Coexistence of long-range antiferromagnetism and short-range inhomogeneous superstructures in an insulating YBCO compound

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Introduction

Numerous experiments indicate that high-T_c cuprate superconductors are intrinsically inhomogeneous even in their superconducting state. These inhomogeneities appear to have various length scales ranging from a nanometer to tens of nanometers, associated with, for example, atomic-scale electronic disorder [1] as in BSCCO and lattice modulations as in the yttrium-barium-copper oxide ($YBa_2Cu_3O_{6+x}$, YBCO) superconductors [2]. As a parent Mott insulator is doped with charge carriers, the long-range antiferromagnetic (AF) state is destroyed, and superconducting ground state emerges above a certain critical doping level. Although the presence of inhomogeneities have been observed in the superconducting part of the phase diagram, it is not clear if the parent insulating compound itself is intrinsically inhomogeneous. In this work, we present unambiguous x-ray scattering results suggesting the coexistence of short-range-ordered incommensurate lattice modulations and long-range ordered AF phase in a high-quality single crystal of YBCO insulator (x=0.14, T_N~405K; tetragonal).

Methods and Materials

Nonresonant magnetic (7.848 keV) and high-energy (36 keV) diffuse x-ray scattering techniques were used on the XOR 4-ID-D beamline to determine the long-range AF order [3] and to search for short-range ordering in a single-crystal sample of YBCO. For the chosen composition, YBCO is a Mott insulator deep within the AF part of the phase diagram. A tandem analyzer-polarizer setup was employed for the polarization analysis in the magnetic scattering part of the work [3].

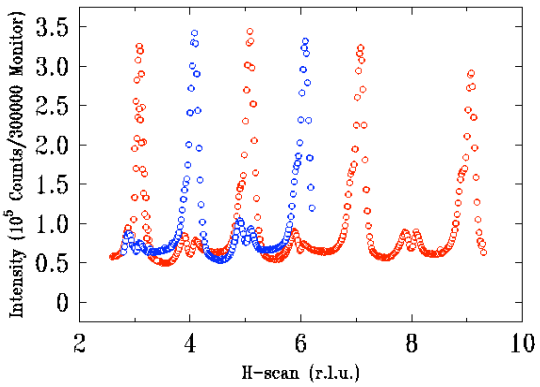

Fig. 1. H-scans for K=0 (red) and K=-1 (blue) at 10 K. L=2.6 in both cases.

Results

Figure 1 shows H-scans for different values of K collected far away from Bragg points. Strong asymmetric peaks characterized by a single wavevector (~0.1, 0, 0) appear on either side of Brillouin zone centers (integer H values). When H and K are of mixed parity, satellites are strong near odd integer H and become weak for same parity. Correlation lengths of the modulaitons in the Cu-O basal plane are only a few unit cells (nanometers) in exent. Preliminary analyses suggest correlated atomic displacements on CuO, BaO, and CuO_2 planes, respectively, to be the origin of the modulation, consistent with the formation of local O ordering in the CuO chains [4], although in the average tetragonal structure the dopant O atoms are supposed to be randomly distributed. Long-range strain (~10 nm) induced by the same dopant O atoms is also present (Fig. 2). Non-resonant magnetic scattering has revealed long-range AF ordering with correlation lengths of ~100 nm in the same crystal (Fig. 3).

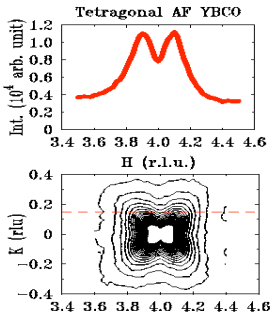

Fig. 2. Bottom: Contour plot of Huang scattering due to long-range strain; Top: Instensity along the red dashed line (bottom); TDS gives a single peak.

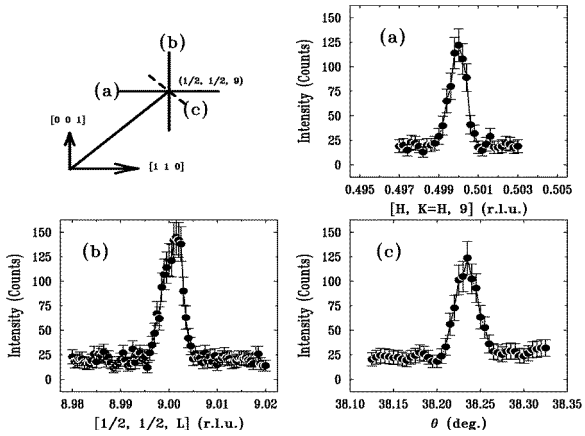

Fig. 3. (a) Longitudinal, (b) L, and (c) transverse scans through (½,½,9) AF Bragg peak, respectively [from 3].

Discussion

Short-range lattice modulation and long-range strain introduce two intrinsic nanometer length scales within the AF phase of YBCO. Thus, YBCO compounds are inhomgeneous throughout the entire electronic phase diagram.

Acknowledgments

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