Superconductivity, magnetism and nematicity in thin films of Fe chalcogenides

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Fe chalcogenide is unique in the sense that it shows at least three different superconductivities (SCs) in the same material; (1) 10-40 K SC with both of hole and electron Fermi surfaces (FSs), which is observed for the broadest cases, including physically pressurized cases, (2) 40-50 K SC with electron FS alone, often realized by the electric field doping and various intercalation etc., (3) 65 K (or higher) SC in ultrathin films on some oxide substrates. In particular, as for the 1st category, Te substituted FeSe, $FeSe_{1-x}Te_x$, in thin film form shows a characteristic T_c behavior as a function of Te content x. Introducing Te suppresses the nematic transition temperature T_0, which vanishes at around a critical concentration x_c, dependent on the degree of strain, and brings a succeeding sudden increase of T_c (for instance 13 K just below x_c to 23 K just above x_c), followed by a gradual decrease of T_c for further increase of x[1]. This T_c behavior is in contrast to that of 2nd category[2], where T_c of Te substituted samples monotonously decreases, suggesting the presence of novel important physics. Since the strain dependences of T_c and T_0[3] are completely reproduced in bulk crystals[4,5], data in film samples should be understood on the same ground in a continuous manner with those of bulk crystals. On the other hand, we recently found that the nematic transition is purely electronic without any lattice distortion in film samples[6]. This means that $FeSe_{1-x}Te_x$ films provide a unique valuable playground to observe the pure responses of electrons unaffected by lattice. We have studied $FeSe_{1-x}Te_x$ (and also $FeSe_{1-y}S_y$) PLD grown films by dc transport[7], ARPES[8], optical properties[9], magnetic properties by μ-SR[10] and DFT calculation[11] above T_c, and superfluid density and quasi-particle dynamics below T_c[11]. Based on all of these studies, and keeping the pure electronic aspect of the responses in these epitaxial film samples in mind, we find that (1) the sudden increase of T_c just after the disappearance of the nematic transition at x_c is caused by the change of the carrier density/density of state of Fermi level at x_c, (2) succeeding gradual decease of T_c with further increasing x is due to the increase of electron correlation, (3) the so-called Uemura relation between T_c and the superfluid density is valid irrespective with the presence/absence of the nematic transition, suggesting that the superconducting mechanism is common in a broad sense, (4) superconducting gap structure is different between SC below x_c and above x_c, which might be related to the orbital switch at the Fermi level caused by the upward shift of d_{xy} orbital with increasing x. These suggest that the characteristic T_c behavior as a function of x is not in line with a scenario which assumes a quantum critical point at some x value, and rather consistent with a more conventional scenario.

We also studied SCs in categories 2 and 3, and realized the highest zero resistivity temperature[2] and the interface superconductivity as the first successful case among PLD grown films[12].

We will introduce detailed data on these issues in the talk.

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