New Simple Photoemission Electron Microscope with an Energy Filter*

László TÓTH*1,2, Hiroyuki MATSUDA*1,2, Tatsuya SHIMIZU*1, Fumihiko MATSUI*1,2 and Hiroshi DAIMON*1,2

*1Nara Institute of Science and Technology (NAIST), 8916-5 Takayama, Ikoma, Nara 630–0192, Japan, CREST,
*2Japan Science and Technology Agency, Saitama 332–0012, Japan

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We have developed a new Wide Acceptance Angle Electrostatic Lens (WAAEL) and applied that as display-type electron energy analyser. Our present lens achieves ±60° (1 sr) acceptance angle and has a good focusing capability with 5-times magnifications. The relative energy resolution is typically from 2 to 5×10^{-3} and depends on the emission area on the sample, as well as, on the diameter of exit aperture. Some preliminary results and discussions related to its energy resolution are shown.

1. Introduction

Photoelectron spectroscopy is a powerful technique to study both electronic and atomic structure of solid and surfaces. Two-dimensional angle-resolved photoelectron spectroscopy provides a rich variety of information. In UPS (ultraviolet photoelectron spectroscopy) region the two-dimensional angular distribution of constant kinetic energy (binding energy) photoelectron reveals the shape of cross section of valence band and one application of it is the Fermi surface mapping. Two-dimensional photoelectron angular distribution in x-ray photoelectron spectroscopy (XPS) is also powerful in the analysis of three-dimensional atomic structure around specific atoms by using the technique of photoelectron diffraction (PED) or photoelectron holography (PEH). Very recently a new method of taking “stereo photograph of atomic arrangements” was invented utilizing the phenomenon of “rotation of forward focusing peaks”. The stereoscopic photographs of atomic arrangements can be displayed directly on the screen of display-type spherical mirror analyzer without any computer-aided conversion process.

In this paper we propose a new wide acceptance angle analyzer up to ±60° (1 sr), which combine the advantages of display-type analyzer with photoemission electron microscope (PEEM).

2. The energy resolution of WAAEL

A schematic diagram of the analyzer is shown in Fig. 1. It consists of an ellipsoidal mesh lens, following cylindrical lenses, deflectors (not shown here), aperture and an MCP with screen. Figure 1 also shows typical trajectories of electrons from a point source for three different kinetic energies with different focus positions. The electron beams with different energy from $E_0 = 1000$ eV (pass energy) focus at different points, but do not focus at the aperture plane. Hence energy analysis is realized when we put a small aperture at the focal plane (at the aperture: $z = Z_0$) of $E_0$ energy electrons. The calculation of the resolving power for a point source is not difficult. In the case of our instrument, the simulation shows that the electrons with $E = E_0 + \Delta E$ energy with $E_0 = 1000$ eV...
focus at $Z = Z_0 + \Delta Z$ with a relation

$$\frac{\Delta Z}{\Delta E} = 1.897 \left[ \frac{mm}{eV} \right]$$

Then the spectral intensity (transmittance) (Fig. 3) as a function of aperture diameter ($d$) and $\Delta E/E_0$ (with $E_0 = 1000$ eV, half acceptance angle $\alpha = 60^\circ$ and 5 times magnification) is

$$I_{rel} = 1 \quad \text{if} \quad \left| \frac{\Delta E}{E_0} \right| \leq 1.24 \times 10^{-3} \times d \quad \text{and}$$

$$I_{rel} = \frac{I}{I_0} = \left( \frac{d}{2} \right)^2 \left( \frac{1.897 \times \Delta E \times \tan \frac{60^\circ}{5} \times 1000}{E_0} \right)^2$$

$$= 1.583 \times 10^{-6} \times \left( \frac{d}{E_0} \right)^2$$

$$\quad \text{if} \quad \left| \frac{\Delta E}{E_0} \right| > 1.24 \times 10^{-3} \times d$$

Finally, the resolving power (Fig. 2) from eq. (2) is given as

$$\frac{\Delta E_{FWHM}}{E_0} = 2 \times \frac{\Delta E \left( I_{rel} = \frac{1}{2} \right)}{E_0} = 3.51 \times 10^{-3} \times d$$

In the measurements as follows we used electron beam ($E_e = 1$ keV, FWHM$_{e-beam}$ = 350–500 µm and incident angle $\lambda = 14^\circ$) that hits the sample at $z = 0$ and detected the image through different apertures by an MCP fixed at $Z_0 + 11$ mm, 11 mm far behind the aperture (Fig. 1). Because the image plane is farther than $Z_0$, the sample had to be shifted $z = 11/5$ mm closer to the mesh-lens resulting larger acceptance angle ($\alpha = 65^\circ$).

We have measured the energy-resolution of WAAEL for 3 different exit-apertures ($d = 1, 3$ and 5 mm) using SUS 316 mesh samples. The relative energy resolutions were measured from the whole image, as well as from a selected small region (0.2%) of the image, and compared them with calculations. In Fig. 2 the solid line shows the resolution calculated by the point source model. The squares and diamonds are the data measured from the whole image and from a selected small region of the image, respectively. It is clearly seen that the point source model cannot describe the measured data, therefore, more realistic calculations are needed which take into account the shape and position of the emission area. Since the electron beam hits the sample surface with an inclination angle $\lambda$, the shape of the emission area becomes elliptic. The shift of sample position in all $x$, $y$ and $z$ directions with $dx$, $dy$ and $dz$ have also been included. At the image plane, which position ($Z$) depends on $\Delta E$, the 5-

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Fig. 2 The calculated and measured energy resolving power for three different aperture diameters ($d = 1, 3$ and 5 mm). The squares show measured data from the whole image while the diamonds from a selected small area. Solid line is calculated by the point source model. Dashed and dotted lines are the same as in Fig. 3.
times magnified image of the ellipse appears. Then each of the $i$-th point of this image can be treated as a point source of electrons which form cones with the angle of $2 \times \alpha/5$ and intensity $I_i$. Some parts of these cones can go through the aperture hole contributing to the measured intensity with $I_{\text{meas}}$. The $I_{\text{meas}}/I_i$ ratios for different energy electrons and their integral for the whole image area were determined by using Monte Carlo Simulation. The results are shown in Figs. 2 and 3. There is an apparent contradiction in Fig. 2 that the measured relative energy resolution from the whole image is higher than the data of the selected (point source like) small region at 5 mm aperture diameter. It can be explained by the fact that the sample is not a point source and not centered on the lens’s axes that can result larger measured maximum intensity for larger apertures that decrease the measured relative energy width in those cases. Although, we could not reproduce the measured data quantitatively (we neglected the sample surface inclination and corrugation) the calculated results qualitatively agree with the measured ones.

4. Conclusion

We have designed, built and tested a new wide acceptance angle electrostatic lens. The measured energy resolution was different from that estimated from a point source, and explained by taking into account the shape and position of the sample. This new analyzer opens a new way for high sensitive analyzer, simultaneous angular distribution measurement from selected area, and photoemission electron microscope (PEEM).

References