



Development of display-type ellipsoidal mesh analyzer: Computational evaluation and experimental validation



H. Matsuda^{a,*}, K. Goto^a, L. Tóth^b, M. Morita^a, S. Kitagawa^a, F. Matsui^a,
M. Hashimoto^a, C. Sakai^a, T. Matsushita^c, H. Daimon^a

^a Graduate School of Materials Science, Nara Institute of Science and Technology (NAIST), 8916-5 Takayama, Ikoma, Nara 630-0192, Japan

^b University of Debrecen, H-4032 Debrecen, Egyetem ter 1, Hungary

^c Japan Synchrotron Radiation Research Institute (JASRI), SPring-8, 1-1-1 Koto, Sayo, Hyogo 679-5198, Japan

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ABSTRACT

An advanced measurement system for two-dimensional photoelectron spectroscopy has been developed to overcome the difficulties faced in the display-type spherical-mirror analyzer (DIANA) having been used so far. One difficulty is to realize selected small area analysis and another is to obtain higher energy resolution. The developed system, which we call “display-type ellipsoidal mesh analyzer (DELMA)”, has an ellipsoidal mesh electrode as its key element, which allows a wide acceptance angle ($>\sim \pm 45^\circ$) comparable to that of DIANA. In this paper we provide details of DELMA on its design and performance. For the imaging performance, we evaluated, using ray-tracing, some important factors that can affect the spatial resolution: off-axis aberration, the effect of shape and position errors, the disturbing effect of mesh holes, and chromatic aberration. In test experiments, a spatial resolution of around 20–30 μm was obtained. The ray-tracing results suggest that this resolution can be improved to be less than 10 μm by decreasing the size of mesh holes and the error of the mesh shape. We also provide computational results for the energy resolution obtained in various conditions. It depends not only on the size of the energy-selecting aperture but also on the size and shape of an irradiation spot. Experimental results for the energy resolution were in good agreement with computational results. An available resolution seems to be as good as in DIANA ($\sim 0.5\%$). A much better resolution is possible in our system by the combination of DELMA and a high resolution concentric hemispherical analyzer. In test experiments using an angle-measurement device, a wide acceptance angle of around $\pm 45^\circ$ has been successfully confirmed. As a practical example of the angular analysis by DELMA, a photoelectron diffraction pattern measured for single crystalline graphite is shown.

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1. Introduction

Photoelectron spectroscopy is a fundamental and widely used surface analysis technique that is still being developed [1]. A substantial progress has been made by the development of photoelectron emission microscope (PEEM) [2–4], which enabled photoelectron spectroscopy from a microscopic area that is selected by photoelectron imaging. Another progress is the development of two-dimensional (2D) photoelectron spectroscopy [5], which opened many new possibilities with the advances in light source technologies. A great deal of contribution to 2D photoelectron spectroscopy has been made by a display-type

spherical-mirror analyzer (DIANA) [6–8]. This analyzer, which allows simultaneous angle-resolved measurement over a wide emission angle of 1π sr ($\pm 60^\circ$), has been successfully applied for, e.g., 3D Fermi Surface and band-structure analysis [9,10,5], photoelectron diffraction spectroscopy [11], photoelectron holography [12], and direct determination of 3D atomic arrangement by stereophotography [13–15].

Unfortunately, DIANA cannot perform selected-small-area analysis like in a PEEM system, because the magnification ratio of DIANA is 1:1 and the focus size is, at best, around 1 mm even if the irradiation-spot size is less than 0.3 mm. On the other hand, a PEEM system equipped with an energy filter can perform 2D photoelectron spectroscopy at low kinetic energies of around 30 eV. This is because a PEEM objective lens achieves a wide acceptance angle by a strong acceleration field between the sample and the lens entrance. However, the acceptance angle considerably decreases

* Corresponding author. Tel.: +81 743726208.
E-mail address: hmatsuda@ms.naist.jp (H. Matsuda).

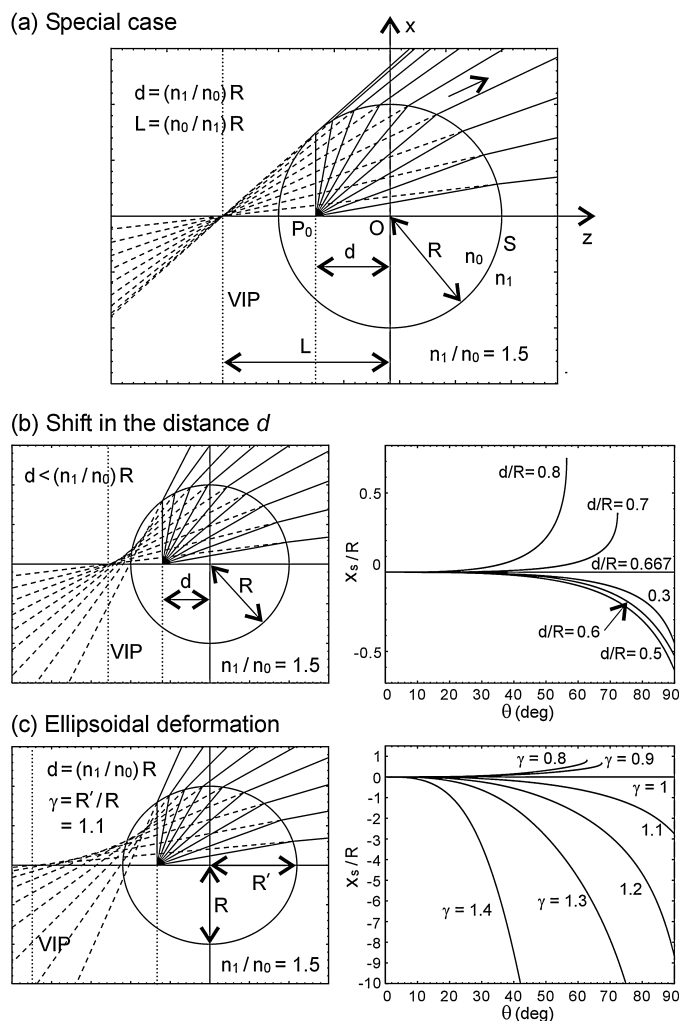


Fig. 1. Effects of refraction of light ray at spherical and ellipsoidal interfaces. The ratio of the refractive indices inside and outside the interfaces is given by $n_0/n_1 = 1.5$. (a) Special case of refraction (with no spherical aberration), where the object position is given by $d = (n_1/n_0)R$, (b) Effect of the shift in the object position, and (c) effect of the deformation of the spherical interface to an ellipsoidal shape. The object position in (c) is the same as in (a). The right figures of (b) and (c) show spherical aberration at the virtual image plane (VIP). The shape parameter γ is given by the ratio of the major to minor radii of the ellipsoid.

with increasing the photoelectron kinetic energy and it becomes less than around $\pm 15^\circ$ for kinetic energies greater than several hundred eV. Consequently, the PEEM cannot perform (or at least cannot perform efficiently) 2D photoelectron diffraction analysis and related measurements, which need kinetic energies greater than several hundred eV and acceptance angles of greater than around $\pm 45^\circ$.

To overcome the above difficulties, a wide-acceptance-angle electrostatic lens (WAAEL) has been proposed [16–19] and developed [20–23]. This lens does not use a strong electric field around the sample, but it can achieve a wide acceptance angle comparable to that of DIANA. The key is the use of an ellipsoidal mesh in combination with other correction electrodes. Optimizing the mesh shape using ellipsoidal shape parameters and other parameters for fine deformation, it is possible to completely correct spherical aberration over a wide acceptance angle up to around $\pm 60^\circ$. This enables photoelectron imaging and then selected-small-area analysis of 2D angular distribution.

The principle of aberration correction in WAAEL is based on that in a spherical mesh lens [24]. It is well known that positive spherical aberration is unavoidable for rotationally-symmetric electron

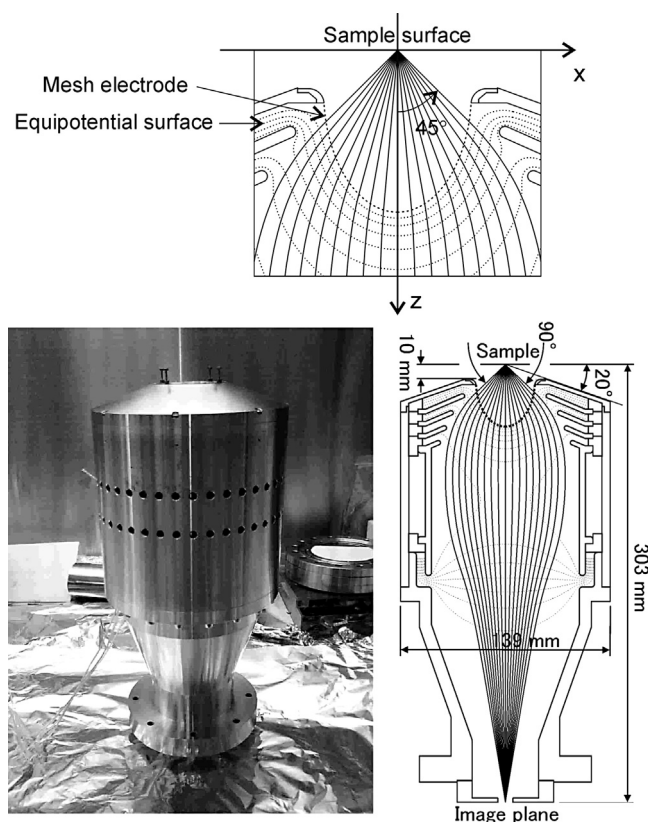


Fig. 2. Wide-acceptance-angle electrostatic lens (WAAEL) and a cross-sectional view of the design. Also shown are equipotential lines and electron trajectories with initial angles up to $\pm 45^\circ$.

lenses with no space charge [25]. A difficulty arises because the spherical aberration greatly increases with increasing the incidence angle. In WAAEL, the electric field around the mesh electrode is followed by a focusing field with positive spherical aberration. The field around the mesh electrode decreases the angular spread of electrons and simultaneously produces negative spherical aberration to cancel the positive spherical aberration produced by the focusing field. Fig. 1 explains the principle of our approach by an analogy with light optics. The analogy is based on the fact that the movement of electrons in an electrostatic field can be seen as successive refractions at equipotential surfaces. Here the square root of an electric potential plays the role of a refractive index. In Fig. 1(a), light rays start from a point source P_0 and are refracted at a spherical interface S , obeying Snell's law, $n_0 \sin \phi_0 = n_1 \sin \phi_1$, where n_0 (n_1) is the refractive index outside (inside) S and ϕ_0 (ϕ_1) is the angle of incidence (refraction) at S . The point source is located on axis at a distance of $d = Rn_1/n_0$ from the center of S , where R is the radius of S . In this case, a virtual image is produced at a distance of $L = Rn_0/n_1$ from the center of S with no spherical aberration, as shown by dotted lines. Negative spherical aberration can be produced by shifting the point source in the positive z direction, as shown in Fig. 1(b). Fig. 1(c) shows that negative spherical aberration can also be produced by deforming the spherical interface to an ellipsoidal shape. An important feature is that the negative spherical aberration can be greatly increased by increasing the ratio γ of the major to minor radii of the interface, which enables to cancel spherical aberration over a wide acceptance angle.

In WAAEL, there is no electric field between the sample and the lens entrance in contrast with PEEM systems, since the mesh (which is located at the entrance of the lens) and the sample are both grounded. Another significant feature is that WAAEL can be applied in a wide range of photon energies including the hard X-ray region

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