

Two-dimensional terahertz spectroscopy of c -axis superconducting coherence in La-based cuprate superconductors

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High- T_c cuprate superconductors (SCs) exhibit highly anisotropic, layered structures comprising superconducting CuO_2 planes separated by insulating layers. Below the superconducting transition temperature (T_c), Josephson couplings between those planes give rise to a supercurrent flow along the c -axis. Recently, two-dimensional terahertz (2D-THz) spectroscopy has emerged as a powerful tool to isolate and detect nonlinear responses originating from this Josephson current in the frequency space. However, detailed investigations of the nonlinear responses, particularly in the fluctuation regime above T_c , remain to be fully established.

In this study, we performed 2D-THz spectroscopy on La-based cuprate SCs, specifically $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ (LSCO) and $\text{La}_{1.6-x}\text{Nd}_{0.4}\text{Sr}_x\text{CuO}_4$ (LNSCO), which host competing or coexisting orders such as the stripe order. In both systems, the Josephson-current-driven nonlinear signals were clearly observed in the superconducting phase below T_c . Notably, in LNSCO ($x=0.15$), the nonlinear signals persisted at temperatures well above the bulk T_c , suggesting the survival of c -axis superconducting coherence in the stripe ordered phase. Given that bulk superconductivity in LNSCO is suppressed concomitant with the development of static stripe order, our comparative results demonstrate that the stripe order plays a pivotal role in stabilizing the observed nonlinear signals above T_c . The nonlinear signal in LNSCO disappears around the onset temperature of 2D superconductivity determined by the magnetic susceptibility measurement [1]. Additionally, we performed optical-pump 2D-THz spectroscopy. The observed nonlinear signals were modulated from their equilibrium states, suggesting that 2D-THz spectroscopy is capable of probing ultrafast dynamics.

In this presentation, we will discuss the origin of the nonlinear signal in the stripe phase with respect to the PDW order to gain insight into the interplay between the stripe order and the superconductivity.

References:

[1] J. F. Ding *et al.*, Phys. Rev. B **77**, 214524 (2008).