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MAGNETIC AND STRUCTURAL STUDIES OF FeSi MULTILAYERS IRRADIATED BY ARGON IONS

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ABSTRACT

MAGNETIC AND STRUCTURAL STUDIES OF FeSi MULTILAYERS IRRADIATED BY ARGON IONS. We prepared Fe/Si multilayers (MLs) by helicon plasma sputtering to investigate the antiferromagnetic couplings (AFC) between Fe layers sandwiched by Si spacers. [Fe (2nm)/Si (1.5nm)]$_{30}$ MLs showed the ferromagnetic couplings (FC). The ion irradiation by 400 keV Ar ions was performed to [Fe (2nm)/Si (1.5nm)]$_{30}$ MLs using AIST 400 keV ion implanter. The magnetic and structural properties were investigated by Vibrating Sample Magnetometer (VSM) and Conversion Electron Mössbauer Spectroscopy (CEMS). The value of saturation magnetization in as-deposited [Fe (2nm)/Si (1.5nm)]$_{30}$ MLs is smaller than that of bulk α-Fe (1700 emu at RT). This decrease of saturation magnetization implies an atomic mixing in the interface region. The values of saturation magnetization decrease with increasing Ar ion dose. The CEMS spectrum of [Fe (2nm)/Si (1.5nm)]$_{30}$ MLs shows the doublet peaks overlapped with broad sextet peaks. The doublet peaks correspond to nonmagnetic $Fe_{1-x}Si_x$ phases formed in the interface region. On the other hand, the distribution of hyperfine fields (H_{hf}) was estimated from broad sextet peaks and smaller values of Hhf correspond to ferromagnetic $Fe_{1-x}Si_x$ phases. The amounts of nonmagnetic $Fe_{1-x}Si_x$ phases in CEMS spectra seem not to change with increasing Ar ion dose but the values of H_{hf} decrease with increasing Ar ion dose. These results indicate the peculiar atomic mixing by Ar ion irradiation in the interface region.

Kata kunci : FeSi Multilayers, magnetic, irradiated by argon ions

ABSTRAK

STUDI STRUKTUR DAN MAGNETIK MULTI LAPISAN FeSi YANG DI IRADIASI DENGAN ION ARGON. Telah dipersiapkan cuplikan multi lapisan tipis FeSi dengan menggunakan teknik *sputtering* dari plasma *helicon* untuk menyelidiki perilaku kopling antiferomagnetik antara lapisan Fe pada *sandwiched* dengan silikon sebagai *spacers* (lapisan pemisah). Pada cuplikan [Fe (2nm)/Si (1.5nm)]$_{30}$ memperlihatkan bahwa kopling antara lapisan Fe bersifat feromegnetik. Untuk mengetahui pengaruh iradiasi ion, dilakukan pula iradiasi ion Argon pada tingkat energi 400 keV di AIST Japan. Kemudian pada cuplikan tadi diteliti sifat magnet dengan VSM (*Vibrating Sample Magnetometer*) dan CEMS (*Convertion Electron Mössbauer Spectroscopy*). Dari pengukuran dengan VSM diketahui magnetisasi jenuh pada *as-deposit* [Fe (2nm)/Si (1.5nm)]$_{30}$ terlihat lebih kecil dibanding dengan *bulk* α-Fe (1700 emu pada suhu kamar). Diduga harga yang lebih kecil dari magnetisasi jenuh terkait dengan peristiwa *atomic mixing* pada daerah antar muka antara lapisan Fe dan Si. Harga magnetisasi jenuh terus berkurang sejalan dengan peningkatan dosis dari ion Argon. Dari data CEMS diketahui perilaku spektrum dari [Fe (2nm)/Si (1.5nm)]$_{30}$ memperlihatkan adanya *peak doublet* yang berhimpitan dengan *peak sextet* . Diketahui *peak doublet* berkaitan dengan keberadaan fasa nonmagnetik $Fe_{1-x}Si_x$ pada daerah antar muka. Sebaliknya, distribusi medan *hyperfine* (H_{hf}) dapat diestimasi dari *peak sextet* dan harga H_{hf} yang kecil berkaitan denagn keberadaan fasa feromagnetik $Fe_{1-x}Si_x$. Diketahui pula populasi fasa nonmagnetik $Fe_{1-x}Si_x$ pada spektrum CEMS tidak berubah dengan peningkatan dosis iradiasi ion Argon, tetapi harga H_{hf} menurun dengan peningkatan dosis ion Argon. Disini dapat disimpulkan telah terjadi peristiwa *atomic mixing* (pertukaran atom) yang *peculiar* (tidak biasa) pada daerah antar muka FeSi ketika dikenakan iradiasi ion Argon.

Key words : Multi lapisan FeSi, magnetik, iradiasi ion Argon

INTRODUCTION

Since the first observation Antiferromagnetic Coupling (AFC) of Fe film separated by Cr or Au by Grunberg et.al[1], interlayer exchange interaction between ferromagnetic layer separated by a non magnetic spacer become a subject of intensive observation. Especially after the evidence of GMR phenomenon in Fe/Cr metallic multilayers(MLs) was found in 1988 by Baibich et.al[2], and discovery by Parkin et.al[3], of the oscillations of the interlayer exchange coupling (IEC) in Fe/Cr/Fe and Co/Ru/Co multilayer, as a function of spacer thickness.

Recently, many interesting phenomena were observed when the metallic spacers between Fe film was substituted by insulator material like Silicon. Strijkers et.al[4] investigated that the formation of a non magnetic phase between Fe and Si layer in Fe/Si/Fe(100) trilayer with crystalline structure of CsCl is responsible for the exponentially decay of AFC while Silicon thickess increase.

Furthermore, Gareev et.al[5] determined the existence of oscillatory interlayer coupling across FeSi spacers layers in Fe/$Fe_{0.56}Si_{0.44}$/Fe trilayers with two maxima AFC as a function of Silicon layer thickness. The first one appeared for Silicon layer thickness t_{Si}=1.2nm, while the second maxima was observed at Silicon thickness 2.6nm. Later, Gareev et.al[6,7] also shown in trilayer of Fe/$Fe_{1-x}Si_x$-wedge/Fe and Fe/$Fe_{0.5}Si_{0.5}$/Si-wedge/$Fe_{0.5}Si_{0.5}$/Fe five layer structure, the coupling strength increases strongly with increasing nominal Silicon content the spacers layer.

That picture above mentioned, according to the theory of interlayer exchange coupling (IEC) with quantum interference model proposed by Bruno [8], IEC become decay for insulator layer spacer and oscillatory coupling for metallic spacer. However, in the case of $Fe_{1-x}Si_x$ phase of Fe/Si multilayer induced by interdiffusion are still un-clear.

In this paper we report the result of magnetic and structural properties in Fe/Si MLs especially in Fe(2nm)/Si(1.5nm) MLs and the effect of ion Argon irradiation on interfacial structure of Fe/Si ML may can induced the IEC and the non magnetic phase $Fe_{1-x}Si_x$.

EXPERIMENTAL

Two series of $[Fe(t_{Fe}=2nm)/Si(t_{Si})]_{30}$ with t_{Si}=1.0 and 1.5nm have been deposited on high resistivity n-type Si(100) substrates by Helicon plasma sputtering. The basic pressure of the chamber was lower than $1x10^{-7}$ Torr. The target size is 50mm in diameter. The substrate can be rotated during deposition to get uniform layer. The Argon gas pressure has maintained $6.7x10^{-4}$Torr. The multilayer structure was achieved by alternating exposing the substrate to Fe or Si target. The deposition rates of Fe and Si were 0.05nm/s and 0.067 nm/s, respectively. Total layer thickness is 60nm.

The 400keV Ion Argon irradiation were performed at doses between $3x10^{13}$ ~ 1 $x10^{15}$ ions/cm^2, to study the effect of ion irradiation on interfacial Fe/Si MLs.

The structure study was performed by XRD using Cu-Ka radiation. The film were cut into the area 10x10mm^2 for measurement magnetization curve up to H=15kOe at RT by Vibrating Sample Magnetometer (VSM).

Conversion Electron Mossbauer Spectroscopy (CEMS) by Mossbauer Spectrometer with 740 MBq ^{57}Co γ-ray source (Rh-matrix) and conversion electron were detected with a proportional counter flowed with He + 10% CH_4 mixture gas.

Rutherford backscattering (RBS) measurements were carried out with 2MeV He^+ using a geometry 165^0 to determine the atomic composition. The RBS analysis was performed with the SIMNRA software.

RESULT AND DISCUSSION

Magnetization Curve

We have prepared two series of samples i.e Fe(2~5nm)/Si(1nm) MLs and Fe(2~5nm)/Si(1.5nm) MLs. The first series have already reported elsewhere[9], where only in case t-=1nm, Fe/Si MLs exhibit Antiferromagnetic nature.

Present we concentrated to analysis the second series, especially on Fe(2nm)/Si(1.5nm) MLs where exhibit Ferromagnetic coupling nature and performed ion Argon irradiation in order to understand the effect of interdiffusion at interfacial region.

From Figure 1a., show the in-plane and perpendicular magnetization curves before ion irradiation. It is clear the interlayer echange coupling(IEC) between Fe layer is Ferromagnetic Coupling (FC). But the value of Saturate Magnetization (Ms) was lower than a-Fe (~1700emu/cc), this situation is represent the existence of atomic mixing between Fe and Si layer at interfacial region.

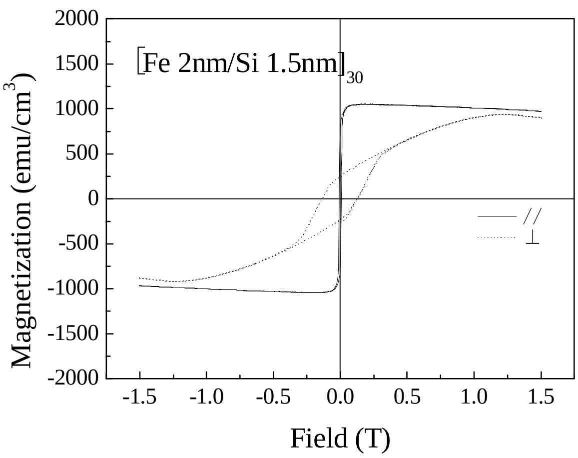

Figure 1a. M-H Curve of as deposit Fe2nm/Si1.5nm MLs

For Fe(2nm)/Si(1.5nm) MLs, Figure 1b. shows the dependence of the value Ms on ion doses. It is clear that the value of Ms decrease when the ion dose increase.

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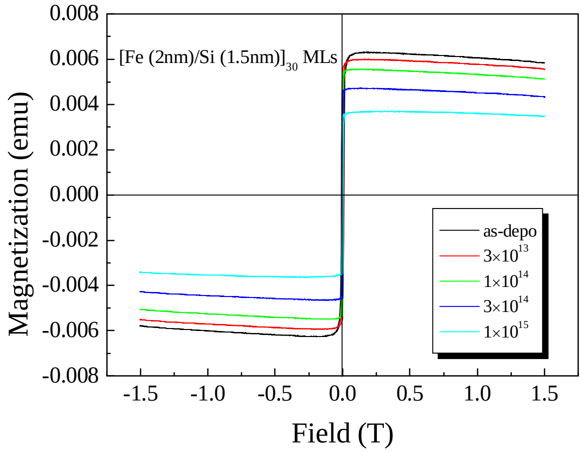

Figure 1b. M-H Curve of Post Irradiated Fe2nm/Si1.5nm

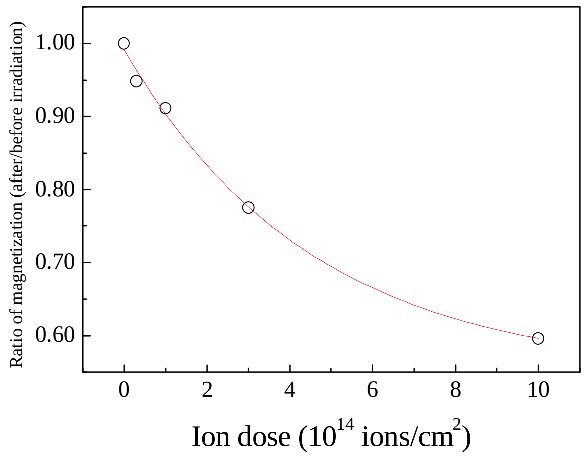

Figure 1c. Ion dose dependence of Fe2nm/Si1.5nm

Summary of the behavior was shown in Figure 1c. ,the ratio of magnetization value after and before irradiation taken exponentially decrease while ion dose increase. This reduction behavior of Ms was represent the mechanism of atomic mixing between Fe and Si layer and interdiffusion at interfacial region during the ion irradiation.

CEMS Spectrums

Figure 2a. shown CEMS spectrum of Fe(2nm)/Si(1.5nm) Mls before ion irradiation. In this figure doublet peak overlapped with sexteth peaks. In this case doublet peak was represent to the non-magnetic phase of $Fe_{1-x}Si_x$ at interfacial region. This spectrums character was different with CEMS spectrum for Fe(2nm)/Si(1nm) MLs, while reported elsewhere by Sakamoto et.al [10]. It was fitted by singlet peak overlapped with sexteth peak and coincidence with isomer shift of CsCl-type FeSi as reported by Fanciulli et.al[11].

Figure 2b. shown that the intensity of doublet peak at CEMS spectrum of Fe(2nm)/Si(1.5nm)

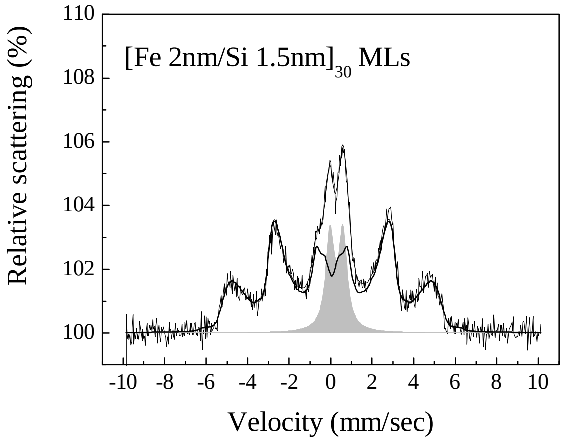

Figure 2a. CEMS spectrum of as deposited Fe 2nm/Si 1.5nm MLs

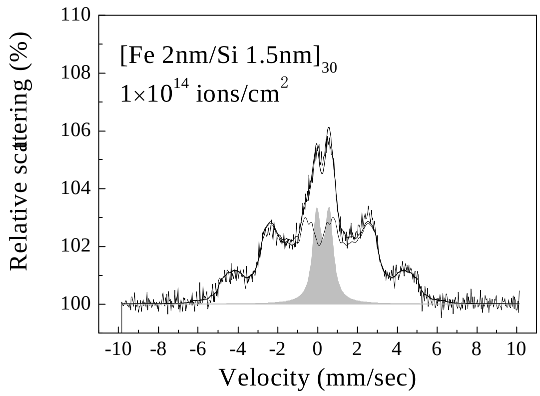

Figure 2b. CEMS spectrum of Post Irradiated Fe 2nm/Si 1.5nm MLs

Mls has not changed after irradiation by ion Argon 400keV. This fact was represented that the amount of non magnetic phase $Fe_{1-x}Si_x$ at interface region not dependence to ion dose.

Therefore, there was indicated the peculiar atomic mixing between Fe and Si layer by Argon ion irradiation. The Ratio of hyperfine field (Hf) after and before ion

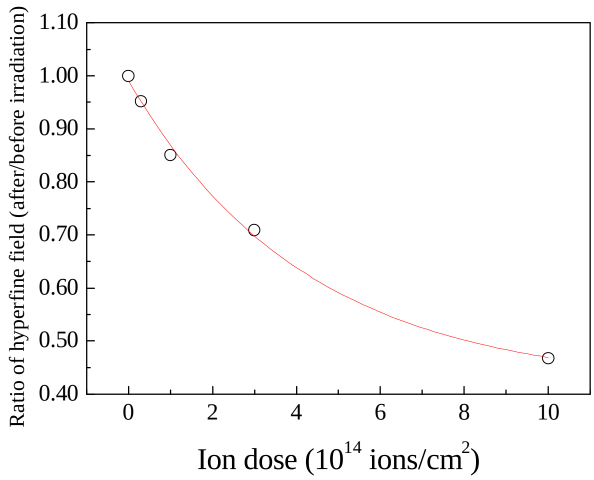

Figure 2c. Ion dose dependence of Ratio of Hyperfine field (Hf) of Fe2nm/Si1.5nm MLs

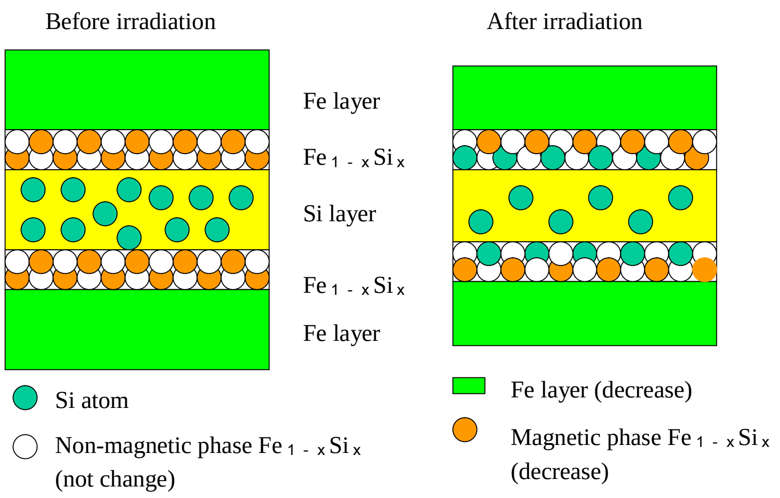

Figure 3. Structure Model of Interfacial Diffusion in Fe/Si Mls system deducted from simulation result of Rutherford Back Spectroscopy(RBS) spectrum.

irradiation was decrease monotically when the ion dose increase, as summaried in Figure 2.c. Ion dose dependence of Ratio of Hyperfine field (Hf) of Fe2nm/Si1.5nm MLs

Structure Model of Fe/Si Multilayer

To describe the mechanism of interdifussion process before and after ion irradiation, we propose the structure model for Fe/Si MLs, as shown in Figure 3.

In as deposited sample, we suggest that at interfacial phase region have two kind of $Fe_{1-x}Si_x$ phase. First one is a non magnetic phase and the second one is a magnetic phase of $Fe_{1-x}Si_x$, as symbolized by white-circle and orange-circle, respectively, as shown in Figure 3a. After Argon ion irradiation ,according to CEMS spectrums, Silicon atom diffuse to $Fe_{1-x}Si_x$ interface region make decrease amount of magnetic phase of $Fe_{1-x}Si_x$, but not change for non-magnetic phase, as illustrated in Figure 3b.

Rutherford Backcsatering (RBS) measurement also were performed to clarify the structure model of $[Fe(2nm)/Si(1.5nm)]_{30}$ multilayer. Good fiting result was indicated that the existence of Fe_3Si and FeSi phase in

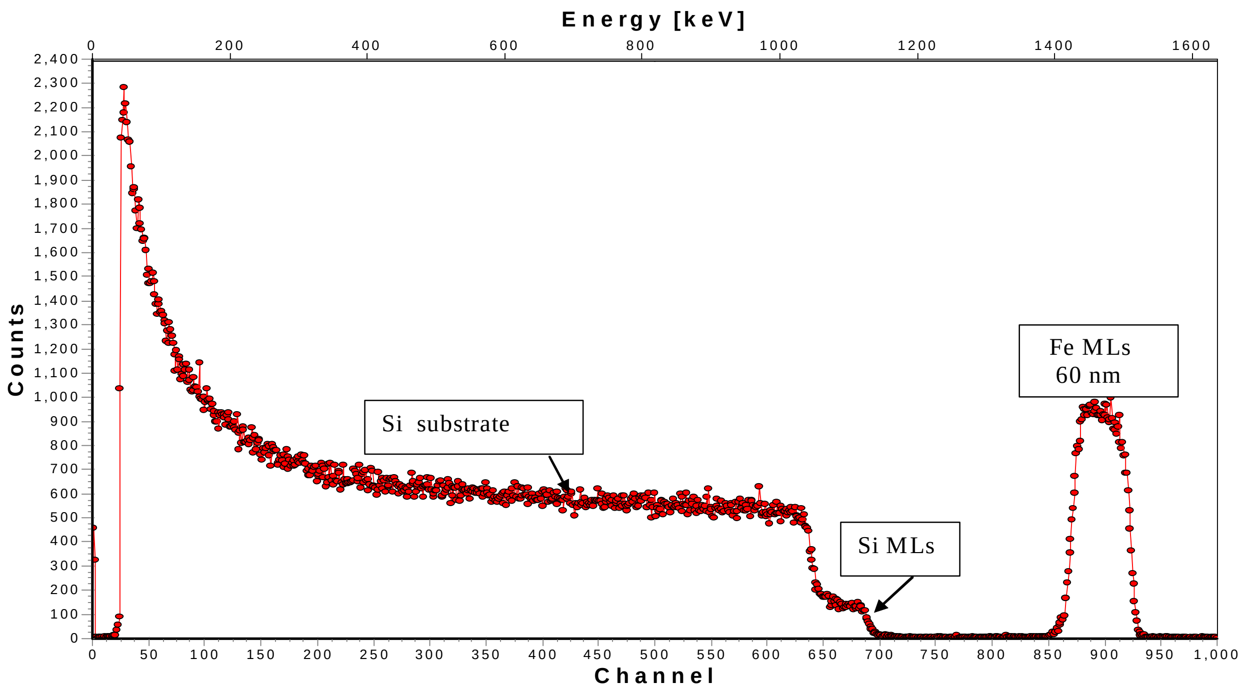

Figure 4. RBS spectrum for $[Fe2nm/Si\ 1.5nm]_{30}$ Multilayer as deposited sample. Fitting was performed with the assumption the existence of Fe_3Si and FeSi phase at Interface.

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the interfacial region between Fe and Si layers, as shown in Figure 4.

CONCLUSION

Irradiation by 400 keV Argon ion on [Fe (2nm)/Si (1.5nm)]$_{30}$ have been performed with ion doses between 3x10$^{1-ÿ}$ - 1×10^{15} ions/cm^{2} .

From VSM & CEMS results, it is shown that increase of Argon ion dose to make decrease the average of hyferfine field and magnetization value. But from CEMS results , amount of the non-magnetic phase $Fe_{1-x}Si_x$ is seen not to depend on Argon ion dose. While magnetization value of the magnetic phase $Fe_{1-x}Si_x$ decreases.

In the case of [Fe (2nm)/Si (1.5nm)]$_{30}$ MLs, during ion irradiation the atomic diffusion contributes to increase of Si concentration in the magnetic phase $Fe_{1-x}Si_{x.}$ For that reason, -like as deposited- the amount of non magnetic phase $Fe_{1-x}Si_x$ does not any change during ion irradiation 0 also for Ferromagnetic coupling between Fe layer.

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TANYA JAWAB

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Pertanyaan

1. Mengapa setelah menjadi FeSi ditembak dengan ion Argon
2. Mengapa FeSi dibuat dengan *helicon* plasma,apakah bisa dibuat dengan teknik PLD dan sebagainya.

Jawaban

1. Untuk mengetahui sejauhmana pengaruh ion Ar *irradiation* terhadap keberadaan *interfacial structure* FeSi.
2. Pada prinsipnya bisa, tapi harus memakai *excange gate*, agar bisa buat multi layer FeSi