

STEREOVIEW OF 3-D ATOMIC ARRANGEMENT BY CIRCULARLY POLARIZED-LIGHT PHOTOELECTRON DIFFRACTION

Stereoscopic photographs of a three-dimensional atomic arrangement have been obtained for the first time [1]. Two-dimensional photoelectron diffraction patterns obtained by left and right helicity light can be used as stereoscopic photographs when the two patterns are simultaneously viewed by the left eye and the right eye. Using a displaytype spherical-mirror analyzer [2], stereoscopic photographs can be obtained directly on the screen without using any computer-aided conversion process.

Atomic arrangements, however, have not been yet directly observed. STM (scanning tunneling microscope) or TEM (transmission electron microscope) can provide atomic images in twodimensional, but not in a three-dimensional atomic arrangement. Detailed atomic positions can be obtained with the use of other tools for structure analysis, such as LEED (low-energy electron diffraction) and X-ray diffraction, however requiring complicated analysis.

When the kinetic energy of photoelectrons from the core state is above several hundred eV, the scattering of photoelectrons from surrounding atoms create an intensity modulation in the angular distribution, known as photoelectron diffraction. The so-called forward focusing peaks appear in a two-dimensional photoelectron diffraction pattern along the direction connecting the emitter and the scatterer of photoelectrons. The recent research has shown that, utilizing circularly polarized light for the excitation of photoelectrons, these forward focusing peaks are rotated in the same direction as the electric vector of the incident circularly polarized light [3]. This was the first observation of the orbital angular momentum of electrons. This circular dichroism occurs for both chiral or magnetic materials and non-chiral and non-magnetic materials such as Si(001) [3] or W(110)-O [4] surfaces.

The rotation angle $\Delta \phi$ of these forward focusing peaks around the photon incident axis is expressed by a simple formula: $\Delta \phi = m / kR \sin^2 \theta$ [3], where *m* is the magnetic quantum number of the photoelectron, k is its wave number, R is the internuclear distance between the emitter and the nearest-neighbor scatterer, and θ is the angle between the directions of incident photon and the outgoing photoelectron. This rotation has been explained as being due to the transfer of angular momentum of the photon to the photoelectron, where its z component angular momentum is changed by ± 1 when excited by the circularly polarized light. The discovery of this rotation property has created new fields in the analysis of atomic, electronic, and magnetic structure of surfaces. Stereomicroscopy of atomic structure we describe herein is one of the most important applications of this phenomenon.

We show an example in Fig. 1, where (a), (b) indicate the photoelectron diffraction patterns of W 4f photoelectrons from W(110) surface at the kinetic energy of 800 eV for left and right circularly polarized light, respectively. This experiment was performed at BL25SU using the high-energyresolution display-type spherical-mirror analyzer [5]. Its energy resolution is 0.3% of the pass-energy, and the angular resolution is higher than 1 degree. When Fig. 1 (a) is looked with the left eye and (b) with the right eye, the three-dimensional arrangement of atoms can be viewed as shown in (c): the A atom looks closer, the B and C atoms look farther, and the others look even farther. This image coincides with the real arrangement of W atoms viewed from the atom O, as shown in Fig. 1 (d). The magnification ratio is approximately 10¹⁰.

These figures can be viewed as stereo-photographs





(a)





Fig. 1. Stereoscopic photographs of W(110) crystal, which is actually the two-dimensional circularly polarized-light photoelectron diffraction patterns of W 4f from the W(110) surface. (a), (b) show the results for left and right circularly polarized light, respectively. The kinetic energy is 800 eV. The small black circles indicate the calculated directions of each forward-focusing peak along the crystallographic axes shown in (c). Looking at (a) with the left eye and (b) with the right eye, the three-dimensional arrangement of atoms shown in (d) can be viewed.





due to the following reasons: the photoelectrons have orbital angular momentum, propagating from a point of some distance called the impact parameter, not from the center of the emitter atom; the angular momentum is the product of the momentum and the impact parameter, thus when the angular momentum is plus (minus), the impact parameter is also plus (minus); and these plusminus impact parameters correspond to our right and left eyes, thus the obtained photoelectron diffraction patterns are the same as the image seen by right and left eyes. More details are described in ref. [1]. Hiroshi Daimon

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