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Two-gap behaviors of the high-T_c cuprate superconductors: Universal versus material-dependent properties

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One of the central issues in the research of the high-T_c cuprates superconductors is whether the pseudogap is a distinct phenomenon from superconuctivity or a gap due to local pairing or incoherent superconducting fluctuations above T_c. In the former scenario, a possible origin of the pseudogap is preformed Cooper pairs lacking phase coherence. In the latter scenario, the pseudogap is due to a competing order such as spin density wave, charge density wave, d-density wave, etc. It has been well known that the pseudogap in the anti-nodal (π,0) region increases with underdoping as observed by angle-resolved photoemission spectroscopy (ARPES). However, the energy gap measured by other experimental methods such as Andreev reflection, which is more directly associated with superconductivity, exhibits opposite trend, that is, the gap decreases with underdoping, suggesting a different origin of the superconducting gap from the antinodal gap.

A recent ARPES study of $Bi_2Sr_2Ca_{1-x}Y_xCu_2O_8$ (Bi2212) has revealed the presence of two distinct energy gaps in different regions of momentum space [1,2]. One is the antinodal region as mentioned above, and increases with underdoping. The other opens in the near-nodal region showing a coherent peak, and does not increase with underdoping. On the other hand, attempts have been made to understand the pseudogap within a single *d*-wave energy gap [3]. In such a single gap picture, preformed Cooper pairs are the most likely origin of the pseudogap.

Since the doping and temperature dependences of the energy gap would reveal the entangled two-gap behavior, we have investigated the energy gap of lightly- to optimally-doped LSCO by ARPES as a function of doping and temperature. In the present work, the momentum dependence of the gap clearly exhibits two-gap behavior as in the case of heavily underdoped Bi2212: the pseudogap Δ^* in the antinodal region and the d-wave like gap Δ_0 around the node (Fig. 1). The doping dependence of the obtained parameter Δ_0 qualitatively explains the reduction of the T_c with underdoping. Furthermore, from comparison of the present results with those on Bi2212 and other cuprates with higher T_c's, we have found that the magnitude of the Δ^* and the pseudogap temperature T^* is not appreciably material-dependent, suggesting that the pseudogap is properties of a single CuO_2 plane. On the other hand, the magnitude of the Δ_0, which is proportional to the superconducting gap, is strongly material-dependent (CuO_2 layer number dependent) like T_c, suggesting that they are influenced by the effect of neighboring CuO_2 planes and block layers.

References

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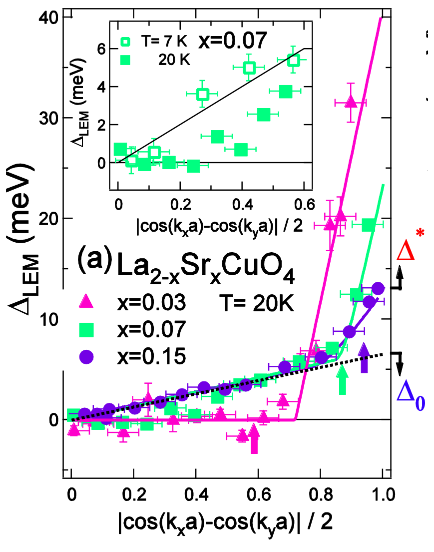

Fig. 1. Angular dependence of the gap of LSCO observed by ARPES. The definition of Δ^* and Δ_0 is shown for x=0.15.