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Surface antiferromagnetic domain structures of NiO (001) studied using UV photoemission electron microscope

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Abstract

Direct observation of the antiferro (AF) magnetic domain structures of a NiO (001) surface is found to be possible using a spectroscopy photoelectron low-energy electron microscope (SPELEEM) and a commercial UV Hg excitation light source without using any polarizers. The principle is based on the magnetic linear dichroism (MLD) effect, where different domain contrasts are produced according to the relative angle between the antiferromagnetic axis and the linearly polarized light. The observed AF magnetic domain structures are strongly affected by both bulk AF magnetic domain structures and the stresses induced during the sample cleaving process. Moreover, the AF magnetic domain structures are found to be irreversible when the sample is heated to over its Néel temperature and then cooled. The possibility of imaging AF magnetic domain structures without using synchrotron radiation or a polarizer is attractive.
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1. Introduction

The application of the exchange-bias effect based giant magnetroresistance effect (GMR) and other spin electronics [1,2] requires greater scientific understanding of AF magnetic materials. As a break through way, photoemission electron microscopy using synchrotron radiation light (SR-PEEM) has been used to study AF magnetic domain structures [3]. PEEM is an imaging instrument that provides a magnified image of the lateral intensity distribution of photoexcited electrons from a sample surface [4]. Using PEEM and linearly polarized X-rays, AF magnetic domain contrasts are obtained because of X-ray magnetic linear dichroism (XMLD) [5–7]. At the same time, the interface domain structures can also be observed because of the elemental specificity of the X-ray absorption process [8,9]. However, the complicated and expensive synchrotron radiation is a limitation preventing SR-PEEM from being widely used. Although there was a report that AF magnetic domain structures can be imaged by using a Hg arc lamp and PEEM [10], the authors used linear polarizers between the lamp and the UV window of the PEEM instrument, and calculated the difference between the two images obtained from s- and p-polarized light, respectively. In the present study, we find that UV light from a Hg arc lamp and PEEM (UV-PEEM) can be used to observe the AF magnetic domain structures of NiO (001) directly without using polarizers or an image operating process. Direct UV-PEEM AF magnetic domain structure observation is important because of its versatile characteristics, even though it lacks the elemental specificity of the X-ray absorption process.

NiO is a typical AF magnetic material with a Néel temperature of $T_N = 523$ K, and many studies on its AF magnetic nature have been reported [5,11]. The crystal structure is slightly deformed to a rhombohedral contraction from

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the original cubic rocksalt structure along one of the four ⟨1 1 1⟩ axes below T_N. The crystallographic twinning leads to four different possible domains, the so-called T(win)-domains. Each T-domain has an easy axis along one of the three [2 1 1]-derived directions, leading to three different S(pin)-domains [12]. Low-energy domain walls between *T*-domains correspond to the crystallographic and magnetic mirror planes ⟨1 0 0⟩ and ⟨1 1 0⟩. The magnetic axis in the wall is the average of those in the two adjacent T-domains.

2. Experimental procedure

The NiO (0 0 1) crystal was cleaved ex situ and immediately introduced into the ELMITEC-manufactured ultra-high vacuum (3×10^{-8} Pa) SPELEEM chamber [13]. The crystal was then annealed at 380 K for 2 h to desorb the contamination resulting from the short exposure to air. The contrast aperture (100 μm) and energy analyzer slit (60 μm) of the SPELEEM were set to minimize the spatial and chromatic aberrations, respectively. A Hg arc lamp (100 W, ORIEL instruments) was used as a light source and the UV radiation impinged onto the sample surface at grazing angle of 16°. The prominent photon energy was 4.9 eV, which is a little higher than the work function of 4.3 eV for NiO (0 0 1). Electrons excited from valence states were transferred using a magnetostatic lens and an energy analyzer to a channel plate/screen assembly and an enlarged map of the emission probability was recorded using a CCD camera.

3. Results and discussion

Fig. 1a and c shows a UV-PEEM image with a field of view of 75 μm and its schematic illustration, respectively. The incident UV light direction and the crystal orientation are expressed on the image. As well as the steps and some contamination, contrasts can be recognized with regular directions in the image. The contrast boundaries mainly run along three directions: [1 0 0], [0 1 0] and [1 1 0]. The contrasts may be AF magnetic domain structures, and the antiferromagnetic axis directions are overwritten on the image. In this case, the directions of AF magnetic magnetic domain walls show good consistency with those obtained by XMLD [11].

To verify that the contrasts are AF magnetic domain structures, we changed the relative angles between the incident UV light and the crystal orientation as below. The relative angles between the incident UV light and the crystal orientation are realized by rotating the sample in-plane using a rotary platform. Fig. 1b shows the UV-PEEM image with the a field of view 75 μm after 45° in-plane

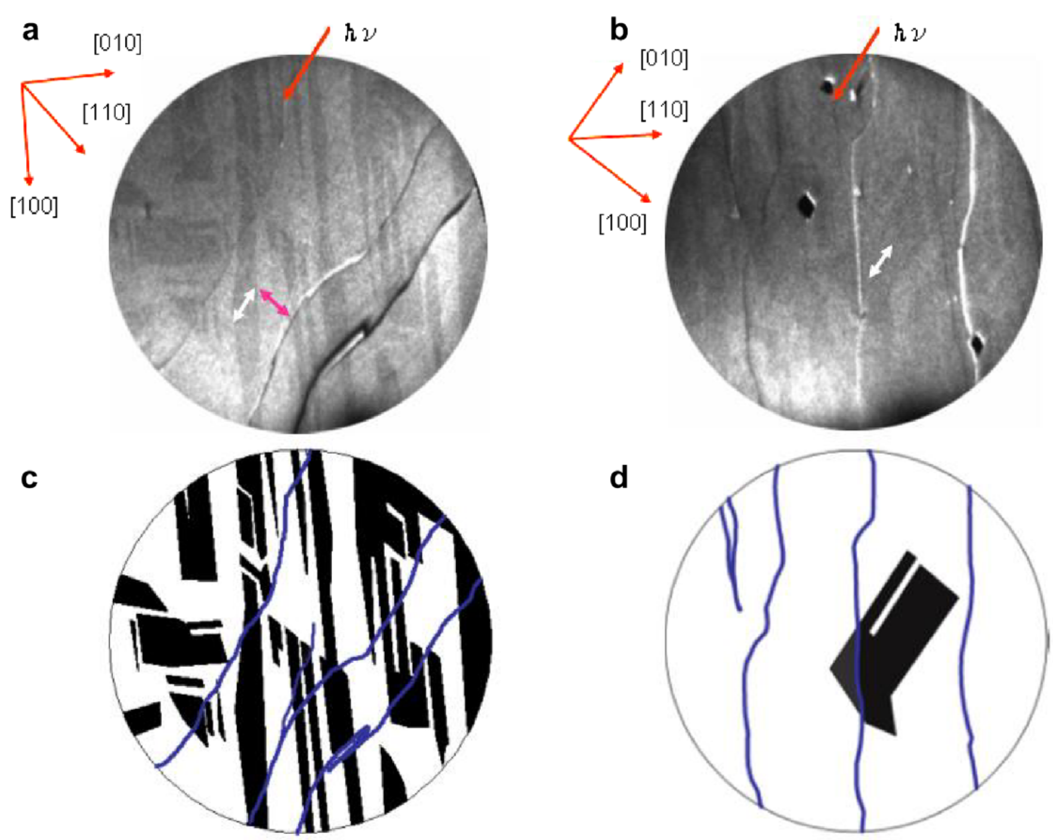

Fig. 1. (a) PEEM image of NiO (0 0 1) with a field of view of 75 μm obtained using Hg arc lamp and SPELEEM and (b) PEEM image with a field of view of 75 μm after 45° in-plane rotation. (c) and (d) shows roughly drawn corresponding schematic illustrations of the domain contrasts for (a) and (b), respectively. The antiferromagnetic axis directions are overwritten on the images.

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