Advanced Materials Research Vols. 535-537 (2012) pp 1319-1322
Online available since 2012/Jun/14 at www.scientific.net

doi:10.4028/www.scientific.net/AMR.535-537.1319

Giant Magnetoresistance in ($Ni_{60}Co_{30}Fe_{10}$/Cu) Trilayer Growth by Opposed Target Magnetron Sputtering

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Keywords: Ferromagnetic, Giant Magnetoresistance, Magnetic sensor, Spintronics, Sputtering, Trilayer.

Abstract. The giant magnetoresistance thin film of ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer were grown onto Si (100) substrate by dc-opposed target magnetron sputtering (dc-OTMS) technique. The growth parameters are: temperature of 100 ^{0}C, applied voltage of 600 volt, flow rate of Ar gas of 100 sccm, and growth pressure of 5.2 x10^{-1} Torr. The effects of Cu layer thickness and NiCoFe layer thickness on giant magnetoresistance (GMR) property of ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer were studied. We have found that the giant magnetoresistance (GMR) ratio of the sample was varied depend on the non-magnetic (Cu) layer thickness. The variation of Cu layer thickness presents an oscillatory behavior of GMR ratio. This oscillation reflects the exchange coupling oscillations between ferromagnetic and antiferromagnetic states, which are caused by an oscillation in the sign of the interlayer exchange coupling between ferromagnetic layers. The GMR ratio is change with increasing of NiCoFe layer thickness and presents GMR ratio of 70.0 % at t_{NiCoFe} = 62.5 nm.

Introduction

The giant magnetoresistance (GMR) effect of a magnetic multilayer film that consists of alternating magnetic and nonmagnetic layers represents a relatively large change in the electrical resistance when an external magnetic field is applied to the films. The effects of GMR has been a focus of intensive study for three decades, both for interesting of fundamental physics [1,2] and important industrial applications as sensors, memory, and read head applications [3,4]. Many application of GMR sensor has been developed, such as: current sensor [5], linear and rotational position sensor [6], head recording [3], and biosensor [7,8].

The GMR thin film is usually prepared using the sputtering, electro deposition or molecular beam epitaxy (MBE). But so far, it not many researchers who reported the manufacture of thin film of GMR by dc-opposed target magnetron sputtering (dc-OTMS) [9]. There are several advantages dc-OTMS method, among others: the resulting film has a high quality of homogeneity within a large area, reducing resputtering process, because electrons with high energies which strike substrate causing resputtering , is compensated again by impact-induced secondary emission, high ionization efficiency and self-discharge that continually able to be maintained under a certain pressure [10]. In addition, operational costs of the dc-OTMS method are cheaper and simpler in comparison with the MBE method.

Experimental

Sputtering target is NiCoFe as ferromagnetic material and Cu as spacer material. Making the target NiCoFe performed by solids reaction with a molar ratio Ni:Co:Fe = 60:30:10. Cu target also make by solid reaction of Cu powder. The ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer was grown onto Si (100) substrate.

Samples of the ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer were deposited in several different thicknesses of layers. Other deposition parameters are fixed. These parameters are: flow rate of Argon gas is 100 sccm, the growth pressure is 0.52 torr, dc voltage is 600 volt, and the temperature is 100^{0}C. The samples were characterized by using SEM (Scanning Electron Microscope) type JEOL JSM-6360 LA, magnetoresistance measurements were made by using a linear four-point probe method with current-perpendicular to-plane.

Result and Discussion

Elemental analyses of ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer based on EDX analysis were also performed using the JEOL JSM-6360LA. Fig. 1A contains the EDX spectra of ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer. The peaks in Fig. 1A correspond to Ni, Co, Cu and Fe, indicating that the ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer were successfully deposition on Si substrate.

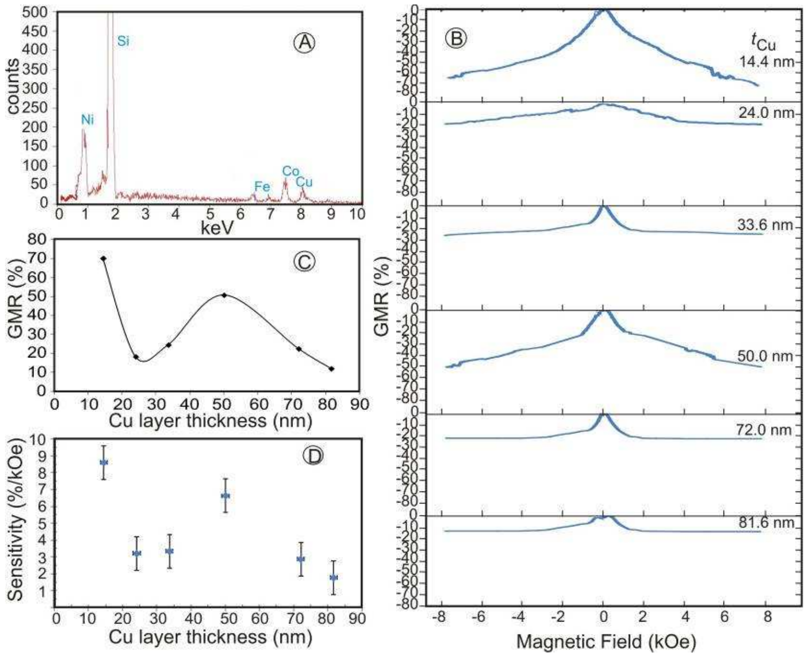

Fig. 1.A. EDX spectrum of NiCoFe/Cu/NiCoFe sandwich. B. GMR ratio as function of applied magnetic field for ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer with different Cu-layer thickness (t_{Cu}) and fixed NiCoFe layer thickness (t_{NiCoFe}) = 62.5 nm. C. GMR ratio in ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer versus Cu layer thickness. D. Magnetoresistance sensitivity dependence of Cu layer thickness.

Effect of Cu layer thickness. GMR ratio of ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer as a function of non-magnetic Cu layer thickness, shown in Fig. 1B. The GMR ratio decrease with increasing Cu layer thickness. When Cu layer thickness is thick, the conductivity through it becomes predominant and the spin dependent scattering is less effective, then the GMR ratio decreases.

Variations of the GMR ratio of the thickness of the spacer layer Cu are shown in Fig. 1C. In general, the behavior of the GMR ratio as a function of non-magnetic layer thickness shows oscillations. This oscillation describes the oscillations of the exchange coupling between ferromagnetic and anti ferromagnetic state. These oscillations caused by oscillations in the sign of the interlayer exchange coupling between ferromagnetic layers of material making up the GMR [11]. Seen that the peak of the oscillation decays exponentially following the equation:

$$\frac{\Delta R}{R} = \left(\frac{\Delta R}{R}\right)_0 \times \frac{\exp(d_{NM}/l_{NM})}{1 + d_{NM}/d_0} \quad (1)$$

with d_{FM} is the thickness of the ferromagnetic layer, d_0 is the effective thickness and l_{FM} is the mean free path of the ferromagnetic. $\left(\frac{\Delta R}{R}\right)_0$ should be viewed as phenomenological parameters. The exponential factor represents the probability that an electron is not scattered within the non magnetic layer. The factor in the denominator describes the shunting effect due to the non magnetic layer. [12]. The decay in GMR ratio with increasing Cu layer thickness can be describe approximately by [12]:

$$\frac{\Delta R}{R} \approx \frac{1}{t_{Cu}} \exp\left(-t_{Cu} / \lambda_{Cu}\right) \tag{2}$$

where t_{Cu} is the Cu layer thickness and λ_{Cu} describes the scattering within the Cu layer interior.

The GMR ratio for large Cu layer thickness is low. This caused by small interlayer exchange coupling in ferromagnetic layers. The interlayer exchange coupling areal energy density is [13]:

$$W_1 = -J_1 \frac{\boldsymbol{M}_1 . \boldsymbol{M}_2}{|\boldsymbol{M}_1||\boldsymbol{M}_2|} = -J_1 \cos \Delta\phi \tag{3}$$

where $\boldsymbol{M}_1$, $\boldsymbol{M}_2$ is magnetizations of both layers, $\Delta\phi$ is angle between the magnetizations and J_1 is coupling coefficient. The positive value of the coupling coefficient J_1 means that coupling is ferromagnetic, a negative value means that it is antiferromagnetic. From Eq. 3 shows that the coupling periodically changed from antiferromagnetic to ferromagnetic. This means that the oscillation occurs in the GMR ratio.

A quality of GMR sensor can be characterized by sensitivity. Sensitivity defined as percentage change in resistance per unit applied magnetic field, $S = (\Delta R/R)/H_s$, where $(\Delta R/R)$ is GMR ratio and H_s is saturation magnetic field. In this experiment, we found maximum sensitivity 8.6 %/kOe. Sensitivity curve with different Cu layer thickness are presented on Fig. 1D.

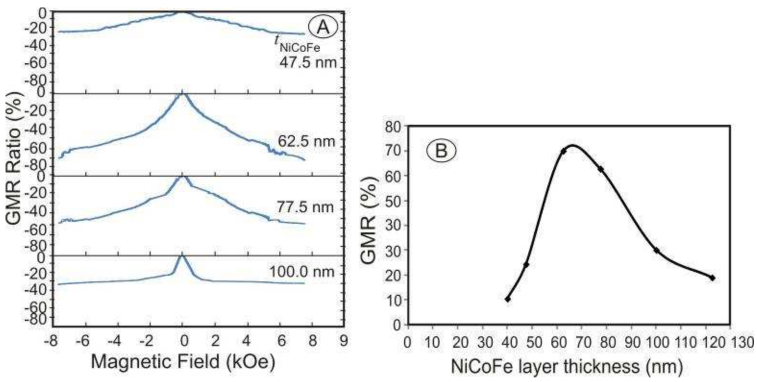

Fig. 2. A. GMR ratio as function of applied magnetic field for ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer with different NiCoFe-layer thickness (t_{NiCoFe}) and fixed Cu layer thickness (t_{Cu}) = 14.4 nm. B. GMR ratio in ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer versus NiCoFe layer thickness.

Effect of NiCoFe layer thickness. Variation of the GMR ratio of a thin film of ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer measured at room temperature for different NiCoFe layer thickness, shown in Fig.2A. In Fig. 2A also shows that the thickness of NiCoFe layer affect the value of GMR ratio and saturation field, H_s. The increase in the saturation field is characterized by an sharp peak of the GMR ratio curve. As the thickness of the NiCoFe layer increases, saturation magnetization of the NiCoFe layer increases. This is because the fraction of magnetic atoms neighboring each other in each ferromagnetic layer increases as the thickness of the ferromagnetic layer increases as observed by Nakatani et. al. in NiFe/Cu multilayer [14].

In the trilayer structure, the small value of the GMR ratio as low NiCoFe layer thickness, probably caused by scattering at the outer surface of a substrate-film interface or buffer layer film. When the NiCoFe layer thickness is greater (above 62.5 nm) that value of the GMR ratio is decrease. This can be explained by the appearance of not active area in the NiCoFe layers that will shunting currents, thus reducing the GMR ratio. Graph of NiCoFe layer thickness versus the GMR ratio is shown in Fig. 2B.

As shown in Fig.2B that the maximum GMR ratio is obtained at a thickness of NiCoFe are 62.5 nm. The maximum position is assumed to be related to the central location of the spin dependent scattering in the ferromagnetic layer. As was argued by Dieny [15], the position of the maximum depends on the location of the spin dependent scattering centers. The decrease in GMR at large NiCoFe layer thickness is due to the increasing shunting of the current in the inner part of ferromagnetic layers. Ferromagnetic layer can be divided into an active part and an inactive part. The active part contributing to GMR ratio and an inactive part shunts the current. The currents density in the inactive part of the ferromagnetic layer then shunts the alignment-dependence conductance of the inner part of the trilayer, and GMR ratio decreases with increasing ferromagnetic layer thickness.

Summary

The ($Ni_{60}Co_{30}Fe_{10}$/Cu) trilayer were prepared using opposed target magnetron sputtering (OTMS) methods on Si (100) substrate. GMR ratio of the samples is strongly influenced by the ferromagnetic layer thickness, NiCoFe and non magnetic layer thickness, Cu. In this research, the maximum GMR ratio of about 70% at room temperature is obtained at a thickness of 62.5 nm of NiCoFe and Cu layer thickness of 14.4 nm.

Acknowledgements

This work was financially supported by the Directorate for Research and Community Service, The Ministry of Education and Culture of Republic of Indonesia through Competency Grant under contract No: 823a/ I1.C01/PL/2011.

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Advanced Engineering Materials II
10.4028/www.scientific.net/AMR.535-537

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