

XPEEM Studies Using a Polarized Photon Source

X-ray Photoemission Electron Microscopy (XPEEM) is a powerful tool for surface and material sciences because it not only provides the images with versatile contrasts but also leads the NEXAFS spectroscopy into a micrometer dimension analysis technique. Coupling with a polarized photon source, the XPEEM can take advantage of the additional degree of freedom in polarization control to explore those photon-material interactions that show unidirectional or uniaxial anisotropy. In this article, we introduce two examples utilizing a polarized photon source provided by an elliptically polarized undulator (EPU) to study the magnetic domain configurations for patterned permalloy structures and the area selective orientation control of pentacene on a self-assembled monolayer (SAM)-patterned Au surface.

Magnetic Domain Configurations for Patterned Permalloy Structures

In the history of magnetic material research, scientific interests and practical applications are often coupled together. For patterned ferromagnetic structures, one of its scientific interests is to provide a fundamental understanding of the competition between multiple energies such as the anisotropy energy and the exchange energy, etc. For practical applications, on the other hand, studies on the patterned media imply the possibility of manipulating magnetic properties through geometry control. We explored the stable states of a ferromagnetic (FM) thin film system patterned into different sizes and shapes. It is expected that the additional geometry constraints of the patterned film exhibits complex magnetization configurations. The new properties may differ from those found in the continuous films.

The patterns under studied include 12 polycrystalline permalloy structures that are divided into

three groups according to their dimensions; $50 \times 10 \mu\text{m}$, $25 \times 5 \mu\text{m}$, and $10 \times 2 \mu\text{m}$ (length \times width). Each group contains four patterned structures; ring, frame, T-shaped, and cross-shaped structures, which represent the geometries of no sharp edge, a junction connected to two-, three-, and four- 90° arms, respectively. These mesoscopic patterns are fabricated by electron beam lithography and the lift-off process on a 10 nm Au covered Si substrate. The presence of a thin gold layer is to avoid image artifact caused by surface charging. After thermally evaporating a 15 nm thick $\text{Ni}_{80}\text{Fe}_{20}$, a 2 nm thick Au cap layer is deposited on top of the patterns to prevent oxidation. Finally, the remanent state is achieved by gradually decreasing a 200 Oe magnetic field that was initially applied along the direction as marked in the Fig. 1.

For the magnetic imaging, a monochromatic X-ray with right or left elliptically polarization ($+\sigma$ or $-\sigma$) is delivered to the sample at a 65° incident angle measured from the surface normal to generate spin-dependent electron emission at specific absorption edges. The image with magnetic contrast is then constructed by the asymmetry process utilizing the opposite absorption enhancement at Fe or Ni L -edges based on the soft X-ray magnetic circular dichroism (XMCD). As a result, the grey scale of an XPEEM image is a function of the angle between the magnetization vector in material (M) and the photon helicity (σ). The element-specific information comes in as each element has its own characteristic absorption edges. In this study, however, taking images at either Fe or Ni absorption edges makes no difference in domain determination because of the permalloy characteristic. All images shown in this paper are taken at Fe L -edges.

In Fig. 1, it is obvious that each structure exhibits different magnetic configuration in their remanent state. For a ring-shaped structure that has a smooth boundary, there appear two domains

heading opposite directions in the structure that corresponds to the so-called head-to-head bi-domain state that was first observed in a Co ring back in 1999. For a frame structure, we observed two grey scales suggesting there are only two domains in four arms. The assignment of magnetization directions on the arms, however, leads to two types of configuration at the four corners; the 90° Néel type domain walls at upper

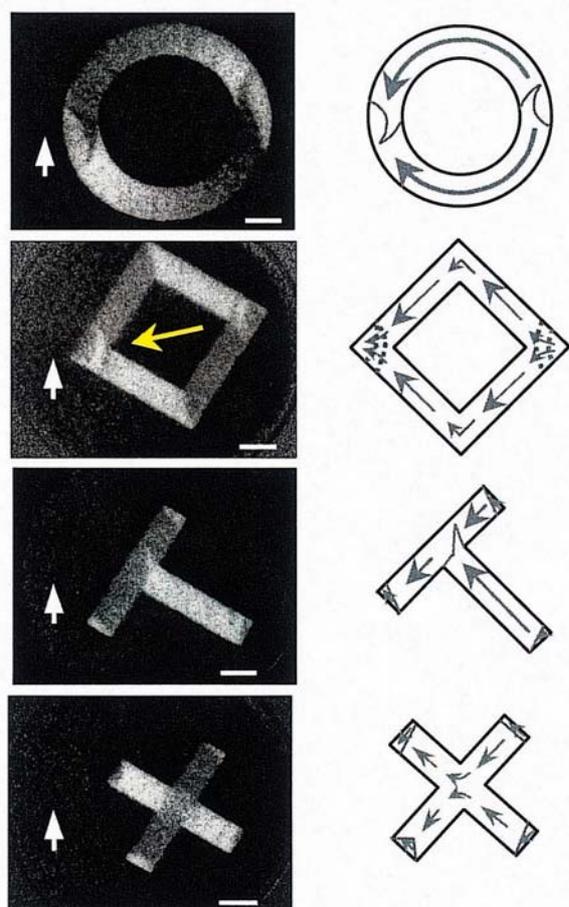


Fig. 1: Four elements are imaged at their remanent state after applying a 200 Oe field along the direction marked by a yellow arrow. In figure (A), a head-to-head bi-domain state is observed for the ring element with its net remanent magnetization aligns with the direction of applied field. For a frame element, a double-parallel state is found with two types of domain transition regions existed at its four corners; a 90° Néel type wall region and a multi-wall region. The existence of multi-wall shows competition between uniaxial anisotropy and demagnetizing field. For the magnetization at the junction of T-element and cross-element, the X-ray images suggest a 90° Néel type wall and a homogeneous 45° transition region, respectively.

and lower corners and the accumulated magnetic charge at the other two. In addition, we observed multi-walls at the corner presumably are due to the competition between uniaxial anisotropy and demagnetizing field. For the T- and cross-structures, their domain assignment is straightforward. Considering the frame structure and the T-structure as a junction connecting with two and three arms, respectively, the domain wall appears less obvious at the junction of the T when comparing with that at the corner of a frame. A new configuration eventually emerges at the junction when the fourth arm is added to it. Similar observations were found in other two sets of structures prepared in different dimensions.

In summary, we observed distinct magnetization configuration in all four structures with clear geometry dependence. Varying the size from $50 \mu\text{m}$ to $10 \mu\text{m}$, however, shows little impact to the domain structures in remanent state. For the magnetization configuration in differently shaped geometries, there exist multiple domains in each structure with their orientation manifested in such a way that its net magnetization lays in the same direction as the applied field. This observation implies that the patterned FM film can exhibit pre-determined magnetization configurations with proper geometry design.

Area Selective Orientation Control of Pentacene on a SAM-patterned Au Surface

Because organic materials are readily processed and compatible with plastic substrates, they have prospective application as a semiconductive layer in a field-effect transistor (FET) or in an optoelectronic device. Among the many conjugated molecules suggested to possess sufficiently large charge mobility, pentacene is a promising candidate for use in fabrication of thin-film transistors because of its large field-effect mobility. Carrier mobility in an organic FET is believed to be determined by the extent of overlap of π -orbitals between adjacent conjugated molecules, which facilitates charge hopping. Whether a conduction pathway is perpendicular or parallel to the plane of the conjugated frame is thus an important aspect of the design of an efficient

device. In developing a practical device, we used self-assembled monolayer as an aligning layer to control the orientation of pentacene with respect to the Au surface.

Pentacene is a fused-ring polycyclic aromatic hydrocarbon molecule. The planar shape of pentacene facilitates crystalline packing and gives strong dichroism for s-polarized and p-polarized incident X-rays. Figure 2 shows PEEM image recorded at pre-absorption carbon K-edge 278 eV. The sample is prepared on a cleaned Au surface which is then patterned by micro-contact printing through ink of self-assembly monolayers.

Pentacene thin film (5 nm thickness) is deposited in vacuum on a patterned Au surface. The PEEM image in Fig. 2 shows that the bright blue area (indicated by the red circle) is pentacene deposited on bare Au surface, whereas the dark region (indicated by the green circle) is deposited on p-terphenylmethanethiolate Au surface. The area selective orientation control is characterized by the relevant micro-NEXAFS spectra of pentacene.

According to the dipole-selection rule, the resonance intensity associated with a specific molecular orbital is largest if the E vector points in the direction of that molecular orbital, whereas the

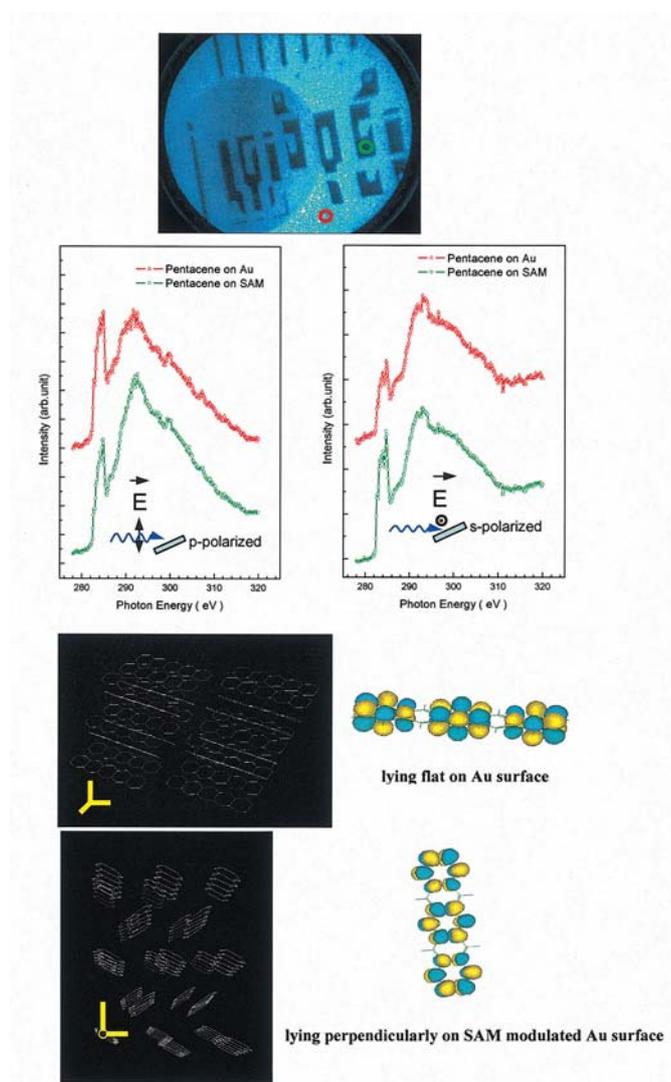


Fig. 2: XPEEM image of a pentacene film (thickness 5 nm) on a patterned terphenylmethanethiolate Au surface shows the area selective orientation control. The image was recorded at 278 eV. To characterize the micro-area orientation in the image, relevant NEXAFS spectra in p-polarized and s-polarized X-rays are presented.

intensity is minimized when the electric field of the linear polarized X-rays is perpendicular to the direction of the orbital. Hence the molecular orientation is easily identified through the analysis of dichroic characteristics of polarization-dependent NEXAFS spectra. Close inspection of micro-NEXAFS spectra of pentacene shows that the bright blue area has higher π^* intensity in p-polarization and higher σ^* intensity in s-polarization. The dichroism in the polarization-dependent spectra of the bright blue region is opposite to that of the dark area which represents pentacene deposited on the SAM modulated Au surface. From the dichroism analysis, we conclude that pentacene is lying flat on the bare Au surface, while it is perpendicular oriented on the p-terphenyl-methanethiolate modified Au surface.

Beamline:

05B2 EPU5.6/PEEM beamline

Experimental Station:

PEEM end station

Authors:

Y. J. Hsu and D. H. Wei

National Synchrotron Radiation Research Center,
Hsinchu, Taiwan

Publications:

- D. H. Wei, Y. J. Hsu, R. Klauser, I.-H. Hong, G.-C. Yin, and T. J. Chuang, Surf. Rev. Lett., (in press).
- D. H. Wei, Y. J. Hsu, G.-C. Yin, and Y. S. Wu, J. de Phys. IV **104**, 77 (2003).
- D. H. Wei, Y. J. Hsu, Y. S. Wu, J. Y. Ou, and J. C. Wu, (submitted).
- Y. J. Hsu, D. H. Wei, Y. S. Wu, W. S. Hu, and Y. T. Tao, (submitted).

Contact e-mail:

yjhsu@nsrrc.org.tw