Thesis Summary

Development of Laser-ARPES System for the Study of the Electronic Structure of Unconventional Superconductors

(非従来型超伝導体の電子構造の研究のためのレーザーARPES システムの開発)

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Superconductors are among the most expected materials that would make huge changes in our lives. They present remarkable physical properties such as zero-resistance and diamagnetism below a certain critical temperature T_c. After many years of investigations, finally, the first microscopic theory of superconductivity in metals was formulated which is widely known as the BCS theory. The central idea of this theory is a weak electron-phonon interaction which leads to the appearance of an attractive potential between two electrons. As a consequence, they form the Cooper Pairs which have some bosonic properties, and bosons, at a sufficiently low temperature, can form a large Bose-Einstein condensate. However, in 1986, the high-T_c superconductors were discovered in copper-oxide system (cuprates). The maximum record of T_c has exceeded the prediction a lot much higher and the mechanism of such high-T_c superconductors could not be explained by the conventional BCS theory anymore. This unexpected founding trigged the investigation boom of the high-T_c superconductors all over the world.

For cuprate superconductors, the hybridization of copper $d_{x^2-y^2}$ orbital and oxygen p_x/p_y orbital forms the low-energy electronic band responsible for the superconductivity. Replacing small amount of Cu with another transition-metal element, one can introduce impurities right on the CuO_2 planes, namely the stage of high-T_c superconductivity, and consequently reduce the maximum critical temperature T_c^{max}. This provides us with a good opportunity to investigate the relation between the energy gap and the high-T_c superconductivity.

Physical properties of cuprate superconductors differ from each other, depending on the number of cupper-oxide layers stacked in a unit cell. As an example, it causes obvious increase in critical temperature T_C when the number of cupper-oxide layers increases from 1 to 3. Such an interesting feature of cuprates indicates a kind of interaction between cupper-oxide layers. Interaction between two cupper-oxide layers in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) results in the splitting of electronic band dispersion near Fermi Surface.

Angle-Resolved photoemission spectroscopy (ARPES) takes the technique of photoemission spectroscopy (PES) one step further, and it is the most efficient experimental technique to determine the entire band structure of a material. ARPES can probe not only the energies but also the momenta of the photoelectrons in solids. Low-energy laser-based ARPES will give us more opportunities on the bulk sensitive studies with the ultra-high energy, momentum and spacial resolutions.

In present thesis, we show our efforts on the development of a low energy laser-based μ-ARPES system. Furthermore, with the advantages (ultra-high spacial resolution etc.) of the μ-ARPES system, we perform its applications on the FeSe superconductor. Secondly, we also show our work on the upgrading of the μ-ARPES system by realizing the polarization-tunable laser light with the help of lambda optics. Using the advantage of polarization-tunable laser, we perform a systematic study on the bilayer band splitting for Bi2212 cuprates.

We also report our bulk sensitive photoemission studies of unconventional superconductors. Such as the systematic low-energy ARPES study of $Bi_{2.1}Sr_{1.9}Ca(Cu_{1-x}Ni_x)_2O_{8+\delta}$ (x = 0, 0.01, 0.03) and the HAXPES study of layered phosphide $ZrP_{2-x}Se_x$ superconductors.