

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

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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 $t_{Si} = 1$ nm and 1.5nm. Present study found that in case of Silicon spacer thickness $t_{Si} = 1$ nm 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 $t_{Fe} = 3$ nm and Si thickness $t_{Si} = 1$ nm.

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 antiferromagnetik antar lapisan Fe. Telah dibuat juga lapisan tipis Fe/Si dengan variasi tebal lapisan Fe antara 2~5nm untuk tebal *spacer* Si tetap $t_{Si} = 1$ nm dan 1,5 nm. Hasil studi kali ini menunjukkan bahwa hanya pada ketebalan *spacer* Si, $t_{Si} = 1$ nm lapisan tipis Fe/Si dengan ketebalan Fe=2nm memiliki sifat antiferromagnetik, selain itu bahan bersifat ferromagnetik. Hasil pengukuran sifat *magnetoresistance*(MR) menunjukkan bahwa rasio MR berharga tertinggi yaitu 0,22% pada ketebalan lapisan Fe $t_{Fe} = 3$ nm dan Si *thickness* $t_{Si} = 1$ nm.

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 $t_{Si} = 2.5$ nm 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 $t_{Si} = 0.5 \sim 4$ nm, and to the Fe thickness t_{Fe} on Fe/Si(1.9nm) for $t_{Fe} = 1 \sim 14$ nm. 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 $t_{Si} = 0.5 \sim 2$ nm at fixed Fe thickness $t_{Fe} = 2$ nm. Furthermore to found the

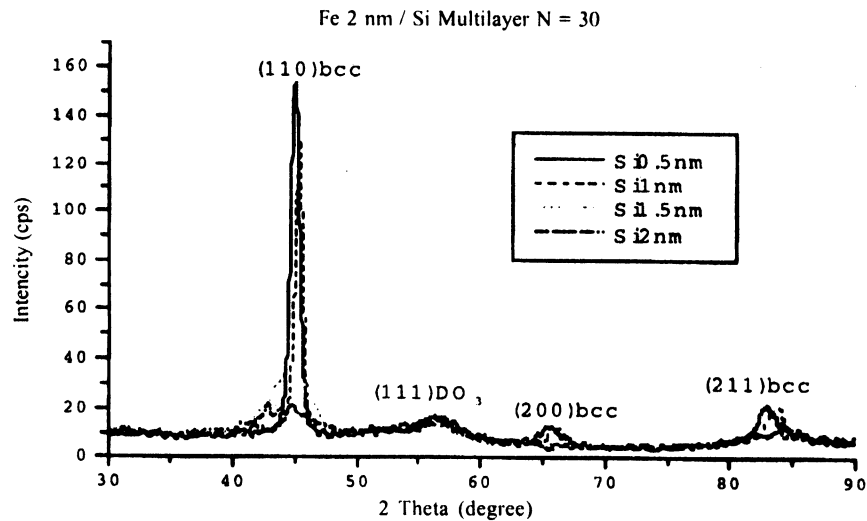


Figure 1. Si layer thickness dependence of X ray diffraction pattern at RT. The peaks of (110), (200) and (211) are belong to Fe-bcc. The (111) peak is belong to DO_3 interfacial phase.

behaviour of magnetoresistance some multilayer have grown at various thickness $t_{Fe}=2 \sim 5$ nm at fixed Silicon thickness $t_{Si}=1$ nm 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 1×10^{-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 6.7×10^{-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 cut with area of 10×10 mm² to measure the hysteresis curve by Vibrating sample magnetometer up to $H=15$ kOe. The magnetoresistance behaviour was performed by dc four point probe method with field up to $H=15$ kOe.

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 $t_{Si}=0.5 \sim 2.0$ 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 $t_{Si}=1.0$ nm multilayer exhibiting Antiferromagnetic(AF) coupling as shown in Figure 2.

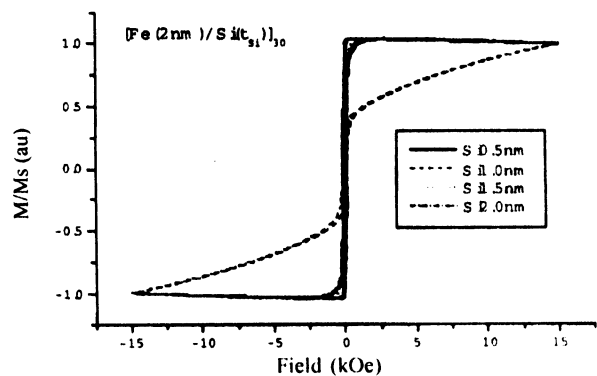


Figure 2. In-plane magnetization curve for $[Fe(2nm)/Si(t_{Si})]_{30}$ MLs at RT.

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

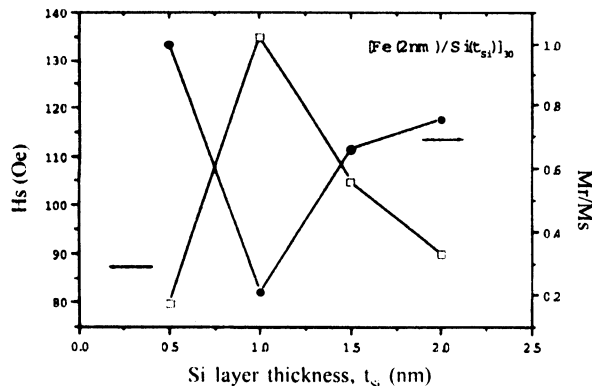


Figure 3. Squareness ratio, Mr/M_s and saturation field, H_s determined at RT from in-plane magnetic hysteresis loops vs. Silicon thickness, t_{Si} for $[Fe(2nm)/Si(t_{Si})]_{30}$ MLs.

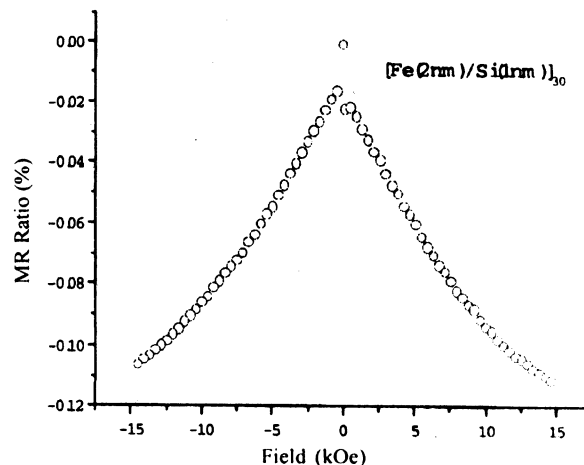


Figure 4. In Plane Magnetoresistance ratio for $[Fe(2nm)/Si(1nm)]_{30}$ MLs at room temperature.

equation $J=H_s.M_s.t_{Fe}/4$ become around $0.005\text{erg}/\text{cm}^2$. 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 $H=15\text{kOe}$ 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 $t_{Fe}=2\sim 5\text{nm}$. The total thickness of Fe layer was fixed at around 60nm . As already mentioned above, only at Silicon thickness $t_{Si}=1.0\text{nm}$ 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 $K\alpha$ 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 H_s , saturated magnetization M_s , squareness ratio Mr/M_s 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, H_s , decreasing of squareness Mr/M_s 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, $t_{Fe}=3.0\text{nm}$ and then decrease monotonically 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 Diény et.al [10], as follow;

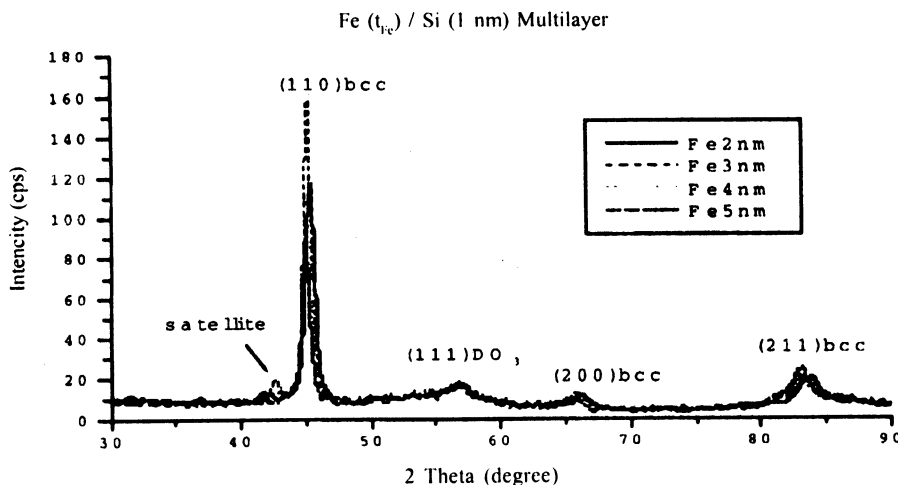


Figure 5. High angle X ray diffraction pattern for $[Fe(t_{Fe})/Si(1nm)]$ MLs taken at Cu $K\alpha$.

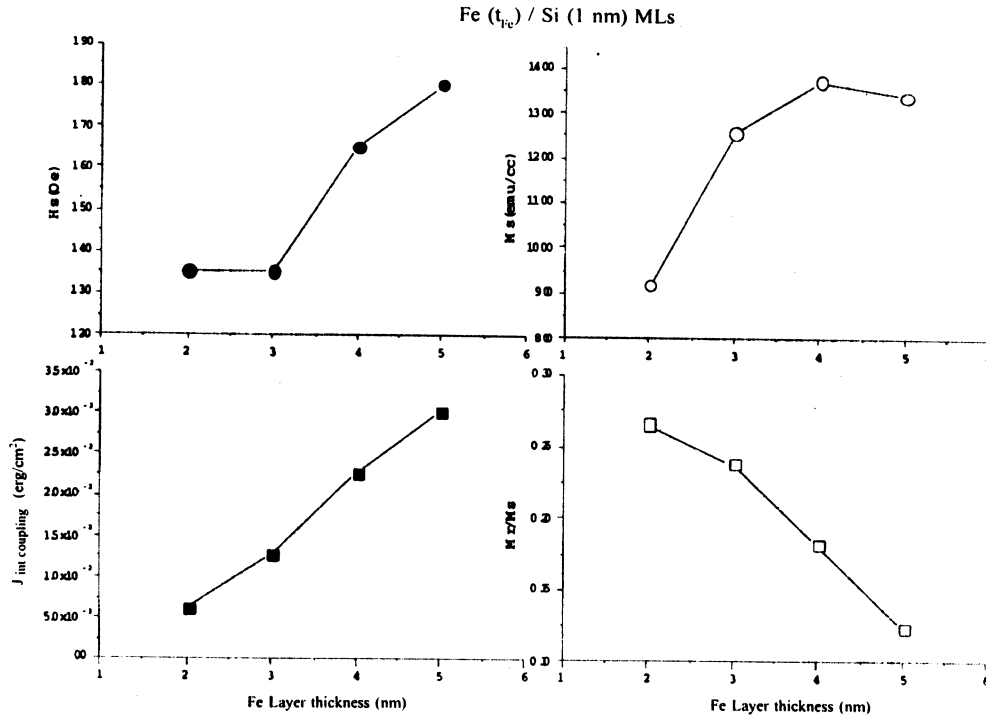


Figure 6. Field saturation H_s, saturated magnetization M_s, squareness ratio Mr/M_s and calculated exchange interlayer coupling J, for [Fe(t_{Fe})/Si(1nm)] MLs were derived from in plane magnetization curve taken at room temperature.

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

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.

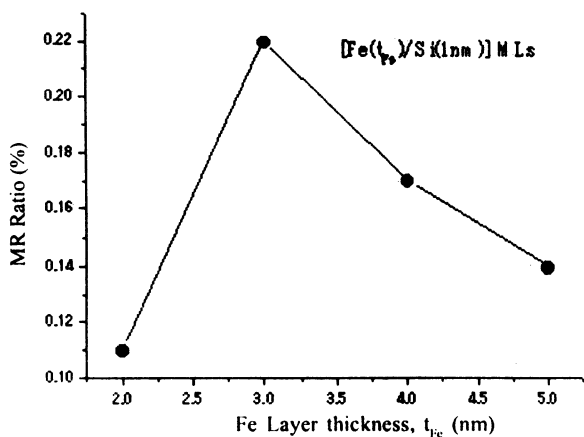


Figure 7. Fe Olayer thickness dependence of magnetoresistance ratio for [Fe(t_{Fe})/Si(1nm)] MLs taken at room temperature.

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%.

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