ISSP + Laser

Ultrahigh resolution laser-angle-resolved photoemission spectroscopy

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It is well known that the variety of properties that conducting materials display stems from the electronic structure at and near the Fermi level (E_F). One of the most fascinating examples is superconductivity, in which pairing of two electrons makes a tiny energy gap at E_F, leading to unexpected physical properties. Angle-resolved photoemission spectroscopy (ARPES) is a very powerful method to measure electronic structure at and below E_F as it can provide the energy(ω) and momentum(k) resolved spectral function A(k,ω) of a solid. ARPES can thus measure band dispersions and Fermi surface topology as a function of temperature(T).[1] It has contributed significantly to our understanding of the electronic structure of solids. In the angle-integrated version also, PES has given us valuable results allowing comparisons with other techniques which probe the one-electron removal function, such as tunneling spectroscopy. Since the discovery of high-T_c superconductors, ARPES studies have followed a remarkable progress in energy and momentum resolution, driven by the purpose of determining the superconducting gap symmetry. These studies have usually employed synchrotron radiation or gas discharge lamps as a photon source coupled to a photoemission spectrometer, and for high energy resolution achieved using a He discharge lamp (He I : 21.218 eV). PES is also usually considered to be very surface sensitive as tunneling spectroscopy, it is well-known that the escape depth of photoelectrons show strong kinetic-energy dependence : it is highly surface sensitive for kinetic energies between 20- 50 eV, but can be made more bulk sensitive by changing the kinetic energy to very low and very high energies.[2] This can be done by simply changing the incident photon energy. Consequently, the increase of escape depth using soft-x rays ($h\nu$ ~ 1000 eV) has been demonstrated with a resolution of ~100 meV.[3] This energy resolution is good enough to study the overall electronic structure but is about 100 times larger than, for example, the SC gap energy scale of a low-T_c superconductor, typically less than 1 meV. The energy resolution using synchrotron radiation with 20-30 eV photon energy is ~ 5 meV (recently ~ 2 meV below 10eV photon energy) for solid-state studies, which is again not enough for studying very low energy scale low temperature electronic structures. While PES using a He I resonance line (21.2 eV) can produce a ~ 1-2 meV resolution, the escape depths using a photon energy of ~ 20 eV are less than 10 Å. This may not be suitable for studying materials having a surface electronic structure completely different from the bulk, as is known for some correlated-electron systems.

To achieve the ultrahigh energy-momentum resolution and high bulk sensitivity, we have developed a low-temperature ultrahigh resolution system for polarization dependent ARPES using a vacuum ultra-violet (VUV) laser ($h\nu$ = 6.994 eV) as a photon source. With the aim of addressing low energy physics, we show the system performance with angle-integrated PES at the highest energy resolution of 360 μeV and the lowest temperature of 2.9 K.[4] At present, we have been achieved 150 meV of energy resolution and 1.8 K of lowest temperature in advanced 7 eV laser ARPES system. These new photoemission systems demonstrate that the ultrahigh resolution ARPES is quite important to understand electronic property of materials.

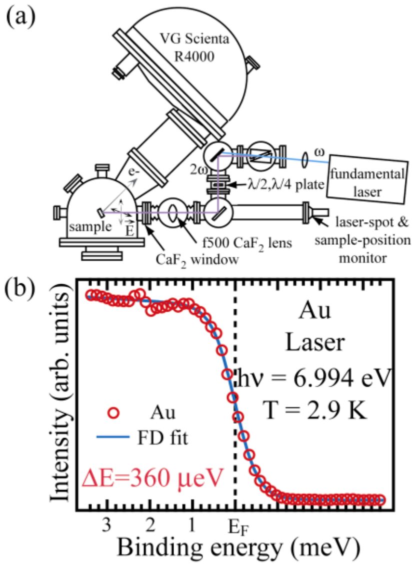

Fig. 1. (a) Schematic diagram of the LPES system. (b) Ultrahigh-resolution PES spectrum of an evaporated gold film measured at 2.9 K (red circles), together with the FD function at 2.9 K convolved by a Gaussian with full width at half maximum of 360 μeV (a blue line).

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