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Short Note

Advantage of Thin-Film Filter for Reliable Photoemission Spectroscopy Using High-Flux Discharging Lamp

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An aluminum film with a thickness of 1500 Å has been used as a filter for the He Iα resonance line (21.2182 eV) from a microwave-driven high-flux discharging lamp to reduce the degradation of sample surfaces during photoemission spectroscopy (PES) measurements. A marked increase in the lifetime of sample surfaces, which overcomes a ~90% intensity reduction, has been observed. The thin-film filter, if combined with a high-flux discharging lamp, provides clean vacuum ultraviolet lights for reliable PES measurements with an ultrahigh resolution. [DOI: 10.1143/JJAP.43.3618]

KEYWORDS: aluminum thin-film filter, discharging lamp, degradation free, angle-resolved photoemission spectroscop

Because of recent advances in the angular and energy resolutions, photoemission spectroscopy (PES) has become one of the most powerful techniques for investigating electronic structures near the Fermi level, E_F, which are responsible for the physical properties of conducting solids.[1,2] The capability of measuring the momentum (k) dependence of a superconducting gap has enabled the direct observation of the d-wave superconducting gap of high-temperature superconductors (high-T_c's),[1,2] and more recently, the Fermi-surface (FS)-sheet-dependent superconducting gap in 2H-$NbSe_2$[3] and MgB_2,[4,5] which have not been obtained with k-integrated probes, providing significant insight into the origin of the unusual normal and superconducting properties.

PES studies with a very high resolution as high as 1 meV can be achieved only when one uses a high-flux microwave-driven He discharging lamp because of the extremely narrower linewidth of He resonance lines. Such an ultrahigh resolution for solid-state PES studies so far cannot be obtained using synchrotron radiation lights. However, compared to PES measurements using synchrotron radiation lights, it is known that PES using a He discharging lamp has a great disadvantage of a shorter lifetime of sample surfaces even if one carries out conceivable treatments.[6] The shorter lifetime of surfaces must be dealt with appropriately to perform ultrahigh-resolution studies on materials with active surfaces, which normally take several hours and require stable sample surfaces during measurements.

Here, we demonstrate that a simple usage of a thin aluminum film can be a clue to preventing the degradation during PES measurements with a He discharging lamp, by comparing angle-resolved PES (ARPES) spectra of high-T_c $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) measured with and without the filter.

Figure 1 illustrates a schematic diagram of the He discharging lamp system, in which a commercial microwave-driven high-flux He discharging lamp with a toroidal grating monochromator (GAMMADATA-SCIENTA VUV 5000 and VUV 5040, respectively) were used. The measurement chamber, the grating chamber, and the He discharging lamp were pumped with turbomolecular pumps independently. An aluminum thin film with a thickness of 1500 Å supported by a Ni mesh (Luxel Corp., VF111-Al) was assembled as a filter between the grating chamber and the lamp, and were turned on and off easily from outside of the vacuum. The base pressures of the measurement chamber during the operation of the discharging lamp with and without the filter were $\sim 1 \times 10^{-10}$ and 2.2×10^{-8} Torr, respectively. The angle-resolved PES spectra were measured with a He Iα resonance line (21.2182 eV) using a hemispherical electron analyzer (GAMMADATA-SCIENTA SES2002) installed at the measurement chamber. The total energy and angular resolutions were set at 8–14 meV, depending on the count rate, and 0.2°, respectively. The samples we used here were as-grown (slightly overdoped) and optimally doped Bi2212 samples with T_c of 86 and 90 K, respectively.[7] The samples were cooled using a liquid helium continuous flow cryostat and sample temperatures were measured using silicon-diode sensors. E_F of samples was referenced to that of a gold film evaporated onto the sample substrate, and its accuracy was estimated to be better than ± 1 meV.

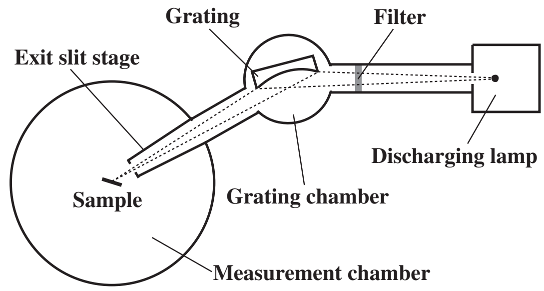

Fig. 1. A schematic diagram of the discharging lamp system used.

Figure 2 shows the ARPES spectra of the Bi2212 samples measured at the Fermi momentum along the $(\pi, 0)$ to (π, π) direction (see, inset) at 6 K below T_c. The time, t, given in Fig. 2 is the total time at which the samples were irradiated with the light. The acquisition times of the spectra without and with the filter were ~2 and ~10 min, respectively. Normalization was performed with an intensity around 0.38 eV binding energy. It is known that Bi2212 has a d-wave superconducting gap with the maximum gap value at this k-position.[1,2] The spectrum of Bi2212 has been known

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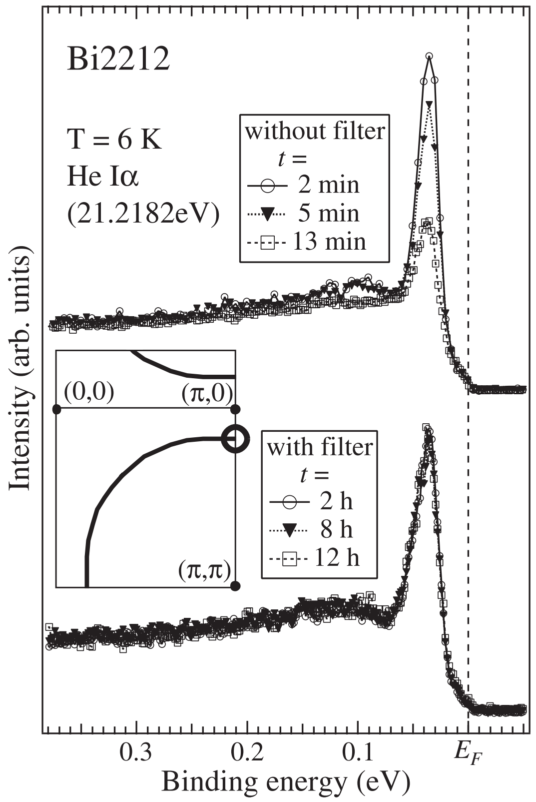

Fig. 2. ARPES spectra of Bi2212 as a function of irradiation time, *t*, measured without (upper) and with (lower) the filter, normalized with intensities around 0.38 eV. The inset shows the FS (curves) and the measured *k* point (an open circle) in the Brillouin zone.

to have a characteristic line shape with a peak followed by a dip and a hump for a higher binding energy, where the energy position of the peak corresponds to the superconducting gap value and decreases as the doping concentration is increased.[1,2] The reason why we chose the Bi2212 samples is that the peak width is very narrow and can be used as a very sensitive detector for surface degradation. Without the filter, the spectrum (upper one) measured at 3 min after the irradiation of the light was started shows a sharp peak at 35 meV, a dip, and a hump, consistent with previous studies.[1,2] However, the intensity of the peak gradually decreases, and at 13 min, it becomes nearly one-half of its value at 2 min. These time-dependent spectra show how fast the sample surface changes using the He discharging lamp without the filter. The surface degradation using the He discharging lamp has been reported and attributed to an increase in structural disorder at the surface.[6] In contrast, with the filter, the time-dependent spectra (lower ones) remain nearly the same both for the spectral shape and intensity of the peak even at 12 h after the irradiation was started. This demonstrates the effect of the filter in a surprising way. These results suggest that the filter removes all sources that degrade the sample surface and therefore the sample surface lasts longer. On the other hand, we found that the photon flux was reduced by an order of magnitude.

The usage of a thin film as a filter for the vacuum ultraviolet lights produced with a discharging lamp has been reported in 70 s[8] but has seemed to be paid less attention, maybe due to the small transmission rate[9] giving rise to a small photoelectron count rate. Even in the present case, the filter reduces the light intensity by nearly 90%. The high flux of the light sources makes the count rate reasonably larger, sufficient for even ARPES measurements as shown in Fig. 2. More importantly, the increase in lifetime is more than the decrease in intensity. Thus the usage of the filter will help ARPES measurements with an ultrahigh resolution, which typically take several h to be completed, for compounds with very active or weaker surfaces but show interesting and fascinating physical properties from both fundamental and applied physics points of view, such as organic conductors, Ce- and U-based compounds, cuprate high-T_c's, and manganites. It can be also applied for ultrahigh-resolution PES studies of electronic structures of clean surfaces and low-dimensional (nano) structures fabricated onto clean surfaces. The transmission rate of an unbacked aluminum film with a thickness of 800 Å is reported to be ~65%,[9] and decreases as the thickness of Al_2O_3 on the surface increases. For the film used in the present study, the calculated transmittance is reported to be ~60%.[10] Larger loss of intensities (transmittance of ~10%) can be attributed to the development of oxide layers during the transportation. The roughness of the film that can give rise to scattering of photons in their way to the grating may also play a role. It may be possible to obtain a higher photon intensity using an oxidation-free film and by placing the filter closer to samples.

We show that an aluminum film with a thickness of 1500 Å can be used as a filter for the He Iα resonance line from a microwave-driven high-flux discharging lamp to reduce the degradation of sample surfaces during PES measurements. A marked increase in the lifetime of sample surfaces, which overcomes the intensity reduction, has been observed. The thin film filter, if combined with a high-flux discharging lamp, provides clean vacuum ultraviolet lights for reliable and precise PES studies with an ultrahigh resolution.

Acknowledgements

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