CROSS TOKAI Experimental Report J-PARC	承認日 Date of Approval 2013/05/27 承認者 Approver TAKEDA Masayasu 提出日 Date of Report 2013/05/27
実験課題番号 Project No. 2013P0302 実験課題名 Title of experiment Research on Correlation between Magnetic Structure and Function in Magnetic Multilayers Relating to Spintronics 実験責任者名 Name of principal investigator TAKEDA Masayasu 所属 Affiliation Japan Atomic Energy Agency	装置責任者 Name of Instrument scientist 武田全康 装置名 Name of Instrument/（BL No.） SHARAKU/BL17 利用期間 Dates of experiments 2012/06/07 日 09:00 ～ 15 日 09:00 2013/01/15 日 09:00 ～ 17 日 09:00 2013/01/17 日 21:00 ～ 18 日 21:00 2013/01/29 日 09:00 ～ 30 日 09:00 2013/01/30 日 21:00 ～ 05 日 09:00

1．研究成果概要（試料の名称、組成、物理的・化学的性状を明記するとともに、実験方法、利用の結果得られた主なデータ、考察、結論、図表等を記述してください。

Outline of experimental results (experimental method and results should be reported including sample information such as composition, physical and/or chemical characteristics.)

The aim of this project is to clarify the correlation between interfacial structures and functions in the magnetic multilayers that are the base of the spintronics using the polarized neutron reflectometer SHARAKU (BL17). In this fiscal year, we planned to study three subjects; (a) magnetic multilayers of the full Heusler alloy Co_2MnSi, (b) the ferromagnetic semiconductor (Ga,Mn)As, and (c) Pt/NiFe magnetic films relating to the spin current phenomenon. We focus on the subject (a) in this report; however, the other two topics are briefly reported first.

We measured the polarized neutron reflectivity (PNR) of a $(Ga_{0.95}Mn_{0.05})As$ with the thickness of 50 nm on the GaAs substrate under a magnetic field of 10 kOe at 3 K, and obsreved the ferromagnetic moments whose magnitude of 0.84 μ_B per Mn atom. This value is consistent with a result of the magnetization measurement. The key issue of this study is whether the ferromagnetic moments are homogeneously distributed along the depth direction from the surface or not. Although our observation suggested the homogeneous distribution, we reserve this conclusion at the moment because of the unexpected small ferromagnetic moment of this sample. We will publish the report after the measurements of a new sample that has the expected magnetic moment of $4\mu_B$.

We tried to simultaneously measure the PNR and the spin current in the Pt/YIG film. Unfortunately, terminals for the measurement of the spin current peeled off during cooling down the sample. The terminals were attached to the sample surface using the electrical conductive paste. We are now discussing the more stable way to maintain the electric contact between the sample surface and the terminals even in low temperatures. The measurements will be performed again after the improvement of the way to fix the terminal.

The specimen of the multilayer of Co_2MnSi was synthesized on a MgO(001) substrate by Dr. Sakuraba (IMR, Tohoku University). The layer structure is Au(3nm)/Co_2MnSi(10nm)/Cr(1.2nm)/Co_2MnSi(20nm)/Cr(5nm)/Au(30 nm)/Cr(15nm)/MgO substrate. In this trilayer, a strong and anomalous 90 degree coupling of the ferromagnetic moments of two Co_2MnSi layers across the thin Cr layer is suggested by the M-H loop measurements. We intended to directly observe the 90 degree coupling using the polarized neutron reflectometry.

1．研究成果概要（つづき） Outline of experimental results (continued).

The measurements were performed at the ambient temperature. The PNR was measured under an external magnetic field of 10 kOe in the sample plane to saturate the magnetization and under a low field of 50 Oe. The ferromagnetic moments are supposed to have the 90 degree coupling under this low field. Incident neutrons were polarized by a polarizer before the sample, and the spin state of reflected neutrons is analyzed by a spin analyzer set between the sample and a detector. Reflectivities at three different glancing angles of 0.2, 0.6, and 1.8 degree were combined to cover a wide q-range from 0.02 to 2 nm^{-1}.

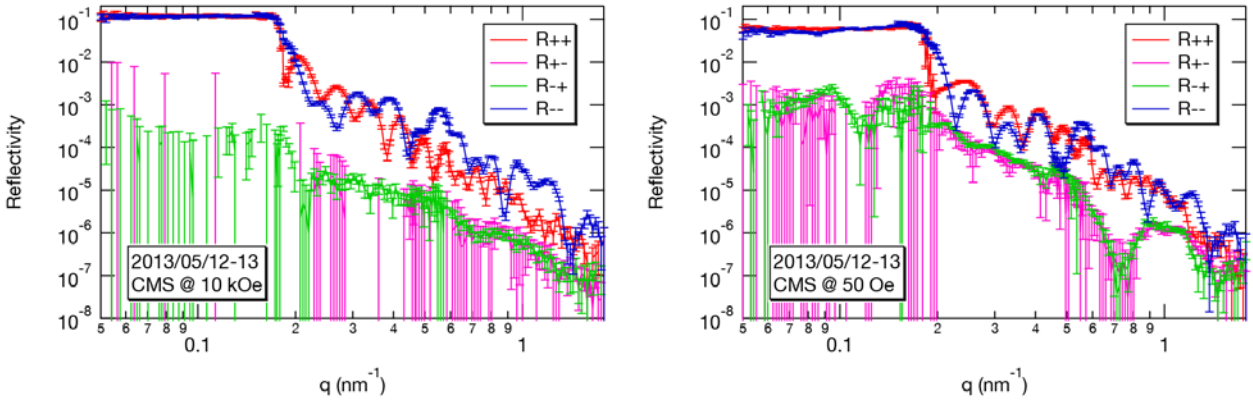

Fig. 1 Polarized neutron reflectivities of the Co_2MnSi trilayer under a high magnetic field (left), and a low field (right).

Figure 1 shows the results of the PNR measurements. The left panel displays the result under the high magnetic field, and the right one under the low field where the 90 degree coupling is expected. In these figures, four kinds of reflectivity, R_{++}, R_{+-}, R_{-+}, and R_{--}, are shown. The first sign in the subscript is the spin state of the incident polarized neutrons, and the second one is the spin state of the reflected neutrons. The spin of the incident neutrons is flipped by the perpendicular components of a net magnetization vector of the sample according to the neutron spins, and is conserved the direction by the parallel components.The reflectivities with the spin-flip are observed even in the data under the saturation field where all the ferromagnetic moments should be parallel to the neutron spin. We are now carefully checking whether this is an intrinsic character or originates in imperfectness of the calibration of efficiencies of the components like the polarizer and the analyzer, and the spin flippers.

One of simulations of the 90 degree coupling is shown in Fig. 2. The feature of the profiles of R_{++}, and R_{--} is qualitatively well reproduced by the simulation. The profiles of R_{+-}, and R_{-+} are also very similar to the experimental result; however, the absolute values are much higher in the simulation than those of the experimental data. Further analysis is now proceeding. The results will be reported elsewhere.

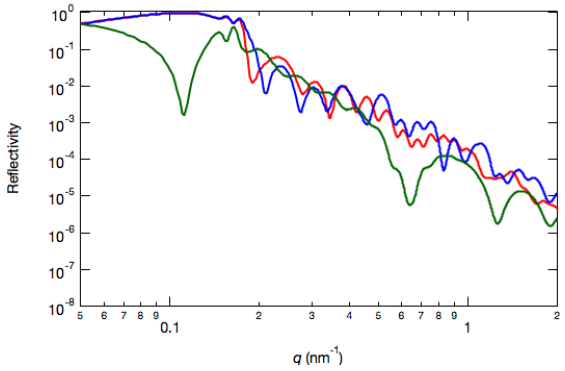

Fig.2 An example of simulation of the polarized neutron reflectivity profiles with the 90 degree coupling.

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