Title	YBCOの酸素欠損位置と超伝導転移温度の関係に関する電子エネルギー損失分光(EELS)研究)
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Abstract

The superconducting transition temperature (T_c) in $YBa_2Cu_3O_{7-\delta}$ (YBCO) is known to exhibit a strongly nonlinear dependence on the oxygen deficiency parameter δ. While this behavior has long been associated with the distribution of oxygen vacancies among different crystallographic sites—particularly the Cu–O chains and CuO_2 planes—the lack of direct, spatially resolved experimental data has limited our understanding of the underlying mechanisms. In this study, we employed scanning transmission electron microscopy combined with electron energy-loss spectroscopy (STEM-EELS) to investigate the site-specific oxygen deficiencies in a series of YBCO thin films with different T_c values (49 K, 64 K, 81 K, and 86 K). Our goal was to elucidate how the spatial distribution of oxygen deficiencies affects superconducting properties, and in particular, to understand the origin of the well-known 60 K plateau in the T_c–δ phase diagram.

The YBCO thin films were synthesized by pulsed laser deposition (PLD) on $LaAlO_3$ (001) substrates and subjected to post-deposition annealing under various oxygen pressures to systematically control the oxygen content. Cross-sectional STEM specimens were prepared using focused ion beam (FIB) milling and low-energy Ar^+ ion polishing to ensure high-quality, damage-free lamellae. High-angle annular dark field (HAADF) imaging was used to identify structural features and guide site-specific EELS measurements. EELS spectra were acquired at atomic resolution, and changes in the pre-peak of the O K-edge—associated with hybridized O 2p–Cu 3d states—were used as a sensitive indicator of local oxygen deficiency.

Our results reveal that in YBCO thin films with $T_c \approx 81$ K and 64 K, oxygen deficiencies predominantly occur at the Cu–O chain sites, while the CuO_2 planes remain relatively intact. In contrast, in the more heavily deoxygenated sample with $T_c \approx 49$ K, significant oxygen loss is observed at both the Cu–O chains and the CuO_2 planes. This transition from chain-only to chain-plus-plane deficiency correlates with a sharp suppression of T_c, consistent with theoretical models suggesting that the electronic structure of the CuO_2 planes is directly responsible for superconductivity, while the Cu–O chains primarily act as a charge reservoir.

These findings provide direct experimental evidence linking the spatial distribution of oxygen deficiencies to the superconducting properties of YBCO. Furthermore, they offer a plausible explanation for the persistence of the 60 K plateau: as long as oxygen loss is confined to the Cu–O chains, the hole concentration in the CuO_2 planes remains relatively stable, preserving superconductivity around 60 K despite variations in δ. Only when oxygen deficiencies begin to affect the CuO_2 planes directly does T_c drop significantly. This work highlights the unique capability of STEM-EELS to resolve local structure–property relationships at the atomic scale and provides new insights into the microscopic origins of superconductivity modulation in high-T_c cuprates.

Key words: YBCO, transition temperature,60 K, STEM-EELS, oxygen deficiency.