Micron-Scale Imaging of Antiferromagnetic Domains in Cr with Magnetic X-ray Microscopy

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Introduction

Below the Néel temperature of 311 K, the conduction electrons in metallic chromium are organized in an antiferromagnetic spin-density wave (SDW).[1] The SDW can be imagined as a sinusoidal modulation of the alternating spin structure typical of antiferromagnets. The period of this modulation is tens of lattice constants, as shown in Fig. 1(a) for the transverse SDW phase. Because the SDW period is incommensurate with the lattice, domains that differ in the orientation of the modulation vector Q can exist. In bulk Cr, Q is constrained to be along <001> directions, leading to three types of domains. Macroscopically observable phenomena such as anomalies in magnetic and mechanical responses[1] as well as the renewed importance of Cr layers since the development of exchange-biased magnetoresistive structures[2] have driven the development of a microscopic understanding of SDW domains in Cr. We have used magnetic x-ray microscopy to image SDW domains and to study the spin-flip transition at 120K.[3]

Method

In order to image antiferromagnetic domains in Cr, we used nonresonant magnetic x-ray scattering with an incident beam focused to a submicron spot by a Fresnel phase zone plate. A real-space map of the antiferromagnetic domain structure was produced by plotting the variation in the intensity of the magnetic scattering signal as the sample was scanned under the beam. The incommensurate SDW leads to magnetic reflections near forbidden Bragg reflections and also to conventional strain wave reflections near Bragg peaks. The locations of these reflections in the (0KL) plane of reciprocal space near (001) and (002) is diagrammed in Fig. 1(b).

Above the spin-flip transition temperature, $T_{SF} \approx 120$ K, spins are oriented transverse to the modulation direction in each SDW domain. Upon cooling through T_{SF}, the spin polarization rotates to point along the modulation direction so that only longitudinally polarized spins are observed. The orientations of the transverse and longitudinal spins are shown with the scattering geometry for this experiment in Fig. 1(c). We used a single crystal Cr (111) sample in which each of the three possible SDW domains was present.

Results and Discussion

A map of the intensity of the magnetic (0 0 1-δ) reflection in a 75 x 75 μm^2 area of the sample appears in Fig. 2(a). To reduce the background due to fluorescence of the sample, images of the magnetic reflection were made with 5.8-keV incident photon energy, below the Cr K edge. The same area was also imaged with the strain reflection at (0 0 2-2δ) as shown in Fig. 2(b). In order to use nearly the same diffractometer angles for the two reflections, an incident energy of 11.6 keV was used for the strain wave reflection. The sample temperature was 130 K, just above the spin-flip transition. The same SDW domain appears in both Fig. 2(a) and (b) and occupies the majority of each image. The maximum count rates for the two reflections were 10 s^{-1} and 1200 s^{-1}.

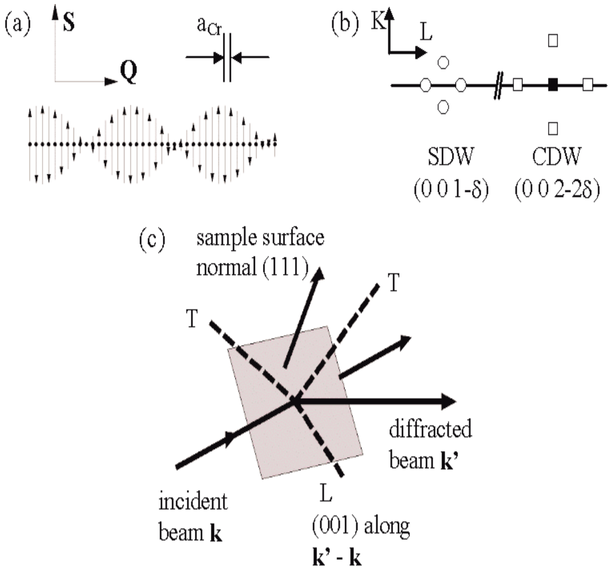

FIG. 1. (a) The transverse spin density wave state of Cr showing the relationship between the spin polarization S and the modulation wavevector Q. The period of the SDW is approximately 20 times the Cr lattice spacing, a_{Cr}. (b) A section of the (OKL) plane of reciprocal space, indicating the positions of the (002) allowed Bragg reflection (solid squares), charge density wave satellite (open squares), and spin density wave satellite (open circles). (c) The diffraction geometry for a Q || (00L) domain. Dashed lines give the directions for transverse and longitudinal spin polarizations (marked with T and L respectively).

The transition between transverse and longitudinal polarization can be observed by making use of the spin-polarization

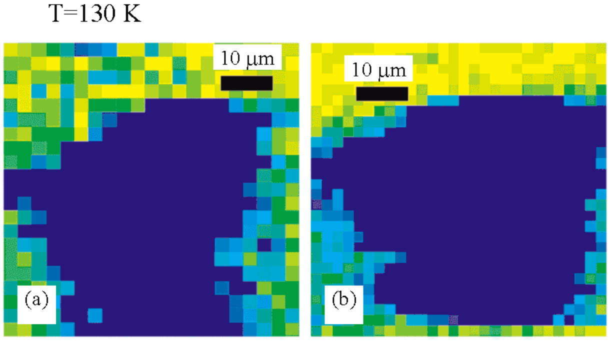

FIG. 2. Images at 130 K, in the transverse SDW phase, of the intensity of scattering in the (a) (0 0 1-δ) magnetic reflection and (b) (0 0 2-2d) strain wave reflection as the sample was scanned under the microprobe beam. The color scale ranges from yellow (lowest intensity) to blue (highest intensity).

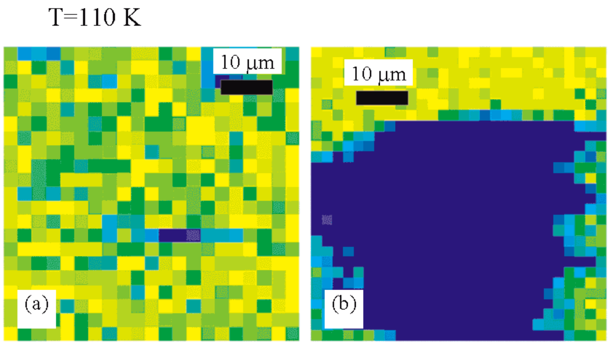

FIG. 3. Images formed as in Fig. 2, with the sample at 110 K in the longitudinal SDW phase. The intensity of the magnetic reflection (a) has diminished due to the rotation of the spin polarization upon cooling through the spin flip transition. The strain wave reflection (b) is unchanged.

dependence of the nonresonant magnetic x-ray scattering cross section. With our scattering geometry, shown in Figure 1(c), the magnetic scattering from transverse spins is a factor of at least 20 more intense than the scattering from longitudinal spins.[4] The images shown in Fig. 3, with the sample held at 110K (a temperature below the spin flip transition) demonstrate this effect. The domains of the SDW modulation direction Q are unchanged, but the magnetic scattering is completely suppressed. We have used this effect to study the spin-flip transition at the micron scale and found that the spin-flip transition temperature can vary by several degrees, even at the scale of a single SDW domain.[3]

Acknowledgments

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