Search for Charge Density Waves in Optimally Doped YBCO Superconductor

Z. Islam,[1] S. K. Sinha,[2] D. R. Lee,[1] J. C. Lang,[1] D. Haskel,[1] G. Srajer,[1]
D. Haeffner,[1] Z. Zhang,[3] S. C. Moss,[3] P. Wochner,[4] W. N. Hardy[5]
[1]Advanced Photon Source, Argonne National Laboratory (ANL), Argonne, IL, U.S.A.
[2]Department of Physics, University of California, San Diego, CA, U.S.A.
[3]Physics Department, University of Houston, Houston, TX, U.S.A.
[4]Max-Planck-Institut für Metallforschung, Stuttgart, Germany
[5]University of British Columbia, Vancouver, British Columbia, Canada

Introduction

We present the results of a high-energy x-ray scattering experiment in search of charge density waves (CDWs) in an optimally doped $YBa_2Cu_3O_{6.92}$ (YBCO) crystal. A wide array of experiments, including reverse-bias scanning tunneling microscopy (STM) [1], neutron diffraction [2], nuclear magnetic resonance/nuclear quadrupole resonance (NMR/NQR) [3-5], and far-infrared (FIR) ellipsometry [6], report the existence of CDWs in the optimally doped YBCO. The CDWs are thought to form along the 1-D CuO chains (**b** axis) with a periodicity of four unit cells. Recent neutron diffraction studies found evidence of charge stripes with modulations of (0.235, 0, 0) and (~0.33, 0, 0) in Refs. 7 and 8, respectively. In this work, we intend to use x-rays to look for superlattice peaks corresponding to these charge modulations and study their temperature dependence.

Methods and Materials

We used a twinned crystal of optimally doped YBCO grown at the University of British Columbia. The sample was a thin, rectangular, 2×1-mm plate with a thickness of less than 100 μm. The crystallographic **c** axis is perpendicular to the large facet. The magnetization measurements revealed the onset of diamagnetic behavior at 93.75K in an applied field of 0.2 Gauss. Complete diamagnetic behavior sets in within ~0.5K below this temperature, suggesting a high degree of compositional homogeneity in the bulk of the sample. Although the transition is very sharp, we observed the presence of very weak Debye-Scherrer rings by using a Weissenberg setup and a charge-coupled device (CCD) camera with an incident energy of 65 keV. This indicates the presence of a minute amount of extraneous phases, either on the exterior or in the bulk of the sample. The high-energy study was carried on the Synchrotron Radiation Instrumentation Collaborative Access Team (SRI-CAT) 1-ID beamline by using 36-keV x-rays. A Si (3 1 1) reflection was used to monochromatize the beam with the undulator fifth harmonic tuned to provide maximum flux at this energy. Intensity was measured by using a Ge solid-state detector. The sample was cooled in a closed-cycle He refrigerator. A diode sensor placed 12 mm from the sample monitored its temperature.

Results

The top panel in Fig. 1 shows a scan along **a*** near the (5, 0, 0) charge Bragg peak at low temperature (8K). A superlattice peak corresponding to a wave vector of $\mathbf{q}_0 = (1/4, 0, 0)$ is clearly visible. The peak intensity is ~450 counts/s, which is some 10^7 orders of magnitude weaker than that of a Bragg peak. We note that the maximum intensity for the peak is observed at K = -0.04. The peak width in the a* direction is much larger than the resolution, indicating a shorter-range correlation along the **a** axis. The bottom panel shows the temperature dependence of this peak. The intensity of the scattering was obtained by fitting a Gaussian function to the K scan (transverse to the **a*** direction) through the peak at each *T*. The background, which is predominantly made up of thermal diffuse scattering (TDS), was found to decrease linearly with temperature, as expected. The diffuse-scattering intensity of the $\mathbf{q}_0$ peak, however, increases at low temperature and appears to level off below ~100K. At 8K, the intensity is larger than the intensity at room temperature by more than a factor of 2.

Figure 2 shows a scan along the **c*** axis through (5.25, -0.04, 0) peak at 8K and 300K. There is clearly a strong intensity modulation that is not purely sinusoidal. Even more interesting is the fact that the modulation at room temperature is remarkably different than at low temperature. This behavior suggests that the nature of the correlation of scattering objects on different scattering planes perpendicular to the **c** axis changes significantly at cryogenic temperature. A direct Fourier transform of the data shows that diffractions from the CuO_2-plane, CuO-chain, and the apical-O plane are correlated. The details of the correlations and their temperature dependence are being worked out.

Discussion

We have made a clear observation of a superlattice peak that becomes significantly stronger at cryogenic temperature. Our observation of $\mathbf{q}_0$ is consistent with earlier neutron diffraction work [7] that found a peak at (0.235, 0, 0). This peak was thought to be due to fluctuating charge stripes in the CuO_2 planes, although there are no matching spin stripes at the expected wave vector of half that value. Since the crystal was twinned, an unambiguous determination of $\mathbf{q}_0$ is difficult. Work is underway to resolve this ambiguity.

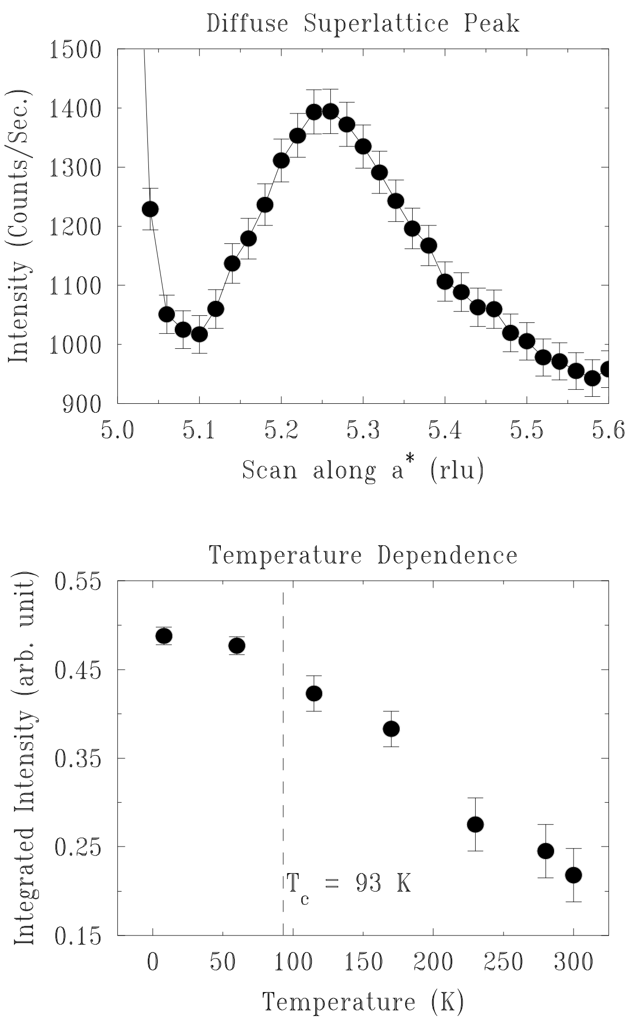

FIG. 1. Top panel: Scan along the ***a**** *axis near (5, 0, 0) Bragg peak at 8K. Bottom panel: Temperature dependence of the diffuse superlattice peak (background that is primarily TDS has been removed).*

Acknowledgments

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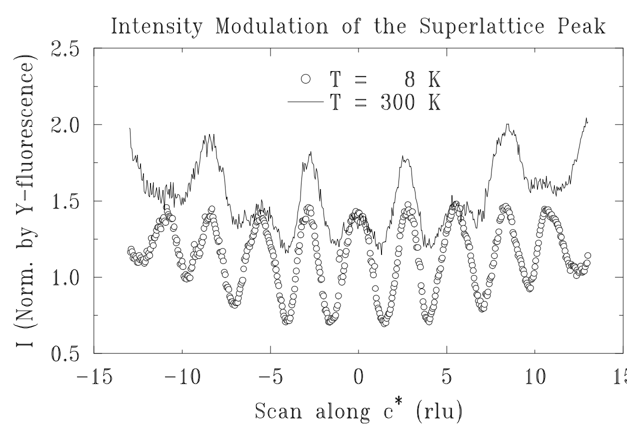

FIG. 2. Intensity modulation of the (5.25, -0.04, 0) peak along the ***c**** *axis. Solid line is for data at room temperature; circles are for 8K data.*