Magnetic structural analysis of magnetic multilayers by complementary use of X-ray and neutrons

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Abstract. A read sensor head of a hard disk drive has a layered structure and consists of several ferromagnetic (F), antiferromagnetic (AF), and nonmagnetic layers. Much attention is now paid to the magnetic structure near the interfaces between the F and AF layers in development of the high performance read sensors because a stable pinning of magnetization of F layer by AF layer seems to be very sensitive to the magnetic structure near the interfaces. It is, however, difficult to study such internal structures using the conventional methods because the interfaces are buried inside the multilayers. Complementary use of X-ray and neutron reflectometry is the most powerful and nondestructive tool to investigate such buried internal magnetic structures.

1. Introduction
A read sensor head is one of key elements to increase the recording density of hard disk drives (HDDs). The read sensor head of HDD consists of several ferromagnetic (F), antiferromagnetic (AF), and noble metal layers. There are two kinds of ferromagnetic layers. One is a free layer, and another is a pinned layer. The pinning is caused by the exchange bias effect between the F and AF layers. The magnetic signals are sensed by changes of resistivity induced by mutual angle between two ferromagnetic moments across the spacer layer. A free rotation of the ferromagnetic moments in the free layer and a stable pinning of those in the pinned layers are essential for the read sensor head.

It is known that the sputtering conditions affect the magnetization (MH) and magnetoresistance (MR) curves in the vicinity of coercive field, $H_c$, and $H_c$ itself. The origin, however, is still unknown. This is a problem to develop the high-performance and high-reliability read sensor heads. An advanced technology to control the magnetization in the multilayers is necessary to solve the problem. Consequently, it is necessary to acquire information on the magnetization in each layer independently and on the detailed magnetic structure in the vicinity of the interface between the pinned and the antiferromagnetic layers.
2. X-ray and neutron reflectometry

One of possible origins of the MH and MR change in the vicinity of $H_c$ is the dispersion of the ferromagnetic moments near the interface. X-ray reflectometer is a powerful and nondestructive tool to investigate the buried internal structures [1]. It is, however, practically difficult to study such magnetic internal structures using the conventional X-ray sources in laboratories. On the other hand, neutron reflectometry (NR) gives us the information on the depth profile of magnetization of the magnetic multilayers. When polarized neutron is used, the sensitivity to the magnetization is much enhanced [2]. Therefore, complementary use of X-ray and polarized neutron reflectometry is an unrivaled way to analyze the internal magnetic structure in magnetic multilayers.

Recently, a new neutron reflectometer, SUIREN (Apparatus for Surface and Interface Investigations with Reflection of Neutrons), was installed at the C2-2 cold neutron beam port of the neutron guide hall in the research reactor, JRR-3, of Japan Atomic Energy Agency (JAEA) [3]. This reflectometer was not designed as a dedicated polarized neutron reflectometer. It is, however, capable of polarized neutron reflectometry using polarizing neutron options.

3. SUIREN as a polarized neutron reflectometer

Figure 1 shows a schematic representation of SUIREN in the polarized neutron reflectometer mode. It consists of neutron monochromator, neutron polarizing mirror, beam slits, spin flippers, sample stage with an electromagnet, neutron-polarization analyzing mirror, and neutron detector. Unpolarized cold neutrons from a cold moderator of JRR-3 are monochromatized by a PG(002) monochromator, and then polarized by the neutron polarizing mirror. Neutrons of $\lambda = 0.38$ nm are usually used for experiments. The higher order contamination of incident neutrons is filtered out by the polarizing mirror. Polarization of the beam is better than 0.97. The spin direction of polarized neutron is controlled by the spin flipper, which is able to make the spin parallel or antiparallel to a magnetic field produced by the electromagnet. The flippers are so-called Mezei $\pi$ flippers, and both flipping efficiencies are higher than 0.99.

When neutrons interact with magnetic moments, $M$, in the magnetic multilayers, neutron is affected only by the component of $M$ normal to the scattering vector, $M_n$. In other words, neutron is insensitive to a component of $M$ parallel to the scattering vector. In addition, there is another selection rule; the neutron spin is flipped by the component of $M_n$ normal to the spin. However, the spin state is not changed by the component of $M_n$ parallel to the spin. Following these selection rules, four kinds of reflectivities, $R_{++}$, $R_{+-}$, $R_{-+}$, and $R_{--}$, are obtained by SUIREN. The signs as the subscripts of $R$ indicate the spin state, up or down, of incident and reflected neutrons in this order. The four reflectivities contain the information on the depth profile of magnetization in the multilayer. The depth profile of magnetic structure is deduced from the reflectivities by fitting of whole reflectivity curves using a model with a suitable magnetic layered structure.

![Fig. 1 Schematic layout of neutron reflectometer, SUIREN, installed at JRR-3 of JAEA.](image-url)
4. An example of the complementary use of X-ray and neutron reflectometry

Figure 2 (a) shows the polarized neutron reflectivities from a multilayer which is a part of a read sensor under a magnetic field of 1.8 kOe using SUIREN. The structure of the sample is described as Si/Ta(5nm)/Ru(5nm)/MnIr(5nm)/CoFe(2nm)/Cu(1nm)/Ru(2nm). The length of the sample in the scattering plane was 35 mm, and the height was 25 mm. The measurements were performed by the \( \theta - 2\theta \) scan from 0.36 to 6.4 degree (2\( \theta \) values). The range of the scan was divided into three regions; i) 0.36 – 1.6 (0.04), ii) 1.6 – 3.2 (0.08), and iii) 3.2 – 6.4 (0.16). The numbers are the 2\( \theta \) values, but those in the parentheses are steps of the 2\( \theta \) angle. The angle divergence of the incident beam was controlled by two sets of horizontal slits and was approximately 4% (\( \Delta \theta/\theta \)) in the whole scan range. The slit width was constant in each scan region. Four scans are necessary to obtain the four kinds of the reflectivity. Each scan took 4 hours and 30 minutes.

The reflectivities with the spin-flip clearly indicate the existence of perpendicular component of internal magnetization under this field. X-ray reflectivity of the same sample is also displayed in Fig. 2 (b). This information is not able to be obtained by the X-ray reflectivity measurements. On the other hand, the statistics and the \( q \) resolution of data in Fig. 2 (b) are better than those of polarized neutron reflectivities in Fig. 2 (a) even though measuring time of the data in Fig. 2 (a) was much longer than that of Fig. 2 (b). The layered internal structural information (paramagnetic one) is more accurately obtained from the X-ray reflectivity data. The complementary use of X-ray and neutron reflectometry will give the reliable depth profile of magnetization of this multilayer on the basis of the structural information from the X-ray reflectivity data. Analyses of both data are now in progress, and the results will be reported elsewhere.

![Fig.2 Four kinds of polarized neutron reflectivities (a), and X-ray one (b) from the same multilayer which is a part of multilayer structure of a read sensor.](image)

References

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