ESRF

Experiment title:
Phase ordering kinetics of the random field ortho-I to ortho-II transition in $YBa_2Cu_3O_{6+x}$

Experiment number:

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Report:

The cell-doubled ortho-II phase is a predominant structural feature of the high temperature superconductor $YBa_2Cu_3O_{6+x}$. It is characterized by short range ordered alternating full and empty CU-O chains in the basal plane, and associated atomic displacements of surrounding atoms, giving rise to strongly modulated diffuse superstructure peaks. The absence of long range order was suggested (*PRL* 74, 1446, (1995)) to arise from random-field effects or from an intrinsic tendency towards glassy behaviour. To investigate the issue of the ordering kinetics and transition character further, this experiment directly measured the correlation length development upon quenching from the disordered to the ordered ortho-II phase.

A 2 mg single crystal of $YBa_2Cu_3O_{6.5}$ was mounted in a specially designed small oven capable of quenching rates of up to 10 °C/sec. The large Kappa diffractometer was used with 22 keV x-rays focussed both horizontally and vertically. The sample was quenched from 1800 C to various temperatures (150, 140, 130, 125, 120, 100,90, and 80) in and around the mid-point of the transition near 125 “C. The short time ordering (10 s < t <20 rein) was determined from measurements of the peak intensity of the (4.5,0,0) superstructure peak. For longer times (1 min < t <8 hrs), the c-axis correlation length was directly determined from repeated l-scans over the (4.5,0,0) peak fitted to Lorentzian-squared line shapes. As a check, h-scans were also conducted over the (1.5,0,8), and the same behaviour was found, although with a larger uncertainty due to the limited intensity and larger resolution function correction. Scans along k were not feasible under these experimental conditions (resolution-intensity tradeoff). A given quench measurement was limited to less than 8 hours, due to poor reproducibility before and after injection (beam heating of the optics resulted in significant travel of the beam spot on the sample, where the varying sample mosaicity and crystal thickness resulted in different apparent correlation lengths). After equilibration, the beam spot would not come to rest at exactly the same position, so that a sample realignment was necessary after each refill.

The peak intensities measured rapidly for short times were matched to the correlation lengths at longer times by taking the square root of the peak intensity together with an appropriate scale factor (this relation arises from resolution function arguments). The data for all times and temperature could be fitted by a single stretched exponential form $\xi(t) \sim 1 - \exp\left(-\sqrt{t/\tau}\right)$ (See Fig. 1). It is important to realize, however, that the signature of equilibration implied in such a function was only observed for temperatures above 1100 C. At lower temperatures, no sign of saturation was observed (See Fig. 2), making it necessary to measure for longer times than what was reasonable in this experiment. Figure 1 shows the full data set, plus fits collapsed onto a universal curve; the straight line corresponds to $\sqrt{t}$ Allen-Cahn growth expected for a pure system with a non-conserved scalar order parameter (NCOP). Figure 2, illustrates, however, that the low temperature late-time evolution is also consistent with logarithmic growth. The insert of Fig. 1 is a plot of the fitted τ vs T, which is extremely steep. Its analysis is still ongoing, in particular with respect to analogous superconducting T_c vs time data.

This experiment directly shows for the first time early stage ortho-II growth kinetics consistent with the expected behaviour of both a pure NCOP system and the early time growth in a NCOP random field system. However, longer measurement times are needed in order to decide which scenario is the correct one (random-field or some other type).

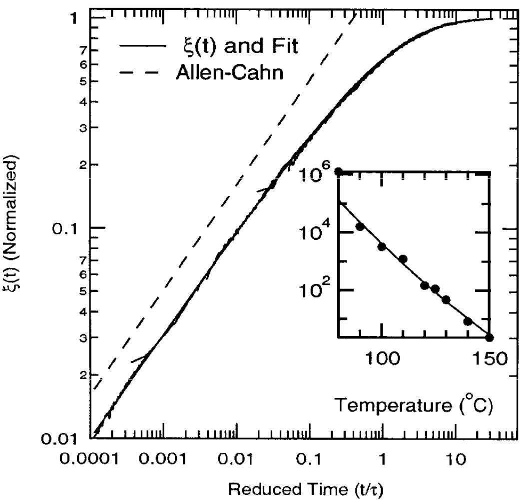

Fig. 1 Scaling plot of the Ortho-II correlation lengths vs time for all quenches. The fitted stretched exponential is also shown, but the agreement is sufficiently good to make it indistinguishable from the data. The dashed line corresponds to Allen-Cahn $\sqrt{t}$ growth. This inset shows the fitted τ (in see) vs temperature. The solid line is an Arrhenius type fit with an activation energy of 1.9 eV. The fitted prefactor, however, is of the order of 10^{-24} see, which is quite unphysical.

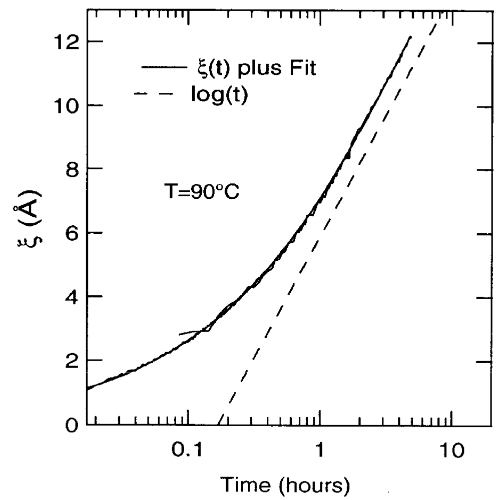

Fig. 2 Plot of the c-axis correlation length development at 90 °C. The fitted stretched exponential is also shown. The dashed line shows the expected dependence for logarithmic growth. Note that this curve alone is equally consistent with both scenarios: Stretched exponential behaviour, or a crossover from Allen-Cahn to logarithmic growth.