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Hollow-cone Foucault Imaging of Magnetic Textures in Hexagonal Ferrite ; $BaFe_{10.35}Sc_{1.6}Mg_{0.05}O_{19}$

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Lorentz microscopy has been used to observe nanoscale magnetic domain structures in magnetic materials [1]. Lorentz microscopy has two imaging methods: In the Fresnel imaging method, magnetic domain walls can be visualized as bright and dark contrast by changing focus conditions of the specimen images and, on the other hand, in the Foucault imaging method, magnetic domains can be visualized under the infocus condition by selecting some of the deflected electron beams. However, the Fresnel method has some disadvantages such as poor spatial resolution, and in the Foucault method, asymmetric images can be formed because an angle-limiting aperture is placed at the asymmetric position with respect to the optical axis, resulting in azimuthally dependent image contrasts.

Recently, we developed the hollow-cone Foucault (HCF) imaging method, in which an incident electron beam on the specimen was tilted with respect to the optical axis with an inclination angle and was circulated in all azimuths around the optical axis [2]. As a result, in the HCF image, we observed both magnetic domains and domain walls simultaneously under the in-focus condition. The optical system for the HCF imaging is shown schematically in Figure 1. The parallel electron beams having less than 10^{-6} rad diffusion angle are irradiated on the specimen, where the inclination angles in X and Y directions were controlled by using the beam deflector system above the specimen. Consequently, the circulating electron beam is illuminated in all azimuthal directions around the optical axis. Under this characteristic experimental condition, small-angle hollow-cone beams with an inclination angle as small as 10^{-4} rad can be realized. The experiment was performed using a 200-kV thermal field-emission TEM (JEM-2100F) and the HCF images were recorded with a 2k × 2k pixel charge-coupled device camera (Ultrascan camera). Each image was recorded through 12 turns in the illumination azimuthal rotation in 7.5 seconds, corresponding to 1.6 Hz.

Thus, we applied the HCF imaging method to magnetic domain observations of Sc-doped *M*-type barium hexaferrites $BaFe_{12-x-\delta}Sc_xMg_\delta O_{19}$ for x=1.6 and δ=0.05 (BFSMO). The hexaferrites have recently shown multiferroicity above room temperature, electric polarization controlled by magnetic fields and unusual helicity reversals in magnetic bubbles [3]. In the experiments, we prepared single crystals of Sc-substituted *M*-type barium hexaferrites grown by a floating-zone method in O_2 flow. A thin samples oriented *c*-axis were prepared by an Ar ion thinning technique. We observed the magnetic domain structure of the ferrimagnetic state whose net magnetic moments point parallel to *c*-axis in hexagonal unit cell at room temperature. Figure 2 shows magnetic textures of BFSMO thin sample at room temperature. In the Fresnel image shown in Fig. 2(a), magnetic stripes can be clearly seen as paired meandering dark and bright lines under the over-focus condition. On the other hand, bright-field and dark-field HCF images, as shown in Figs. 2(b) and 2(c), magnetic domain walls having the in-plane components of magnetization can be visualized as bright contrast and the magnetic domains having out-of-plane components of magnetization can be visualized as dark contrast under the in-focus condition.

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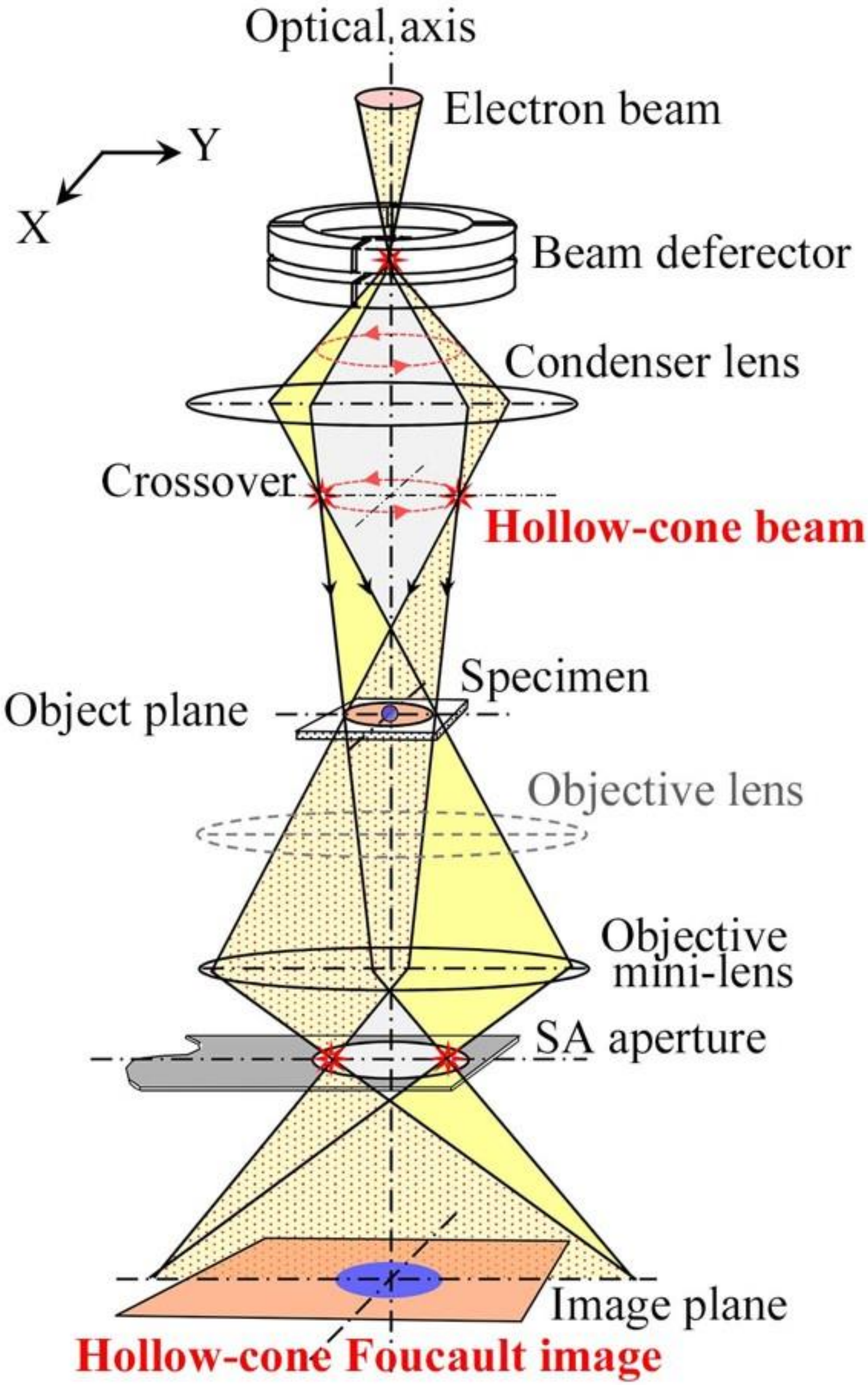

Figure 1. Schematic diagrams of the optical system for the HCF imaging.

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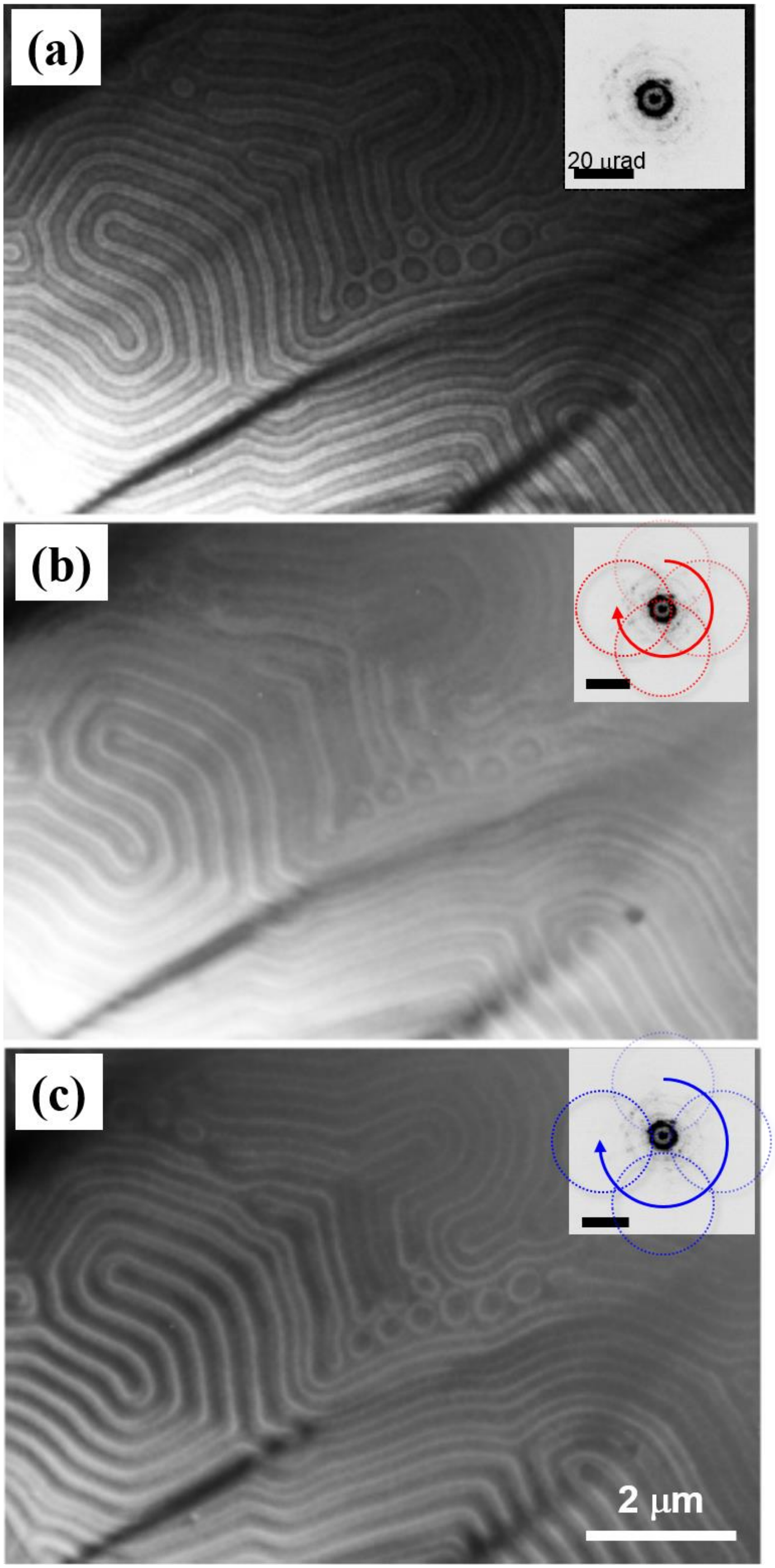

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Figure 2. Magnetic textures of BFSMO at room temperature. (a) Fresnel image (b) Bright-field HCF image and (c) Dark-field HCF image. (Insets) SmAED patterns.

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