ICROS-SICE International Joint Conference 2009
August 18-21, 2009, Fukuoka International Congress Center, Japan

Effect of Cu Layer Thickness on Giant Magnetoresistance Properties of NiCoFe/Cu/NiCoFe Sandwich

Mitra Djamal[1*], Ramli[1,3], Yulkifli[1,3], Khairurrijal[2]

[1]Theoretical High Energy Physics and Instrumentation Research Group, Faculty of Mathematics and Natural Sciences,
Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, Indonesia
[2] Physics of Electronic Materials Research Group, Faculty of Mathematics and Natural Sciences,
Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, Indonesia
[3] Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang,
Jl. Prof Dr. Hamka Airtawar Padang 25131, Indonesia
[*]E-mail: mitra@fi.itb.ac.id

Abstract: The NiCoFe/Cu/NiCoFe sandwiches were grown onto Si (111) substrate by dc-opposed target magnetron sputtering (dc-OTMS) technique. The growth parameters are: temperature 100 ^{0}C, applied voltage 600 volt, flow rate of Ar gas 100 sccm, and growth pressure 5.2 x10^{-1} Torr. The effects of Cu layer thickness on giant magnetoresistance (GMR) property of NiCoFe/Cu/NiCoFe sandwich were studied. We have found that the giant magnetoresistance (GMR) ratio is varied depend on the non-magnetic (Cu) layer thickness. The variation of Cu layer thickness of NiCoFe/Cu/NiCoFe sandwich 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.

Keyword: Magnetoresistance, Opposed Target Magnetron Sputtering, Layer Thickness, Exchange Coupling.

1. INTRODUCTION

Giant magnetoresistance (GMR) materials have huge magnetoresistance and other magnetic and electrical properties. The GMR materials have magnetoresistance ratio twice to thirty times larger than anisotropic magnetoresistance (AMR) materials such as permalloy, which typically changing its resistance in advance. The magnetic and electrical properties of GMR materials can be varied over very wide ranges. This makes possibilities to use GMR materials for wide variety of sensor applications, and also for devices that are derived from GMR materials. Giant magnetoresistance (GMR) was first observed in France in 1988 [1]. Currently, this technology offers a unique set of sensor characteristics that include high sensitivity, good temperature stability from –55 ^{0}C to over 150 ^{0}C, and excellent linearity over a wide dynamic range.

GMR can be qualitatively understood using the Mott model [2], which was introduced in the beginning 1936. The model explains sudden increase of resistivity of the ferromagnetic metals as they are heated above the Curie temperature. Mott proposed two main points for that issue. Firstly, the electrical conductivity in metals can be described in terms of two largely independent conducting channels, corresponding to the up-spin and down-spin electrons, which are distinguished according to the projection of their spins along the quantization axis. The probability of spin-flip scattering processes in metals is normally small compared to the probability of the scattering processes in which the spin is conserved. This means that the spin-up and spin-down electrons do not mix over long distances, such that the electrical conduction occurs in parallel for the two spin channels. Second, in ferromagnetic metals the scattering rates of the up-spin and down-spin electrons are quite different, whatever the nature of the scattering centers is. According to Mott, the electric current is primarily carried by electrons from the valence *sp* bands due to their low effective mass and high mobility. The *d* bands play an important role in providing final states of the scattering of the *sp* electrons. In ferromagnetism the *d* bands are exchange-split, so that the density of states (DOS) does not equal for the up-spin and down-spin electrons at the Fermi energy. The probability of scattering into these states is proportional to their density. The scattering rates are spin dependent, which means the scattering is different for two conduction channels.

In the usual case of transition metal as ferromagnetic (FM) layer, the thickness of the spacer is chosen in order to magnetically decouple the magnetic layers (i.e. thickness larger than a few atomic planes to break the direct coupling exchange path, and to prevent indirect coupling). The transport across the spacer must conserve the spin information, thus the spacer thickness must be kept thinner than a few mean free paths (current-in-plane CIP-GMR) or spin diffusion lengths (current-perpendicular to-plane CPP-GMR).

The study of GMR effect is very important for the development of science and technology for future device applications, and further research efforts have been made to better understand the fundamental mechanism of the spin-transport phenomena.

2. EXPERIMENTAL

NiCoFe/Cu/NiCoFe sandwich were grown onto Si (111) substrate by opposed target magnetron sputtering (OTMS) technique. The sputtering targets were NiCoFe and Cu. The NiCoFe target was prepared by solid reaction method with molar ratio Ni:Co:Fe = 60:30:10. Raw material for producing NiCoFe target consists of 99.90% nickel powder, 99.99% cobalt powder and 99.99% iron powder. The Cu target also had been made by solid reaction from 99.50% copper powder.

Samples of the NiCoFe/Cu/NiCoFe sandwich were deposited in several different time of growth, so that they had different thickness of sandwich layers. Other deposition parameters are fixed. This parameters are: flow rate of Ar gas is about 100 sccm, the growth pressure is 5.2 $x10^{-1}$ Torr, dc Voltage is 600 volt, and the temperature is 100^0C. The samples were characterized using SEM (*Scanning Electron Microscope*) type JEOL JSM-6360 LA, EDAX (*Energy Dispersive Analysis by X-Ray Diffraction*), and magnetoresistance measurements were made using a linear four-point probe method with current-perpendicular to-plane.

3. RESULT AND DISCUSSION

From previous work [3], we found that growth time influence the thin film thickness. The increase of growth time increases the atoms which patched on the substrate. The selected sample of NiCoFe/Cu/NiCoFe sandwich had characteristic of surface structure as shown in SEM image in Fig. 1.

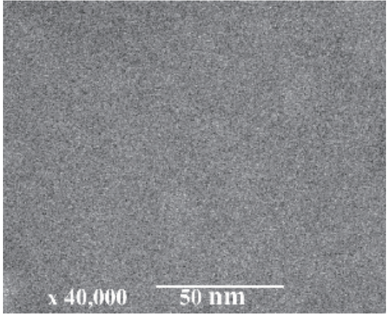

Fig. 1. SEM image for NiCoFe/Cu/NiCoFe sandwich with t_{Cu} = 14.4 nm

Fig. 2 shows X-ray diffraction spectra for NiCoFe/Cu/NiCoFe sandwich at t_{Cu} = 14.4 nm, 24.0 nm and 48.0 nm. It shows that intensity of the peak of film decreases with increasing t_{Cu}.

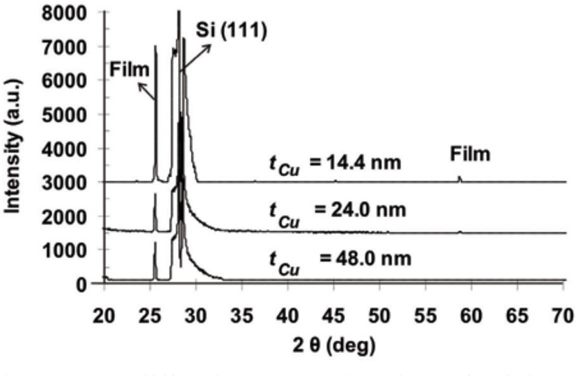

Fig. 2. X-ray diffraction spectra for NiCoFe/Cu/NiCoFe sandwich.

The GMR ratio is calculated by using definition, GMR ratio (%) = $\{(R_H - R_0)/R_0\}$x100%, where R_H is the resistance in presence of magnetic field and R_0 is the resistance in absence of magnetic field. Fig. 3 shows the GMR ratio curves for NiCoFe/Cu/NiCoFe sandwich with various Cu layer thickness (t_{Cu}) and fixed NiCoFe layer thickness (t_{NiCoFe} = 38.5 nm) at room temperature. The decrease in MR change with increasing t_{Cu} can be explained using the series-resistor model of Valet-Fert model under the long spin diffusion approximation [4].

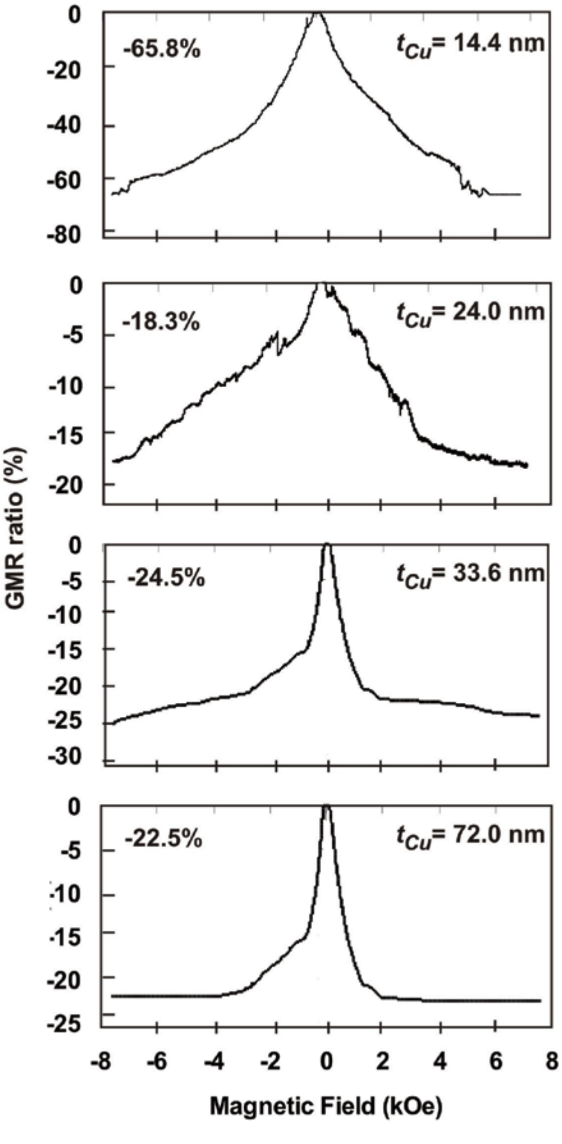

Fig. 3. GMR ratio curves at room temperature for sandwich NiCoFe (62.5 nm)/Cu (t_{Cu}) /NiCoFe (62.5 nm).

Fig. 3 also shows that the saturation field of GMR curves decrease with increasing t_{Cu}. This observation is probably due to a reduced dipole-dipole interaction between NiCoFe layers.

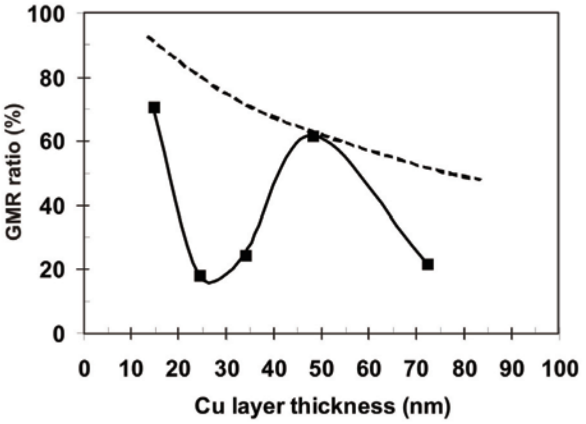

Fig. 4. Variation of magnitude of GMR ratio versus Cu layer thickness. The dotted line shows the decay of GMR ratio with increasing of Cu layer thickness.

Fig. 4 shows variation of magnitude of GMR ratio versus Cu layers thickness. Their general appearance is a classical behavior of MR evolution with magnetic field that has been observed in many multilayers [4,5,6] based on ferromagnetic transition metal and a non magnetic layers.

Mtalsi, *et.al* [5] also obtain the MR variation versus Cu layer thickness for $Ni_{80}Fe_{20}/Cu$ multilayer presents an oscillatory behavior. The oscillation reflects the exchange coupling oscillations between ferromagnetic and antiferromagnetic states. This oscillation is caused by an oscillation in the sign of the interlayer exchange coupling between ferromagnetic layers [6].

The dependence of GMR value on the non-magnetic layer thickness in magnetic multilayer and spin valves qualitatively ascribed to two factors [7], ie: (i) With increasing spacer thickness the probability of scattering increases as the conduction electrons traverse the spacer layer, which reduces the flow of electrons between the ferromagnetic layers and consequently reduces GMR. (ii) The increasing thickness of the nonmagnetic layer enhances the shunting current within the spacer, which also reduces GMR. These two contributions to GMR can be phenomenological described by the following expression:

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

The parameter l_{NM} is related to the mean free path of the conduction electrons in the spacer layer, d_{NM} is spacer layer thickness. The parameter d_0 is an effective thickness, and $(\Delta R/R)_0$ is a normalization coefficient.

The decay in GMR value with increasing Cu thickness can be described approximately by [8]:

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

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

4. CONCLUSION

The NiCoFe/Cu/NiCoFe sandwich was successful grown onto Si (111) substrates by opposed target magnetron sputtering. With this structure of material, we have successful to make material composition that has GMR ratio between 18% until 66%. The Cu layer thickness influences the GMR ratio with oscillatory behavior. The GMR ratio oscillates with increase of non magnetic (Cu) layer thickness.

Acknowledgements
This work was (partially) supported by Asahi Glass Foundation (AGF) Grant, 2008.

REFERENCES

[1]. M.N. Baibich, J.M. Broto, A. Fert, F. Nguyen Van Dau, F. Petroff, P. Eitenne, G. Creuzet, A. Friederich and J. Chazelas, "Giant Magnetoresistance of (001)Fe/(001)Cr Magnetic Superlattices", *Phys. Rev. Lett*., Vol. **61**, 2472;2475 (1988).

[2]. A. Fert, "Nobel Lecture: Origin, development, and future of spintronics", *Rev. Mod. Phys*., Vol. 80, No. 4 (2008).

[3]. M. Djamal, Ramli, Yulkifli, Kadek Juliana Parwanta, and Indra Andriana, "Deposition of Ferromagnetic (FM) and Non-Magnetic (NM) Thin Film Using Sputtering Method for The GMR Material" *Proceedings of the Second International Conference on Mathematics and Natural Science* (ICMNS 2008), Bandung, 28-30 October 2008.

[4]. X.-T. Tang, G.-C. Wang, and M. Shima, "Layer thickness dependence of CPP giant magnetoresistance ini individual CoNi/Cu multilayer nanowires grown by electrodeposition", *Phys. Rev. B* **75** 134404 (2007).

[5]. D.M. Mtalsi, M.EL Harfoui, A. Qachaou, M. Faris, J.B. Youssef and H.L. Gall, "Giant magnetoresistance in ($Ni_{80}Fe_{20}/Cu$) multilayers", *Mor .J. Condensed Matter*, Vol.**3**, No.1, 94-97 (2000).

[6]. D. Tripathy and A. O. Adeyeye, "Effect of spacer layer thickness on the magnetic and magnetotransport properties of $Fe_3O_4/Cu/Ni_{80}Fe_{20}$ spin valve structures" Phys. Rev. B **75**, 012403 (2007).

[7]. S.S.P.Parkin, "The Magic of Magnetic Multilayers", *IBM Journal of Research and Development*; Vol.**42**, No.**1**, pp.3 -6 (1998).

[8]. Tsymbal.E.Y and D.G.Pettifor (2001). *Perspectives of Giant Magnetoresistance*, in Solid State Physics, ed. by H. Ehrenreich and F. Spaepen, Vol. **56** , Academic Press, 2001, pp.113-237.

[9]. S.S.P. Parkin, *Ultrathin Magnetic Structures II*, Springer-Verlag Berlin Heidelberg, **Chapter 2.4**, pp.148-194 (1994).

Corresponding author:
MITRA DJAMAL
Theoretical High Energy Physics and Instrumentation Research Group, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung,
Jl. Ganesa 10, Bandung 40132. Indonesia, Tel (+62 22) 2500834, Fax (+62 22) 2506452
E-mail: mitra@fi.itb.ac.id