Spin Polarization Domains within the Transverse Spin Density Wave Phase of Antiferromagnetic Chromium

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Introduction

At temperatures below the Néel transition (311K) and above the spin-flip transition (123K), the conduction electrons in chromium form an antiferromagnetic spin density wave (SDW) in which the spin polarization is orthogonal to the wave vector of the spin modulation [1]. Within the domains of the modulation vector (which can lie along any of the <001> axes of the bcc chromium lattice), the spin polarization can be along either of the remaining <001> directions. The division of the spin population between these two states has been experimentally observed in x-ray [2] and neutron scattering [1] with beams approximately 1 mm in diameter. The spatial variation in populations is clear at distances of millimeters from neutron topography experiments [3] but has not previously been explored at a smaller scale. We have used magnetic x-ray microdiffraction to image spin polarization domains with a spatial resolution below 1 μm.

Methods and Materials

The experimental method used to image the domains of the spin polarization in the transverse SDW is similar to our previous microdiffraction study of the spin flip transition [4]. An incident beam of 5.8 keV x-rays was focused to a spot size of approximately 0.5 μm by using a Fresnel zone plate. The (111)-oriented Cr single-crystal sample was mounted on a diffractometer in a continuous flow cryostat and positioned at the focal point.

Nonresonant magnetic x-ray scattering [5] from the real space structure of spins in chromium leads to discrete Bragg reflections in reciprocal space. Because the SDW modulation vector **Q** is incommensurate with the chromium atomic lattice, these magnetic reflections are well isolated from scattering due to the electrons in the atomic cores (see Fig. 1). There are six such reflections around each forbidden reflection of the bcc lattice. These six reflections can be divided into three sets that correspond to modulation vectors lying along the three <001> axes, as indicated by the color coding of the reflections in Fig. 1. The cross section for magnetic scattering depends on the spin polarization and scales as $\left|\mathbf{S}\cdot(\hat{\mathbf{k}}\times\hat{\mathbf{k}}')\right|^2 + \left|\mathbf{S}\cdot\hat{\mathbf{k}}(1-\hat{\mathbf{k}}\cdot\hat{\mathbf{k}}')\right|^2$ [6]. We oriented the sample as shown in Figure 1(b), with the [001] direction in the diffraction plane and the [011] axis normal to the plane. Thus, for SDW reflections along the [001] axis in reciprocal space (produced by domains with **Q** along [00L]), the cross section for longitudinally polarized spins is a factor of 30 smaller than for the transverse spin directions, for which the cross sections are equal. For reflections corresponding to **Q** along [H00] or [0K0], however, the directions for which the spin polarization is large are no longer both transverse to **Q**. In these cases, one transverse phase and the longitudinal phase have large cross sections, and the second transverse cross section is smaller. The variation of the magnetic scattering cross section with the direction of the spin polarization is shown in Fig. 2.

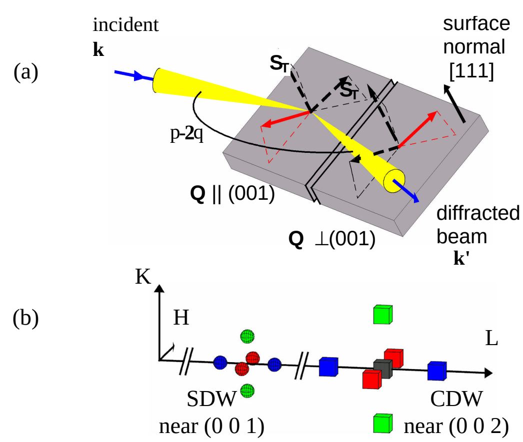

*FIG. 1. (a) The (111)-oriented Cr sample was mounted so that the [001] axis was in the plane defined by incident and diffracted beams **k** and **k'**. The normal to the diffraction plane was along the sample's [110] axis. (b) SDW reflections (spheres) appear in reciprocal space near (001) and can be divided into pairs corresponding to domains of **Q** along [100] (red), [010] (green), and [001] (blue). Corresponding reflections arising from the charge density wave (CDW) and strain wave appear near (002) (cubes).*

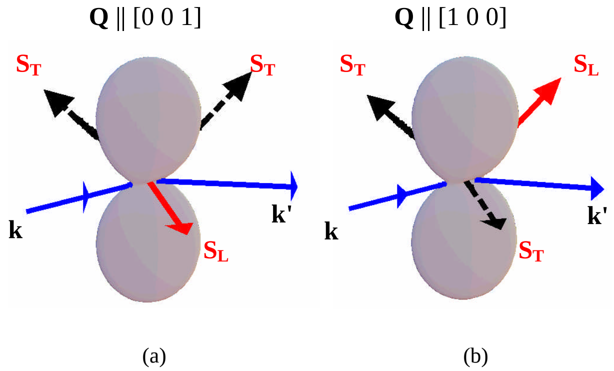

FIG. 2. Polar plots of the magnitude of the nonresonant magnetic x-ray scattering cross section as a function of the orientation of the spin polarization vector. (a) For **Q** *along the [001] direction, the cross section is a factor of 30 larger for transverse spins than for spins in the longitudinal polarization state. (b) For* **Q** *along [100], the cross section is large for the longitudinally polarized spins and for [010]-polarized transverse spins. The [001]-polarized transverse spins have a smaller magnetic scattering cross section.*

Results and Discussion

We have formed images of the spin polarization domains by using the spin-polarization dependence of the magnetic x-ray scattering cross section. The diffractometer was aligned to the (δ,0,1) reflection, and images of the extent of the magnetic scattering were made at 110 and 140K. At 110K, the spin polarization is longitudinal, and the entire **Q** domain leads to magnetic scattering and a signal at the detector [Fig. 3(a)]. Regions that are dark in Fig. 3(a) have **Q** $\perp$ [100]; spins in the dark region have a spatial modulation that does not satisfy the Bragg condition with these diffractometer settings. At 140K, above the spin flip transition at 123K, the extent of the **Q** domain is unchanged, but the magnetic scattering comes from a smaller area because only one of the transverse spin domains has a large cross section [Fig. 3(b)]. Areas that are dark in Fig. 3(b) but bright in Fig. 3(a) are thus in the portion of the **Q** || [100] modulation vector domain with **S** || [001].

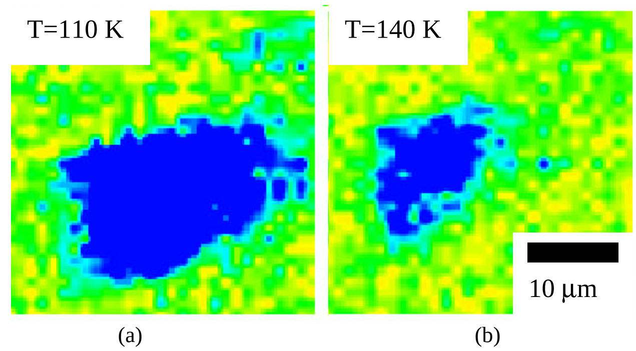

FIG. 3. Images at (a) 110K and (b) 140K of the intensity of the (d, 0, 1) reflection as a function of the position of the sample. At 110K, the entire **Q** *domain is visible, but at 140K, only the transverse SDW domain with S along [010] is visible.*

Acknowledgments

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