Magnetic-Field Control of Ferroelastic Domains in $FeCr_2O_4$

The magnetic field response of Jahn-Teller distortion associated with the *e* orbital was investigated by synchrotron X-ray diffraction in $FeCr_2O_4$. This compound exhibits successive phase transitions associated with the spin and orbital degrees of freedom of Fe^{2+} ions with six 3*d* electrons (*S*=2) on the tetrahedral sites. Structural domains exhibit two-step rearrangements when a magnetic field is applied along the *c*-axis in the orthorhombic phase of $FeCr_2O_4$. The domain rearrangements result in large magnetostriction, which approaches 0.28%. The *c*//**H** domain does not reappear even after the magnetic field is removed, resulting in residual striction of about 0.1%.

Materials with large magnetostriction show promise for the design of actuation devices with large stroke. The orbital degree of freedom in strongly correlated electron systems influences physical properties such as magnetic anisotropy, lattice elasticity, and electric conductivity. If the occupied 3*d* orbital state is coupled to electron spin, the Jahn-Teller distortion can be changed by applying a magnetic field, and consequently large magnetostriction arises in such materials. In this work, we investigated the response of Jahn-Teller distortion to an external magnetic field in $FeCr_2O_4$ [1].

X-ray diffraction measurements were performed on BL-3A. The photon energy of the incident X-ray beam was 14 keV. A single-crystalline sample was mounted in a split-type superconducting magnet. The magnetic field direction was set parallel to the $[001]_c$ axis in the cubic setting. The X-ray diffraction profile of $(660)_c$ reflection was measured by using a CCD camera to investigate domain alignment. Note that the (066), (606), and (660) reflections correspond to domains in which the *a*, *b*, and *c* axes orient parallel to the external magnetic field, respectively, since the magnetic field is perpendicular to the scattering plane.

Figure 1 shows X-ray diffraction profiles of a single crystal of $FeCr_2O_4$ in several magnetic fields at 7 K, where the chromite is in the conical spin phase. After zero-field cooling, the (660) reflection is clearly split into three peaks because of orthorhombic distortion [2]. The (606) reflection disappears at 0.4 T and the intensity of the (066) reflection increases, indicating that the *b* axis is interchanged with the *a* axis in the domain where the *b* axis initially orients parallel to the magnetic field (*b*//**H**). Increasing the magnetic field to 4 T, the (660) reflection also disappears, indicating that the *c* and *a* axes are swapped in the *c*//**H** domain. As a consequence, only *a*//**H** domains remain. The relation between magnetization direction and Jahn-Teller distortion strongly indicates that the occupied 3*d* orbital should tend to extend vertical to the spin direction. When the magnetic field is removed, the (606) reflection reappears, suggesting that 75% of the *b*//**H** domain is restored. On the other hand, the (660) reflection corresponding to the *c*//**H** domain does not reappear, as shown in Fig. 1.

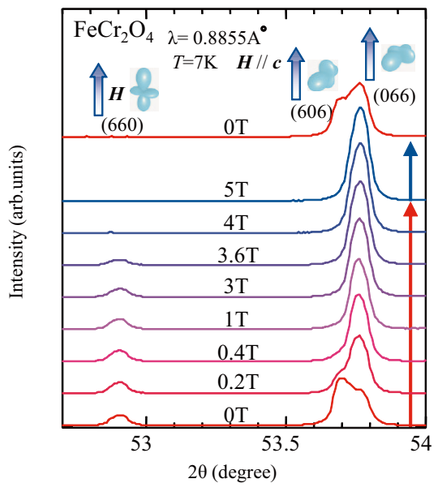

Figure 1
X-ray diffraction profiles of (660), (606), and (066) reflections of $FeCr_2O_4$ in several magnetic fields at 7 K [1].

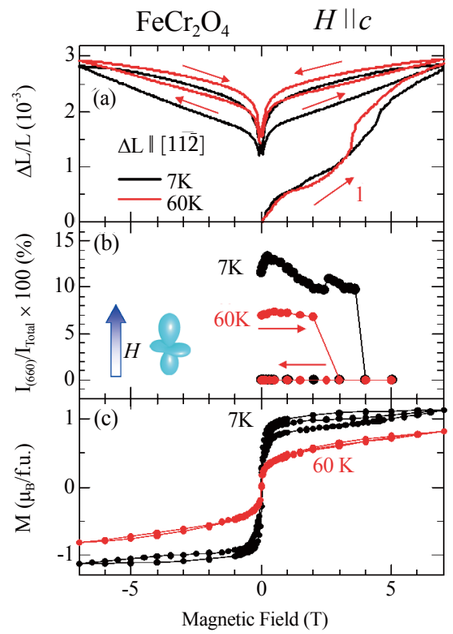

Figure 2
Magnetic field dependence of (a) relative strain observed using a strain gauge, (b) intensity of X-ray (660) diffraction, and (c) magnetizations of $FeCr_2O_4$ at 7 K and 60 K. All the measurements were performed after a zero-field cooling process [1].

Rearrangement of the domain structure causes magnetostriction. If the six types of domains are generated at random in zero-field cooling, the magnetic-field-induced strain $\Delta L/L$ along the $[001]_c$ axis is expected to approach 10×10^{-3}. Figure 2 (a) shows $\Delta L/L$ along $[11–2]_c$ as a function of the magnetic field along the $[001]_c$ axis at 7 K measured by a strain gauge. Rapid growths of $\Delta L/L$ are observed at around 0 T and 4.5 T in the first field-increasing run, corresponding to the domain rearrangements, as shown in Fig. 2 (b). One can also see residual strain of 1.2×10^{-3}, which is attributed to non-reversible domain switching. Hysteresis in the magnetization process shown in Fig. 2 (c) also originates from the domain rearrangements. Similar striction is observed also in the collinear ferrimagnetic phase.

REFERENCES

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