A high-resolution angle-resolved photoemission spectroscopy study of many-body interactions in the Al(100) surface state

（高分解能角度分解光電子分光によるAl(100)表面状態の多体効果に関する研究）

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The microscopic understanding of the electronic properties of metals is a fundamental problem in condensed matter physics. Historically, the first theory capable of giving a qualitatively explanation of metallic behavior is based on the “independent-particle picture”. But in the real, electrons interact with the surroundings in the solids. Therefore, dependent particle picture or many-body interactions should be considered [1]. Furthermore, many-body interactions attract much interest in various systems due to its important role in the understanding of many physical properties in solids.

One of the most powerful experimental probe for the many-body interactions is the high-resolution angle-resolved photoemission spectroscopy (ARPES). Energy-band dispersion of electron states including the information of many-body interactions can be observed by the ARPES measurement. Recently, the energy and momentum resolutions of ARPES have been drastically improved, and it is now possible to examine fine electronic structures, such as a kink structure or a sudden reduction of the Fermi velocity near the Fermi level ($E_F$) in detail. By means of the quantitative analyses of high-resolution ARPES lineshape, one can evaluate the dimensionless coupling parameters of the electron-phonon interaction ($\lambda_{ep}$) and electron-electron interaction ($\lambda_{ee}$) at a given point on Fermi surfaces.

On the Al(100) surface, there exists a free-electron-like surface-derived state centered at the $\Gamma$ point of the surface Brillouin zone (SBZ). The energy distribution curves (EDCs) of the Al(100) surface state have been quantitatively examined using a one-step-model calculation. Many high-$T_c$ superconductors have a low-dimensional
electronic structure. We believe that a detailed quantitative examination of the many-body interactions in an ideal two-dimensional Fermi liquid like the Al(100) surface state should provide a good reference for understanding the unusual physical properties of novel materials.

In this thesis, we have performed new development of quantitative ARPES study on Al(100) surface state using synchrotron radiation. A circular Fermi surface derived from Al(100) surface state can be identified. A kink structure derived from electron-phonon interaction can be clearly observed in the energy band dispersion near the Fermi level ($E_F$), which was attributed to the electron-phonon interaction. According to self-energy analyses, the electron-phonon and electron-electron coupling parameters at 50 K were determined as $\lambda_{ep} = 0.67$, $\lambda_{ee} \sim 0$, respectively. The effective mass enhancement of the Al(100) surface state was mainly derived from the electron-phonon interaction. Temperature dependence of the kink structure as measured by $\lambda_{ep}(T)$ was almost quantitatively explained by the calculation using the theoretical Eliashberg function (as shown in Fig. 2). A quasiparticle peak with a narrow linewidth (15 - 20 meV) was elucidated near $E_F$, which was explained reasonably well by the simulated spectral function incorporating the self-energy evaluated in this study. We found that the electrons at surface were strongly scattered by the defects at surface, and the linewidth is significantly broadened.