*Vol. 5, No. 1, Oktober 2003, hal : 24 - 28*
*ISSN : 1411-1098*

# STRUCTURAL AND MAGNETIC PROPERTIES OF Fe/Si MULTILAYER GROWN BY HELICON PLASMA SPUTTERING

**Setyo Purwanto[1], Isao Sakamoto[2], M. Koike[2] and H. Tanoue[2]**
*[1]R&D Centre for Materials Science and Technology-BATAN*
*Kawasan Puspiptek, Serpong, Tangerang 15314*
*[2]Photonics Research Institute,*
*AIST-JAPAN*

## ABSTRACT

**STRUCTURAL AND MAGNETIC PROPERTIES OF FE/SI MULTILAYER GROWN BY HELICON PLASMA SPUTTERING.** Helicon plasma sputtering method has been used to grown the Fe/Si multilayer (MLs) with various thickness of Silicon spacer around 0.5 ~ 2nm for Fe thickness fixed at 2nm in order to investigated the antiferromagnetic coupling behaviour. Also we grown the MLs with various Fe thickness around 2-5nm for Silicon spacer fixed at $t_{Si}$ =1nm and 1.5nm. Present study found that in case of Silicon spacer thickness $t_{Si}$=1nm multilayer film exhibit antiferromagnetically ordering, beside this thickness the MLs are ferromagnetic. The maximum magnetoresistance ratio is 0.22%, it appears at the Fe thickness $t_{Fe}$=3nm and Si thickness $t_{Si}$=1nm.

***Key words*** : Fe/Si Multilayer, structural and magnetic properties, helicon plasma Sputtering, magnetoresistance

## ABSTRAK

**SIFAT STRUKTUR DAN MAGNETIK MULTILAPISAN Fe/Si YANG DITUMBUHKAN DENGAN *SPUTTERING* PLASMA HELICON** . Lapisan tipis banyak lapis Fe/Si telah ditumbuhkan dengan memanfaatkan teknik *sputtering plasma Helicon* dengan variasi tebal lapisan *spacer* Si antara 0,5~2nm untuk tebal lapisan Fe 2nm. Kondisi ini dibuat untuk mempelajari kelakuan kopling antiferomagnetik antar lapisan Fe. Telah dibuat juga lapisan tipis Fe/Si dengan variasi tebal lapisan Fe antara 2~5nm untuk tebal *spacer* Si tetap $t_{Si}$ =1nm dan 1,5 nm. Hasil studi kali ini menunjukkan bahwa hanya pada ketebalan *spacer* Si, $t_{Si}$=1nm lapisan tipis Fe/Si dengan ketebalan Fe=2nm memiliki sifat antiferomagnetik, selain itu bahan bersifat feromagnetik. Hasil pengukuran sifat *magnetoresistance*(MR) menunjukkan bahwa rasio MR berharga tertinggi yaitu 0,22% pada ketebalan lapisan Fe $t_{Fe}$=3nm dan Si *thickness* $t_{Si}$=1nm.

***Kata kunci*** : Lapisan tipis banyak lapis Fe/Si, struktur dan sifat magnetik, sputtering plasma helicon, magnetoresistance

## INTRODUCTION

Since the evidence of Giant Magnetoresistance phenomenon in Fe/Cr multilayer was found at 1988 by Baibitch et.al [1], investigation on this kind of materials growing rapidly. There have many interesting behaviour been appear when the spacer between Fe film substitute by non metallic materials likes Silicon. Fullerton et.al [2] investigate the strong Antiferromagnetic(AF) coupling in sputtered multilayer for Fe(3nm)/Si(1.5nm) with switching fields of 6 kOe, at room temperature. In this case the interlayer was found to be a crystalline interdiffused Fe-Si alloy. Furthermore, Inomata et.al [3] at 1995, were determined the existence of two different types antiferromagnetic(AF) interlayer coupling as a function of Si layer thickness. First kind was appear at multilayer Fe(2.6nm)/Si(1.2nm), with the MR ratio 0.14% at room temperature. The second kind has shown at Si thickness $t_{Si}$=2.5nm with MR ratio value around 0.1% at room temperature. Recently, Tong et.al [4] have observed the dependence of magnetoresistance ratio to the Si thickness $t_{Si}$ on Fe(<2nm)/Si for $t_{Si}$=0.5~4nm, and to the Fe thickness $t_{Fe}$ on Fe/Si(1.9nm) for $t_{Fe}$=1 ~ 14nm. Also, Sakamoto et.al [5] have grown Fe/Si Mls by using Helicon Plasma Sputtering and studied its structural and magnetic properties.

In this paper we present the results study on the structure, magnetic and magnetoresistance properties of multilayer Fe/Si grown at ambient temperature by Helicon Plasma Sputtering method [6]. In order to investigate the interlayer coupling behaviour between Fe layer through Silicon spacer, we prepared some multilayer with various Silicon thickness $t_{Si}$=0.5 ~ 2nm at fixed Fe thickness $t_{Fe}$=2nm. Furthermore to found the

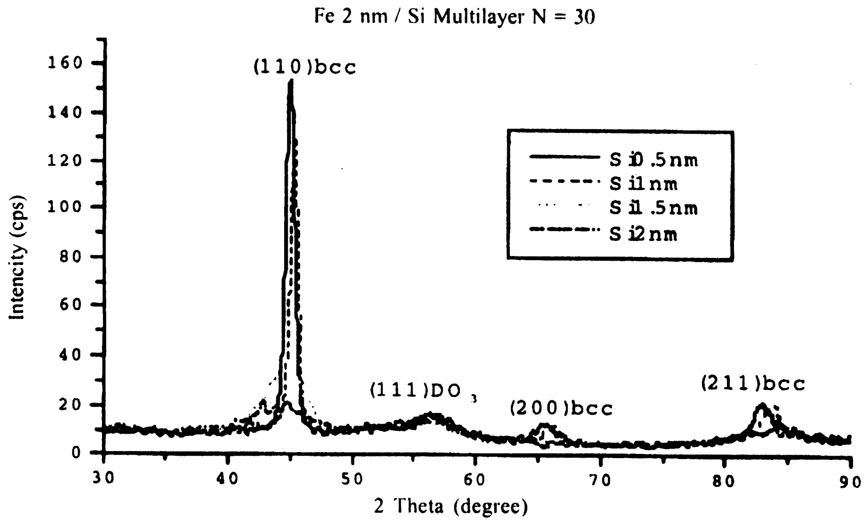


***Figure 1.*** Si layer thickness dependence of X ray diffraction pattern at RT. The peaks of (110), (200) and (211) are belong to Fe-bcc. The (111) peak is belong to $DO_3$ interfacial phase.

behaviour of magnetoresistance some multilayer have grown at various thickness Fe $t_{Fe}$=2 ~ 5nm at fixed Silicon thickness $t_{Si}$=1nm and 1.5nm.

## EXPERIMENTAL DETAILS

Several series of Fe/Si multilayer (MLs) as mentioned above have deposited on Si(100) at ambient temperature by Helicon plasma sputtering method. The vacuum had base pressure of the chamber lower than $1x10^{-7}$ Torr. The target size is 50mm diameter. The substrate can be rotated during deposition to get uniform layer. An Argon gas pressure has maintained at around $6.7x10^{-4}$ Torr. The multilayer structure was achieved by alternately exposing the substrate to Fe or Si target controlled by computer. Deposition rate of Si and Fe were controlled to be 0.05nm/sec and 0.075nm/sec, respectively. Structural of multilayers were determined by X ray diffraction with Cu source. The films were cute with area of $10x10mm^2$ to measure the hysterisis curve by Vibrating sample magnetometer up to H=15kOe. The magnetoresistance behaviour was performed by dc four point probe method with field up to H=15kOe.

## EXPERIMENTAL RESULTS AND DISCUSSION

### Silicon Spacer Thickness Dependence

The first series of $[Fe(2nm)/Si(t_{Si})]_{30}$ multilayer were prepared with various Si layer thickness $t_{Si}$=0.5~2.0 nm, for investigating the Si layer thickness dependence of structural, magnetic properties and magnetoresistance. From Figure 1., It is clear the peaks of Fe-bcc strongly depend to Silicon spacer thickness, in while the (111) peak of $DO_3$ phase belong to spacer layer relatively not.

The existence of $DO_3$ phase was appear for all Si thickness might be related to interdiffusion between Fe and Silicon layer as report elsewhere [7]. The crystalline size of Fe/Si MLs estimated from the Fe (110) using Scherer formula[8] are 9.4, 10.8, 1.5 and 1.8nm for Silicon thickness 0.5, 1.0, 1.5 and 2.0nm respectively. The large grain size was indicated that only few intermixing between Fe and Si occurs, while for small one Fe and Si there were mixed more.

Our magnetization measurement results were confirm that only at Si thickness $t_{Si}$=1.0nm multilayer exhibiting Antiferromagnetic(AF) coupling as shown in Figure 2.

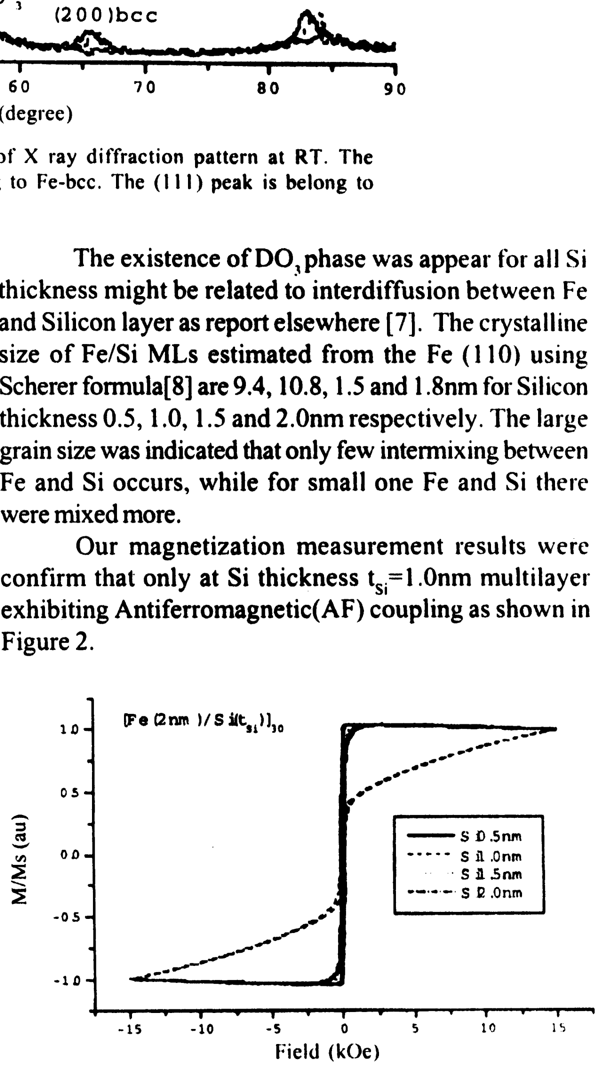


***Figure 2.*** In-plane magnetization curve for $[Fe(2nm)/Si(t_{Si})]_{30}$ MLs at RT.

Characteristic features of Antiferromagnetic(AF) coupled multilayer in-plane hysterisis loops have a large saturation field Hs and low remanence Mr relative to Ms, as summarized from Figure 2 and shown in Figure 3. There is a peak in Hs and low remanence Mr for Silicon thickness $t_{Si}$=1.0nm clearly due to AF coupling, besides of this thickness no evidence of additional AF behaviour. The strength of AF coupling J, was determined from

Vol. 5, No. 1, Oktober 2003, hal : 24 - 28
ISSN : 1411-1098

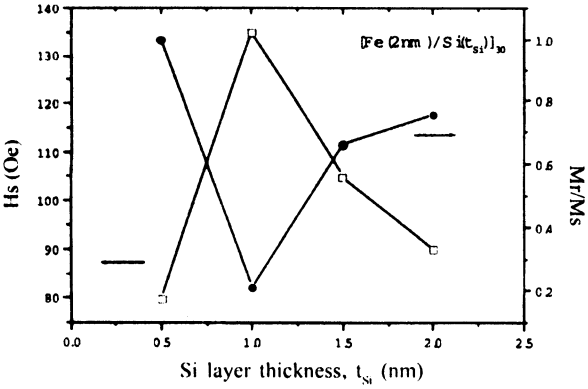


***Figure 3.*** Squareness ratio, Mr/Ms and saturation field,Hs determined at RT from in-plane magnetic hysterisis loops vs. Silicon thickness, $t_{Si}$ for $[Fe(2nm)/Si(t_{Si})]_{30}$ MLs.

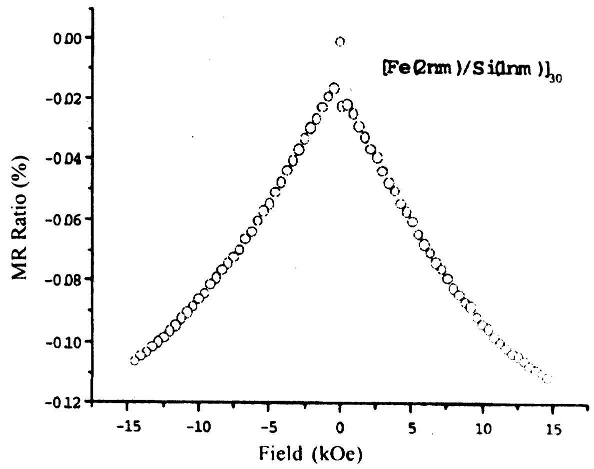


***Figure 4.*** In Plane Magnetoresistance ratio for $[Fe(2nm)/Si(1nm)]_{30}$ MLs at room temperature.

equation $J = Hs.Ms.t_{Fe}/4$ become around 0.005erg/cm$^2$. This value was consistent with prediction by P. Bruno et.al [9] for interlayer magnetic coupling between ferromagnetic films separated by an insulating layer.

Magnetoresistance measurement were performed by using dc-four point probe with film surface parallel to H applied up to H=15kOe at RT. Figure 4 was shown in plane magnetoresistance ratio for $[Fe(2nm)/Si(1nm)]_{30}$ MLs at room temperature.

## Fe Layer Thickness Dependence

We have grown two series Fe layer thickness dependence, first is $[Fe(t_{Fe})/Si(1nm)]$ MLs and the second series is $[Fe(t_{Fe})/Si(1.5nm)]$ MLs for $t_{Fe}$=2~5nm. The total thickness of Fe layer was fixed at around 60nm. As already mentioned above, only at Silicon thickness $t_{Si}$=1.0nm multilayer exhibiting Antiferromagnetic coupling. Therefore in present we discuss rather detail on the result of that series.

Figure 5 was shown that X-ray diffraction pattern of $[Fe(t_{Fe})/Si(1nm)]$ MLs taken at Cu Ka wavelength. From the pattern that is clear if multilayer grown on (110) Fe texture with spacer layer also became crystalline as indicate by existence of superlattices peak at low angle scattering.

Figure 6. have shown some summarized of field saturation Hs, saturated magnetization Ms, squareness ratio Mr/Ms and calculated exchange interlayer coupling J, for $[Fe(t_{Fe})/Si(1nm)]$ MLs. It is clear that with increasing Fe layer thickness, multilayer become strongly exhibiting antiferromagnetic as indicated with the linier increase of saturation field,Hs, decreasing of squareness Mr/Ms ratio also the exchange interlayer coupling became strength.

There is any interesting result evidence from Fe layer thickness dependence of magnetoresistance properties at this system as shown in Figure 7. Magnetoresistance ratio value have increased up to 0.22% at Fe thickness,$t_{Fe}$=3.0nm and then decrease monotically while Fe layer thickness increase.

This phenomenon of the dependence of magnetoresistance ratio in this system may be can 0 be explain by phenomenological equation as proposed by Dieny et.al [10], as follow;

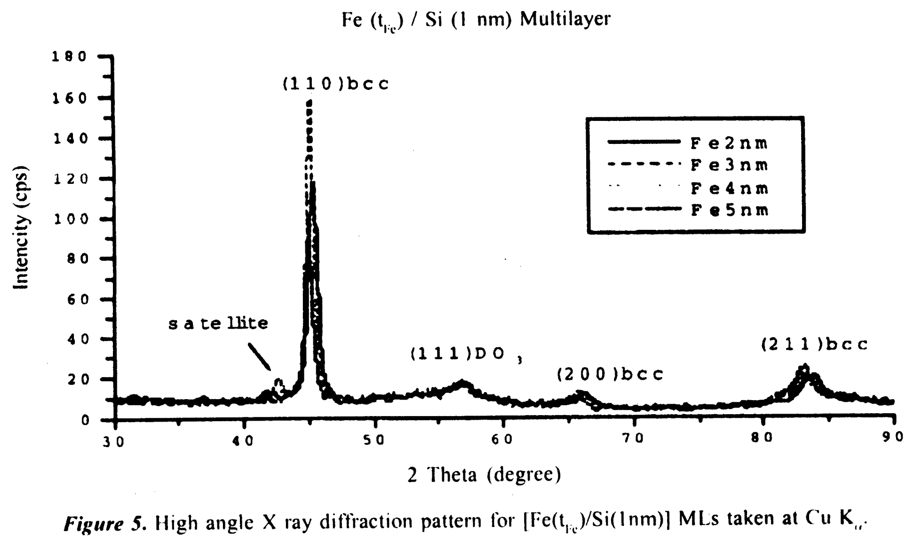


***Figure 5.*** High angle X ray diffraction pattern for $[Fe(t_{Fe})/Si(1nm)]$ MLs taken at Cu $K_{\alpha}$.

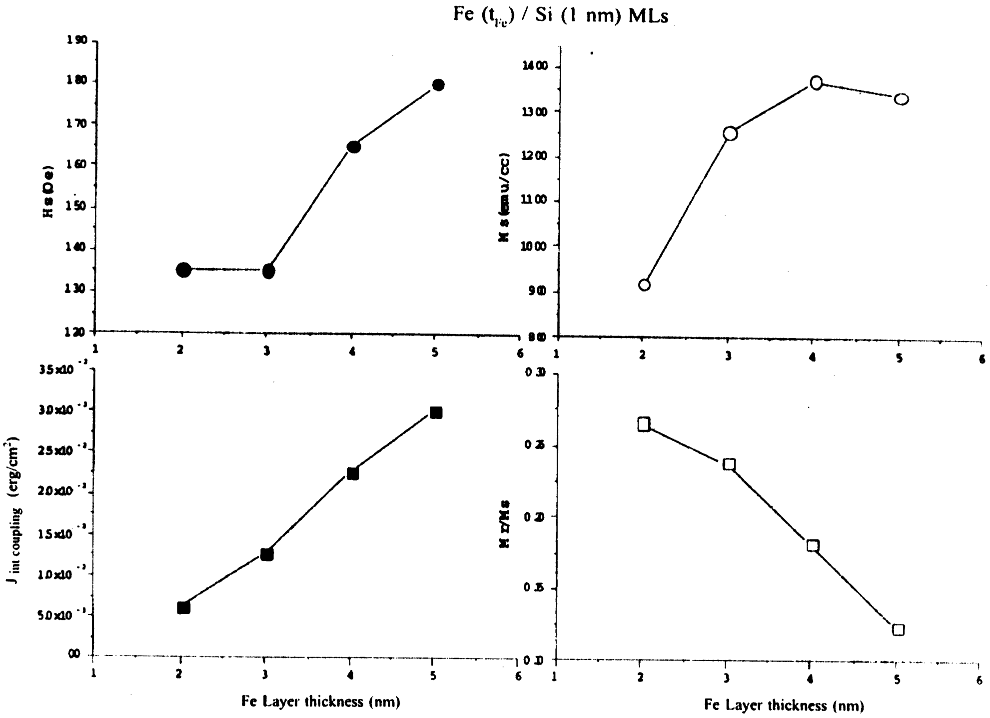


***Figure 6.*** Field saturation Hs, saturated magnetization Ms, squareness ratio Mr/Ms and calculated exchange interlayer coupling J, for [Fe($t_{Fe}$)/Si(1nm)] MLs were derived from in plane magnetization curve taken at room temperature.

$$GMR(t_{Fe}) = (DR/R)_0 \, [1-\exp(-t_{Fe}/l_{Fe})]/(1+t_{Fe}/t_0) \quad \text{.............(1)}$$

The factor $[1-\exp(-t_{Fe}/l_{Fe})]$ is the angle averaged probability for an electron of the type with largest mean free path to scattered within the Fe layer before being scattered diffusely at the outer boundary. This factor explain the fact that if the Fe layer are too thin, the contrast between mean free paths for both spin directions will reduced, because the longer of both mean free paths is lowered by the diffuse scattering at the other boundaries, so that the MR ratio is lowered. The denominator expresses the shunting effect due to the Fe layer.

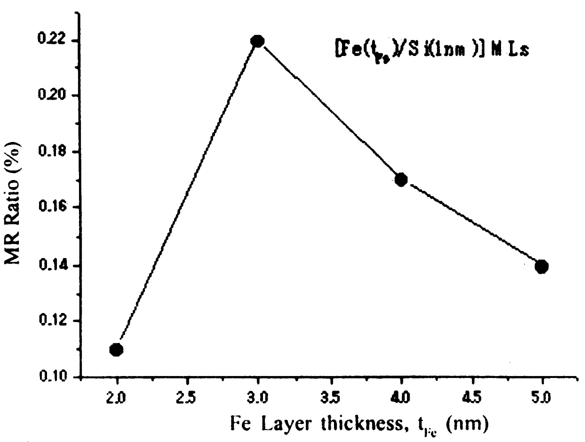


***Figure 7.*** Fe 0layer thickness dependence of magnetoresistance ratio for [Fe($t_{Fe}$)/Si(1nm)] MLs taken at room temperature.

## SUMMARY

We have develop Fe/Si multilayer by using Helicon plasma sputtering and studied its structural, magnetic and transport properties. We found that for $[Fe(2nm)/Si(t_{Si})]_{30}$ multilayer exhibiting antiferromagnetic only when Silicon thickness $t_{Si}$=1.0nm. Magnetoresistance properties in the case of [Fe($t_{Fe}$)/Si(1nm)] Mls became maximum when Fe thickness $t_{Fe}$=3nm, with Mr ratio 0.22%.

## ACKNOWLEDGEMENTS

This work was supported by National Institute of Advanced Industrial Science and Technology under the Scientist Exchange Program in Nuclear Energy Research of the Science and Technology Agency Government of Japan. I am very grateful to Dr. Isao Sakamoto for fruitful support, help and valuable discussions, and thank to Dr. H. Tanoue, for ion beam and RBS experiments, Dr. Koike for prepared samples by Helicon plasma sputtering and Prof. N Hasashi, for RBS measurement.

## REFERENCES

[1]. M.N. BAIBITCH, J.M. BROTO, A. FERT, F. NGUYEN VAN DAU, F. PETROFF, P. ETIENNE, G. CREUZET, A. FREIDERICH, J. CHAZELAS, *Phys. Rev. Lett.* **61**, (1988) 2472 2472

*Vol. 5, No. 1, Oktober 2003, hal : 24 - 28*
*ISSN : 1411-1098*

[2]. E.E. FULLERTON, J.E. MATTSON, S.R. LEE, C.H. SOWERS, Y.Y. HUANG, G. FELCHER, S.D. BADER, *J. of Magn. And Magn. Matter.* **117**, (1992) L301

[3]. K. INOMATA, K. YUSU, Y. SAITO, *Physical Rev. Lett.* **74**(10), (1995) 1863

[4]. L.N. TONG, M.H. PAN, J. WU, X.S. WU, J. DU, M. LU, D. FENG, H.R. ZHAI, H. XIA, *Eur. Phys. J. B 5,* **61** (1998)

[5]. I. SAKAMOTO, S. HONDA, H.L. SHEN, M. KOIKE, H. TANOUE, *Phys. Stat. Sol.* (a)**189**(3), (2002) 72

[6]. M. KOIKE, M. CHIWAKI, ISAO H. SUZUKI, N. KOBAYASHI, *Rev. Sci. Instrum.* **66**(2), (1995) 2141

[7]. A. CHAIKEN, R.P. MICHEL, M.A. WALL, *Phys. Rev. B.* **53**(9), (1996) 5518

[8]. B.D. CULLITY, *Elements of X-ray Diffraction*, Addison Wesley, (1978) 101

[9]. P. BRUNO, *Phys. Rev. B.* **49**(18), (1994) 13231

[10]. B. DIENY, P. HUMBERT, V.S. SPERIOSU, S. METIN, B.A. GURNEY, P. BAUMGART, H. LEFAKIS, *Phys. Rev. B.* **45**(2), (1992) 806