Substrate Engineering to tune the ground state of nanoscale cuprates thin films

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A central challenge in cuprate high-temperature superconductors is the limited ability to tune their intrinsic properties. In contrast to many two-dimensional materials, the carrier density in cuprates is typically fixed during synthesis, leaving few means to externally control their electronic phases. Developing new ways to tune these materials is therefore essential for uncovering the mechanisms behind high-temperature superconductivity and for realizing enhanced performance.

Strain engineering has recently emerged as a powerful approach to manipulate the key properties of cuprates—particularly charge and spin orders and their delicate interplay with superconductivity. Thin-film cuprates, in particular, offer new degrees of freedom through their interaction with the underlying substrate.

In this presentation, I will show how the nanoscale surface morphology of reconstructed substrates can be used as an effective tuning knob. Nanofaceted substrates formed during high-temperature annealing induce a unidirectional potential landscape in nanometer-thick $YBa_2Cu_3O_{7-x}$ films, stabilizing electronic nematicity and a unidirectional charge density wave (CDW). The resulting ground state is qualitatively distinct from that of thicker films and bulk crystals [1,2].

Strikingly, this nanoscale structural tuning also leads to a substantial enhancement of superconductivity: the onset transition temperature increases by more than 20 K, and the upper critical magnetic field exceeds that of equivalently doped single crystals by over 50 T [3]. These effects can be captured by an effective interfacial potential at the film–substrate boundary, which couples to the emergent nematic and CDW orders.

Overall, these results demonstrate that substrate and strain engineering provide powerful and versatile routes to tune and enhance superconductivity in cuprates, establishing a new paradigm for designing high-performance quantum materials.

[1] Restored strange metal regime via suppression of charge density waves in an underdoped cuprate superconductor. E. Andersson, … T. Bauch, F. Lombardi, Science 373, 1506 (2021)

[2] Tuning the ground state of cuprate superconducting thin films by nanofacets substrates, G. Mirarchi, …, T. Bauch, …, F. Lombardi, G. Seibold, Commun. Materials 5, 146 (2024).

[3] Boosting superconductivity: how nanofaceted surfaces transform the ground state of ultrathin YBCO thin films, E. Wahlberg,…, T. Bauch, F. Lombardi, accepted for publication in Nature Comm., arXiv.2502.03986References