Development of ultra-high resolution photoemission spectroscopy in Japan.

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Recommended with a Commentary by Sadamichi Maekawa, Tohoku University, Sendai.

Photoemission spectroscopy is one of the key experimental tools in condensed matter physics. It has especially been useful in discovering several important and unique features of the single-particle spectra of high temperature superconductors, such as a non-Fermi liquid normal state, d-wave gap in the superconducting state and an anisotropic pseudogap in part of the phase diagram in the normal state. Recently much effort is being devoted to increase the momentum and energy resolution of this spectroscopy, especially in Japan. About 7-8 years ago, by using a state-of-art photoelectron spectrometer and He discharge lamp, Takahashi's group (Tohoku University) and Namatame' group (Hiroshima University) achieved a resolution of about 5 meV. About 5-6 years ago, Shin's group (ISSP, Tokyo University) reached this to about 1.4 meV by using low temperatures. This high resolution photoemission spectroscopy is mainly due to the use of a state-of-art photoelectron spectrometer made by the Swedish company, Sienta. This is close to the limiting photoemission resolution, because the line width of the He discharge lamp is about 1meV,

Very recently, Shin's group made a breakthrough obtaining a 1 meV resolution. Watanabe's group (ISSP, Tokyo University) developed a new light source whose line width is narrower than 1meV. Shin's group has overcome the space charge effect which affects the resolution. A quasi-CW VUV laser was specially developed for this high resolution photoelectron spectroscopy. The photon energy is about 7 eV with 0.26 meV linewidth and a repetition rate is around 80 MHz. This is currently the highest photon energy possible with a quasi CW laser. The intensity is quite high with 10^{15} photons/s. This intensity is much larger than that of the other available light sources. A new analyzer has been developed by Sienta especially for laser-photoelectron spectroscopy. The resolution of this photoelectron spectrometer is about 0.25 meV. The total resolution of the Laser-PES system, measured by using the Gold Fermi-edge is estimated to be about 0.36 meV. This is the highest resolution currently available. The most important point for this high-resolution achievement is the development of the special laser for the photoelectron spectroscopy.

The photoemission results for superconducting materials, such as $CeRu_2$(ref. 1) and MgB_2(Tsuda et al.), as well as several exotic superconductors are presented in the references. These superconductors have anisotropic and/or have multiple superconducting gaps. The results demonstrate that in the low photon energy photoemission, it is possible to probe the bulk (Eguchi et al), which is a very important new feature. Laser-photoemission has opened the new window to the photoemission world, because of the higher resolution, sensitivity to the bulk, and a strong intensity.

Meanwhile progress is also being made using synchrotron radiation (SR); A Hiroshima group has achieved a resolution of about 0.7 meV.

1.T. Kiss, et al., Phys. Rev. Lett., 94 (2005)57001-57004.