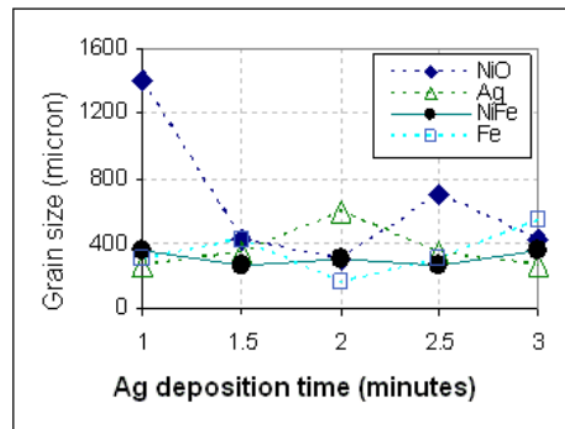
(b)

Figure 4. Intensity and grain size NiFe/Ag/NiFe multilayers vs deposition time of Ag

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It appears that the level of regularity of the atomic structure of each phase fluctuates. All the phases are relatively more regular on t_{Ag} = 2 minutes. Similarly the grain size particularly for NiFe and Ag increases too.

c. Magnetic Properties of NiFe/Ag/NiFe Multilayers

The magnetic properties of multilayers were determined by VSM. The result is M-H loop with M refer to magnetization and H is external magnetic field or magnetization field. Many parameter found from the curve are remanence (M_r), coercivity (H_c), and saturation field (H_s). From the values we could decide if the sample includes soft magnetic materials is, or the hard one. Magnetic material which has a good quality for a soft magnetic field sensor is that has a large M_r and small H_c. Figure 5 shows the curve for the sample with t_{Ag} = 2 minutes.
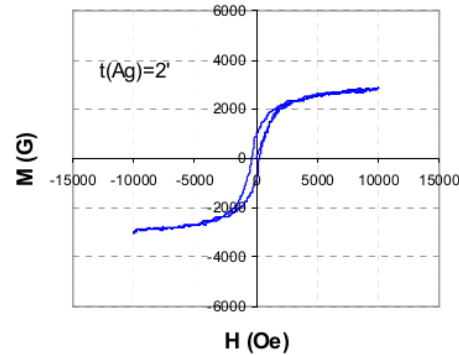

Figure 5. M-H loop graphs of multilayers NiFe/Ag/NiFe on t_{Ag} = 2 minutes

In this research we use magnetization field ranging from -15.000 up to 15.000 Oe for entire samples. In fact variation of t_{Ag} affects the M-H loop profiles of each sample. Magnetization field required to reach the saturation magnetization (M_s) of about 10 000 Oe. This means that in this field the direction of magnetic domain is parallel to magnetization field. In Figure 6 it is shown the graphs of remanence and coercive field of each sample.
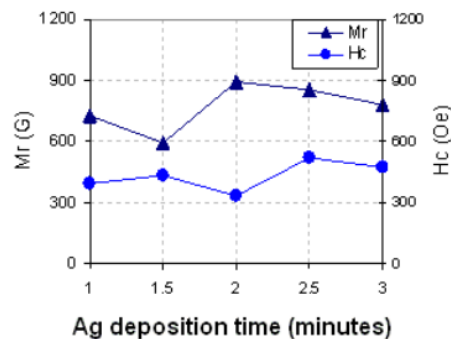

Figure 6. Magnetic remanence, coercive field and magnetostatic energy of NiFe/Ag/NiFe on variation of t_{Ag}

From these graphs it is known that the sample resulted in the deposition t_{Ag} = 2 minutes has the highest M_r and lowest H_c i.e. 893.59 gauss and 330.67 Oe respectively. This means that the film has the greatest magnetic intensity while the spins are quite easily to switch from up to down or vice versa due to external magnetic field. From the calculation of magnetic energy the film has magnetic energy 107.232 G Oe which is the high level energy for soft magnetic material.

d. GMR Ratio of NiFe/Ag/NiFe Multilayers

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GMR ratio is investigated by four point probes using CIP mode. Profile of GMR ratio indicate the sensitivity level of magnetic material to response the changes of external magnetic field. The results are showed in Figure 7. The magnetic field used is set from -20 gauss to 20 gauss.
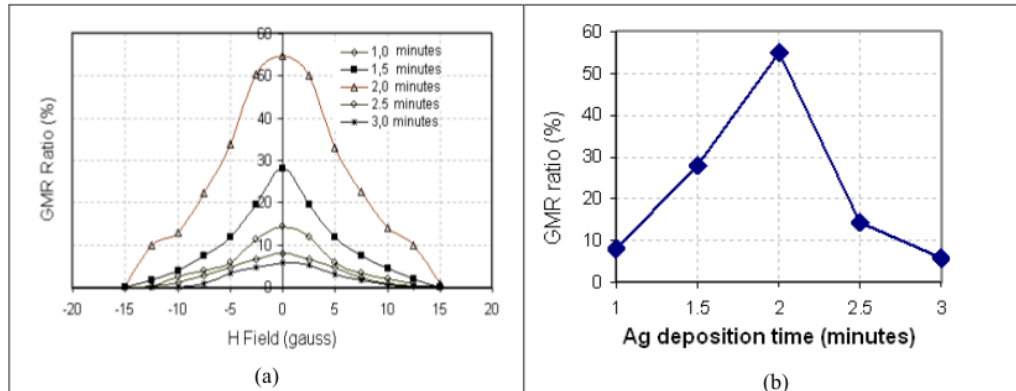

Figure 7. GMR ratio of each NiFe/Ag/NiFe multilayer

From the images it is appears that the largest GMR ratio corresponds to the sample with the t_{Ag} = 2 minutes that is 54.86%. This result is much greater than single-layer GMR ratio of about 6% (Toifur *et al*, 2002). Referring to the Pool statement that the GMR effect for *n* layers is proportional to $(n-1)/n$ which *n* is the number of magnetic layer (Pool, 1993), and then for 2 magnetic layers the resulting GMR ratio is about a half or 50%. My result is higher than what Pool express was. Layer also provides the GMR profile enough symmetry in response the magnetic fields at both positive and negative directions. Spin-spin indicates the easily switching under influence the external magnetic fields. The magnetic field required to switching is about 5 gauss.

CONCLUSIONS AND SUGGESTIONS

By designing a multilayers type superlattice, using deposition field of 150 G during deposition process, and supplying temperature $200°$ C on substrate, the GMR ratio can be increased up to 9 times more than that in single-layer. Besides, two minutes deposition time of Ag is the most suitable condition to produce the largest GMR ratio. Features of this multilayers are the high ordering of atomic arrangement, the large grain size, the large magnetic remanence and the small coercive field. With this situation the film is very suitable used as candidate of soft magnetic field sensor material.

In accordance with the advice of Kano et al. (1993), it is still possible to increase the magnitude of this GMR effect if the thickness is decreased again to 4 to 6 nm for the magnetic layer and 1.5 to 2 nm for nonmagnetic layer. With this thickness, it is possible for electron spins to achieve the maximum scattering, so the effects of GMR can reach more than 80%.

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