Magnetism
X-ray magnetic circular dichroism (XMCD)

Visualization of antiferromagnetic spins in spintronic devices

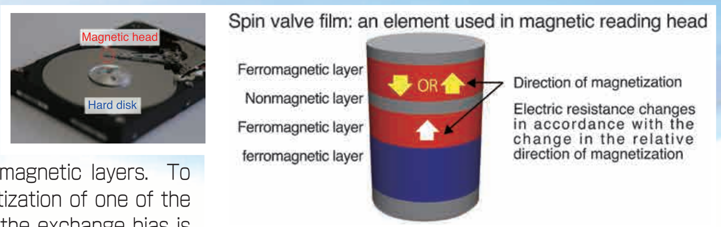

Fig. 1 Spin valve thin film in spintronic devices such as hard disk drive

Spintronics is a research field dealing with both charges and spins of electrons and is used in fields such as magnetic recording. Spin valve films are spintronic devices and have been used in the magnetic reading head of hard disk drives (Fig. 1). The spin valve film basically has the ferromagnetic layer/nonmagnetic layer/ferromagnetic layer/antiferromagnetic layer structure. In the spin valve film, the electric resistance changes in accordance with the relative direction of magnetization of the two ferromagnetic layers. To change the relative direction of magnetization, the direction of the magnetization of one of the ferromagnetic layers must be fixed (exchange bias). It is considered that the exchange bias is induced by pinning the antiferromagnetic spins with respect to the magnetic field; however, the detailed mechanism behind this phenomenon has not yet been clarified.

It is difficult to detect antiferromagnetic spins by general magnetization measurement methods because spins are compensated in an antiferromagnetic material. When a circularly polarized X-ray is incident on a spin-polarized material, X-ray absorption intensity differs between left and right circularly polarized lights, which is referred to as X-ray magnetic circular dichroism (XMCD). By adjusting the energy of the incident X-ray with that of the absorption edge of the target element, element-specific spin information can be obtained. In this study, XMCD measurement was carried out using BL25SU to detect the uncompensated antiferromagnetic spins induced by exchange coupling between antiferromagnetic and ferromagnetic spins by a technique that is interface sensitive. In the element-specific magnetization curves of Cr spins in the antiferromagnetic chromium oxide (Cr_2O_3) layer/ferromagnetic cobalt (Co) layer structure, shifts in the vertical direction as well as along the magnetic-field axis owing to the exchange bias were observed [Fig. 2(A)]. In addition, asymmetric XMCD spectra with respect to positive and negative magnetic fields were confirmed [Fig. 2(B)]. From these results, it was confirmed that Cr spins are pinned with respect to the magnetic field and this pinning is caused by the canted spins in the antiferromagnetic layer [Fig. 2(C)]. These findings are expected to serve as basic information in the clarification of the origin of exchange bias and the development of spintronic devices.

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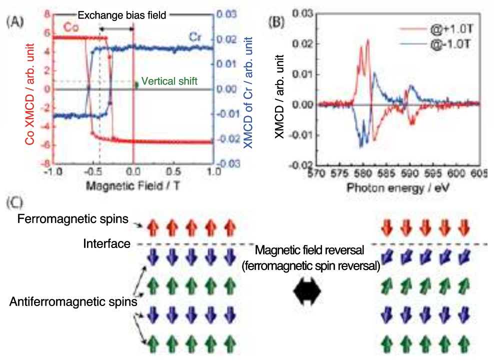


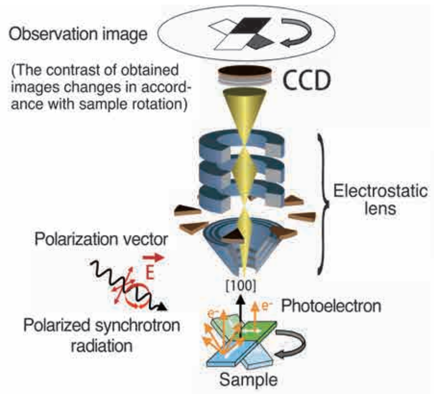
Fig. 2
(A) Element-specific magnetization curves of ferromagnetic Co spins and antiferromagnetic Cr spins obtained by XMCD measurement. (B) XMCD spectra of Cr and (C) expected spin structure at the interface

Magnetism
Photoemission electron microscopy (PEEM)

Visualization of magnetic domain structure at the interface of magnetic thin films

In modern society, we receive great benefit from magnetic recording devices such as memories and hard disks. These magnetic recording devices make use of the phenomenon called exchange bias, and its detailed clarification is necessary to use the phenomenon in a wider range of applications. For example, the observation of the exchange coupling of spins between an antiferromagnetic substrate and a ferromagnetic thin film formed on it is required.

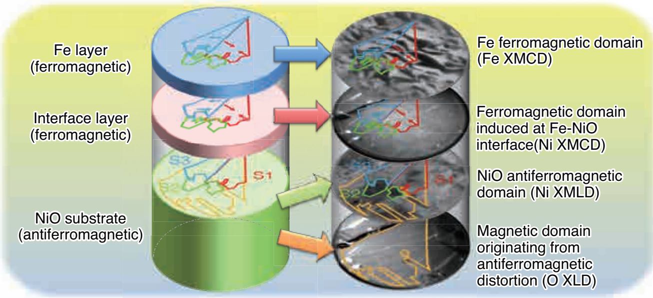
The element-specific observation of magnetic domains of various magnetic materials is realized by combining photoemission electron microscopy (PEEM), X-ray magnetic circular and linear dichroisms (XMCD & XMLD) using BL17SU and BL25SU. The figure shows the schematic of this experimental method. Depending on the direction of magnetization in the magnetic domain of a sample and the direction of the polarization vector of the incident X-ray, the number of electrons emitted from the surface differs. The image of the region where many electrons are emitted is bright whereas that of the region with fewer electrons being emitted is dark, when the images are magnified using an electrostatic lens.



In this study, an iron (Fe) thin film (thickness, ~0.9 nm) was formed on a nickel oxide (NiO) substrate, which is known as a typical antiferromagnetic material, to analyze the magnetic structure. Using various states of magnetic dichroism at the absorption edges of elements constituting the system, information on (1) the magnetic domain originating from the antiferromagnetic distortion of the NiO substrate (yellow frame), (2) three magnetic domains (S1-S3) originating from spin ordering, (3) the ferromagnetic domain of the top layer of the Fe thin film, and (4) the ferromagnetic domain of the interface (in which Fe, Ni, and O are mixed) is obtained. The sample was rotated with respect to the incident direction of the light. From the change in the contrast of the obtained images, the spin directions in each magnetic domain were determined. The exchange coupling of spins among the substrate, top layer, and interface was clarified.

This observation technique is considered to be applicable to the development of new materials for inductor circuits, in addition to magnetic recording. At SPring-8, this technique is combined with time-resolved measurement of the movements of the magnetic domain and wall with respect to an external field.

BL17SU, BL25SU Toyohiko Kinoshita (JASRI)



(Top) Schematic of magnetic domain observed by PEEM. (Bottom) Results of observation of magnetic domain in antiferromagnetic substrate and in Fe surface and interface of Fe/NiO(100). The arrows indicate the directions of magnetization (spins) in magnetic domains

Industrial Application
Infrared microspectroscopy imaging

Success in visualization of localizations of proteins and lipids in hair

Around the age of 35 years, people's hair concerns shift from hair damage to hair aging. Curliness, waviness, and dryness are included in the top common hair problems and cause people to feel a change in their hair quality. A well-known change in hair caused by aging is the increase in the number of curly hairs. The localization of proteins in such curly hair has been studied by various methods. However, the localization of lipids in the hair has remained unclear. In this study, the localizations of proteins and lipids were visualized using an infrared (IR) microspectroscopy system at SPring-8. This system combines a microscope and an IR spectrophotometer and can be used to determine the localization of components in a specific region. Information on fine regions has been difficult to obtain with general IR measurement systems. Detailed data on the cross-sectional localization of components in hair have not been available.

Cross-sectional imaging revealed that proteins (amide bonds) and lipids (CH bonds) were uniformly localized in hair with a nearly round cross section and that the inside of the hair had a uniform composition localization (Fig. 1). For curly hair, however, lipids were sparsely localized (the number of CH bonds was small) at sites where proteins were densely localized (the number of amide bonds was large). In contrast, the lipids were densely localized at sites where proteins were sparsely localized (Fig. 2). That is, the localizations of proteins and lipids were in an inverse relationship.

In this study, an uneven localization of hair components, such as proteins and lipids, in curly hair was confirmed at the microlevel by visualizing a more detailed localization of hair components than before. It was found that the localization of proteins is different from that of lipids in curly hair; this is the so-called state of "hair distortion". Therefore, the curliness of hair can be improved by correcting the uneven localizations of proteins and lipids throughout the curly hair.

BL43IR Satoshi Inamasu (Kracie Home Products, Ltd.,)

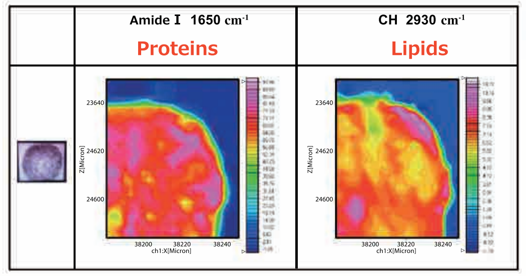


Fig. 1
Mapping of components in hair with a nearly round cross section Red region has a dense localization of components

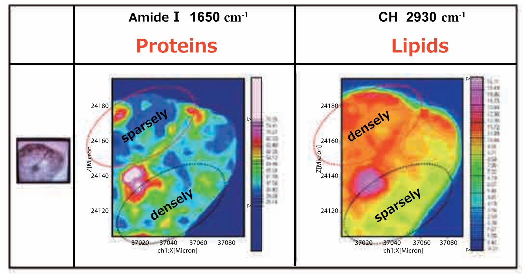


Fig. 2
Mapping of components in curly hair

Industrial Application
Momentum Imaging

Establishment of Four-Dimensional (4D) Nano Design, a Technology for the Development of New Materials Used for High-Performance and High-Quality Tires

The development of fuel-efficient tires is very important from the viewpoint of the global environment, and the development and promotion of technologies related to fuel-efficient tires are strongly desired. Grip performance is realized owing to the energy loss due to the deformation of a tire as a result of its contact with a road surface. Therefore, the two contradictory requirements, i.e., improving the fuel efficiency and grip performance, should be balanced by advanced methods. In this study, the technique of two-dimensional ultrasmall-angle X-ray scattering (2D-USAXS) with a camera length of 160 m using the high-brilliance X-rays of BL20XU was developed. The high-precision data obtained by 2D-USAXS, together with the 2D small-angle X-ray scattering (2D-SAXS) using BL03XU and BL40B2 (Fig. 1), were analyzed by the two-dimensional pattern reverse Monte Carlo method (2Dp-RMC) which was developed at the Earth Simulator supercomputer (Fig. 2). With the results of this study, a both-ends-modified polymer was developed by Sumitomo Chemical Co., Ltd., which was used to develop fuel-efficient tires. The rolling resistance of the tires was reduced by approximately 39% (approximately 6% less fuel consumption in JC08 mode) and the wet grip performance was improved by approximately 9% compared with those of conventional tires manufactured by Sumitomo Rubber Industries, Ltd.

BL03XU, BL20XU, BL40B2
Hiromichi Kishimoto (Sumitomo Rubber Industries, Ltd.)

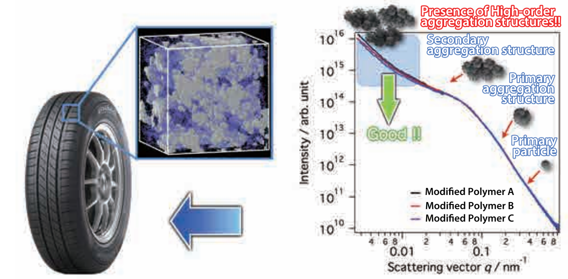


Fig. 1
One-dimensional scattering profile obtained by superimposing 2D-USAXS and 2D-SAXS data

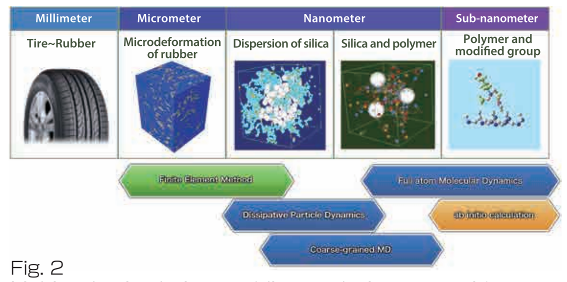


Fig. 2
Multiscale simulation enabling analysis over a wide range of spatial scales