Soft X-ray Spectroscopy of Solids

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1. Introduction

The BL-25-IN beam line is a soft X-ray undulator beam line equipped with a twin helical undulator for circularly polarized synchrotron radiation in the range from 500 to 3000 eV. Quick helicity change with more than 100 Hz will be possible, while alternatively emitting the oppositely polarized light on the same optical axis. Advanced understandings of electronic structures of the materials, which are very interesting from the viewpoint of material sciences, and of the geometric structures of surfaces will be strongly promoted on this beam line. The very brilliant and circularly polarized radiation from the undulator installed in SPring-8 combined with an extremely high resolution monochromator and spectrometers are fully utilized for the scientific applications sited above.

2. Outline of Experimental Station

Due to the limitation of the available budget in the initial stage of the construction of this beam line, we decided to concentrate on the construction of a display type two-dimensional photoelectron spectrometer, besides the high resolution soft X-ray monochromator. Figures 1 and 2 show the design of a display type two-dimensional spherical mirror analyzer to be used to most of the scientific applications given above. Figure 3 shows the vacuum system. A two dimensional angular distribution pattern of photoelectron at one particular kinetic energy (E_K) is recorded simultaneously by a CCD camera. The operation principle of this analyzer is given in Ref. 1 and typical performance is reported in Ref. 2 and 3. Since we cover

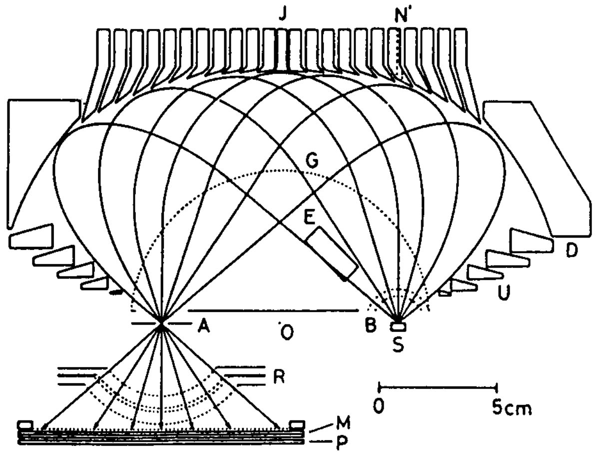

Fig.1. Schematic view of the two-dimensional display analyzer.

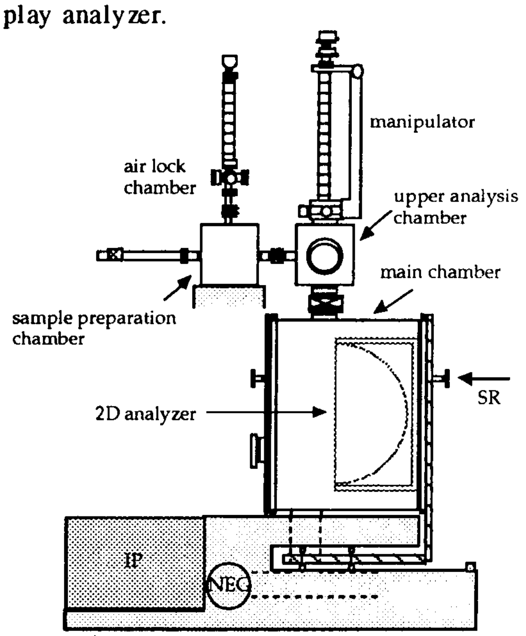

Fig. 2. Schematic view of the 2-D display type photoemission apparatus.

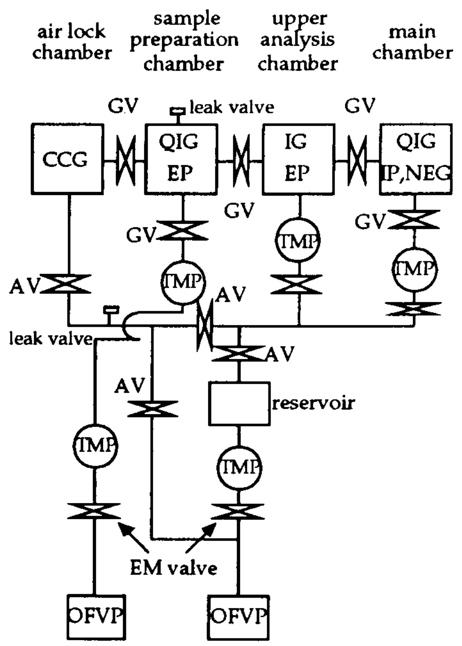

Fig. 3. Vacuum system

the photon energy range from 500 to 3000 eV, the size of the analyzer is almost doubled to provide a resolution of 1/1000 for the electron pass energy of the analyzer.

3. Research Subjects

3.1 Photoelectron holography(PEH)

Surface geometrical structure, for example, of the surface adsorbed system can be well studied by means of the photoelectron diffraction (PED). Although PED can determine the 3-dimensional structure, it usually requires tedious trial and error cycles to determine the surface structure. The photoelectron holography (PEH) can be easily done by using many two-dimensional PED patterns recorded at different kinetic energies. By this method we can obtain three-dimensional image of the surface structure by applying simple Fourier transformation to the observed 2-dimensional photoelectron diffraction patterns. Figure 4 shows a result of photoelectron holography for a Si(001) surface obtained from the Si 2*p* photoelectron distribution patterns [4]. This method has a special advantage over the conventional PED. Its usefulness has been confirmed in several surface systems. So far we have done the experiment at AR NE1 beam line at KEK, but more flux and more beamtime at SPring-8 will strongly promote this experiment. With use of the circularly polarized undulator radiation at NE1 beam line, we have found the rotation of the photoelectron diffraction pattern from non-chiral and non-magnetic crystal (Si(001)). This corresponds to the observation of the rotational motion of photoelectrons. This phenomenon provides a clue to the photoelectron diffraction mechanism and is very important in the development of theories. This effect can be also utilized to develop a new method of 3-dimensional surface structure analysis without using even the Fourier transformation [5].

By utilizing the internally excited spin-polarized photoelectrons by the circularly polarized light, we can also study the spin-polarized photoelectron diffraction to reveal the geometry of the atoms with spin polarized electrons. It will be possible to investigate the spin ordering and its fluctuation even of antiferromagnetic materials. New frontier of science will be opened in this field.

3.2 Magnetic circular and linear dichroism in the angular distribution (MCDAD and MLDAD) of the photoelectron

These subjects are recently attracting much interest. For understanding these phenomena, it is essential to consider the photoexcitation process by a polarized light correctly, including phase difference between l to $l+1$ and $l-1$ transitions. Also, solid state effects, such as diffraction of the photoelectron by the neighboring atoms, seem to be quite important for a

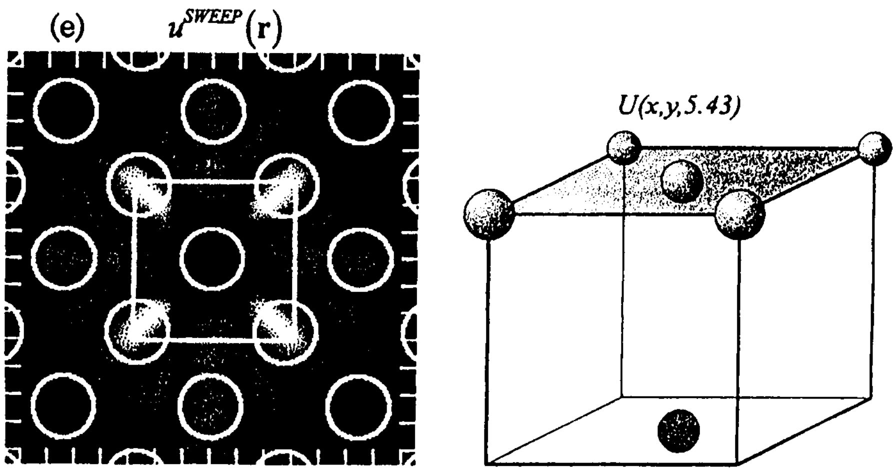

Fig. 4. Results of photoelecton holograpy for a Si(001) surface [4].

quantitative explanation.

Using the circular polarization of this beam-line, we plan to make measurements of MCDAD from ferromagnetic samples. In addition to MCDAD in the core-level photoemission, that in the valence-band and the surface-state photoemission will be measured. In order to enable quantitative discussion, we will also develop methods for theoretical analyses incorporating both atomic features and solid state effects.

A powerful apparatus that will be used for the measurement of the angular distribution is the above mentioned display-type spherical mirror analyzer. On the screen of this analyzer is displayed the angular distribution of the photoelectron with a specific kinetic energy. Typical results for single crystal graphite are shown in Fig.5 [3]. This enables one a more effective measurement of the angular distribution compared with usual apparatus for angle-resolved photoemission, which needs rotation of the sample or the apparatus to yield the distribution.

The photon-energy of the beam-line makes it possible to measure photoemission from valence band and a wide range of cores. 2*p* and 3*p* cores of transition metal and 3*d* and 4*d* cores of rare-earths are promising targets, and we might be able to add 4*d* and 5*d* cores of actinides. Thin film of rare earth on transition metal will be one of the interesting topics.

Multilayers of magnetic metal and other magnetic or nonmagnetic metal will be very important from a viewpoint of application. It is recently pointed out that, because the photoelectron excited by a circularly polarized photon is rotating, the photoelectron diffraction pattern rotates in accordance with the polarization. In order to distinguish this effect from magnetic effect, it is indispensable to make measurements by changing both the magnetization of the sample and the polarization of the light. The latter,

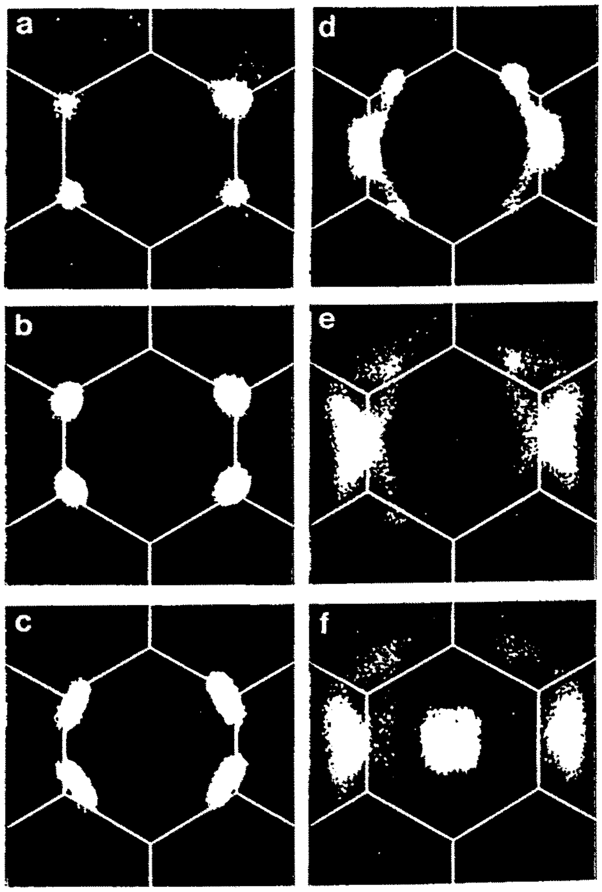

Fig. 5. Two dimensinal photoelectron distribution pattern from a single crystal graphite[5].

which might not be very easy when circular polarization is obtained by off-plane radiation of the synchrotron, can be easily realized in our twin helical undulator.

3.3 Spin resolved photoemission

The photoelectrons, Auger electrons and secondary electrons of magnetized ferromagnetic materials can be spin-polarized due to the spin-exchange interaction. Even for nonmagnetic materials, spin-polarized photoelectrons can be excited by use of circularly polarized light. This phenomenon is due to the selection rule of the electric dipole transition from or to the state with non-negligible spin-orbit splitting. Photoelectron spin-polarization phenomenon for magnetic materials has so far been observed for the excitation in the low hv region. Unusual spin polarization

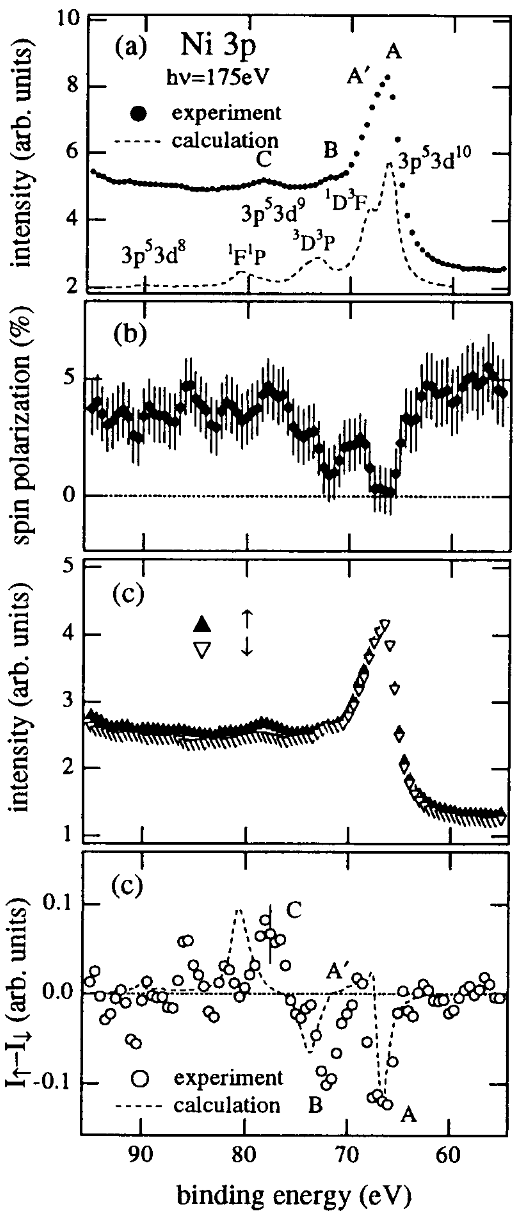

Fig. 6. Spin-resolved photoemission sprctra of Ni 3*p* core level [6].

of the photoelectrons in the angle resolved measurement with lower surface symmetry provides information on the surface geometrical structure. For hv in the soft X-ray region, the photoelectron excited from the *p* core state of the non magnetic atom to far above the Fermi level (E_F) by the circularly polarized light can be likewise spin-polarized. These spin-polarized photoelectrons can be effectively used for the photoelectron diffraction study. The angle resolved spin-resolved photoemission will be done after the exit slit of the SES200 analyzer. For the spin analysis of core photoemission spectra, we will use the W(001) spin LEED analyzer developed and tested at BL-19B of PF with use of the VLSPGM monochromator. One of the typical results for ferromagnetic Ni is shown in Fig. 6. For more conventional spin measurement we will install another VUV chamber with a rotatable spin-LEED analyzer.

6. References

[1] H.Daimon and S.Ino, Rev. Sci. Instrum. **61**, 57 (1990) and references therein.
[2] H.Daimon, et al., Jpn. J. Appl. Phys. **32**, L1480 (1993).
[3] H.Nishimoto, et al., J. Phys: Condensed Matters (1996), in press.
[4] T.Nakatani, et al., to be published.
[5] H.Daimon, et al., to be published.
[6] Y.Saitoh, et al., Phys. Rev. B**52**, R11549(1995).