BL25SU
Soft X-ray Spectroscopy of Solid

1. Introduction

BL25SU is utilized for soft X-ray spectroscopic studies on electronic/magnetic states and surface structures of condensed matter. The beamline consists of two branch lines. The A-branch is specialized for high-energy-resolution X-rays suitable for electron spectroscopy experiments, whereas the B-branch is optimized for a high-photon-flux beam with small-angle divergence [1–3] and is mainly used for X-ray magnetic circular dichroism (XMCD) experiments.

The main topics regarding the beamline apparatuses in FY2023 are as follows: (i) construction of a left-right circularly polarized light switching measurement system for photoelectron holography, (ii) construction of an automatic incident energy measurement program and X-ray absorption measurement program for micro–soft X-ray angle-resolved photoemission spectroscopy (ARPES), and (iii) renewal of standard samples for photon energy calibration at B-branch.

2. Status of the experimental apparatuses

2-1. Spectroscopic low-energy electron microscope (SPELEEM) (A-branch first station)

The SPELEEM apparatus (LEEM III with energy analyzer, ELMITEC GmbH) that had been operated at BL17SU [4] and moved to BL25SU in August FY2021 started operation for user experiments in the 2022B term. Prior to the operation, the measurement software used at BL17SU was substantially modified in order to control the BL25SU optics. With this software, tasks such as sequential measurements under different conditions, X-ray absorption spectroscopy (XAS), chemical mapping, XMCD, and X-ray photoemission spectroscopy are possible.

2-2. Retarding field analyzer (RFA) (A-branch second station)

Photoelectron holography can be used to study acyclic local structures with multiple chemical states [5]. This method requires wide-range photoelectron angular distribution patterns measured with sufficiently high energy resolution to resolve chemical shifts in the inner-core levels. A display-type RFA with a resolution ($E/\Delta E$) as high as 2000 is currently in operation for such measurements [6]. With the benefit of this apparatus, achievements such as the determination of dopant sites in BiS_2-based superconductors [7] and the elucidation of the arrangement of interfacial defects at the oxide layer of diamond semiconductors [8] were attained. In FY2022, a manipulator for sample cooling was installed to enable photoelectron holography experiments below 6 K. In FY2023, a left–right circular polarization dependence measurement program was developed. By using the 0.1 Hz kicker system, low-noise, high-yield photoelectron holography images can be obtained. The utilization of the circular dichroism of photoelectron holography is expected to improve the accuracy of the determination of the three-dimensional atomic arrangements of dopants.

2-3. Microbeam ARPES (A-branch third station)

The ability to distinguish flatly cleaved areas (which are, in many cases, microscopic) from poorly cleaved sample surfaces is valuable for ARPES [9]. To enhance this capability, a micro-ARPES end- station equipped with a DA30

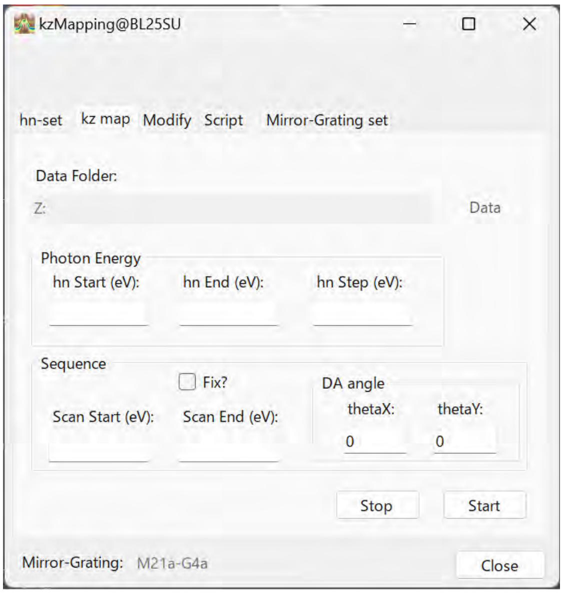

Fig. 1. An automatic measurement program for incident-photon-energy-dependent measurements.

analyzer (Scienta Omicron) and a micro-focusing mirror was developed [10, 11]. The typical focusing size is 0.4 μm (vertical) × 10 μm (horizontal). The beam spot size on the sample surface is as small as 10 μm even at a glancing angle of 5 degrees. This end station has been open for public use since FY2018. In FY2022, an automatic real-space scanning program was constructed. This program is coded using LabVIEW software and allows the user to freely select a 1D, 2D, or 3D scan mode. Considering the spot size, the scanning step can be set to ~1 μm at minimum. Currently, we are building an analysis macro using Igor software. In FY2023, to investigate the electronic structure along the k_z momentum (perpendicular to the sample surface), an automatic measurement program for incident-photon-energy-dependent measurements has been developed (Fig. 1). This program is coded using Python and Autohotkey and allows the user to freely select between swept and fixed scan modes. It can reduce the physical and mental burden on the user in ARPES measurements, which usually require long scanning times. In addition, to perform resonant photoemission spectroscopy, we developed a soft X-ray absorption measurement program for the total electron yield mode (Fig. 2). This program is coded using Python. This program also allows users to analyze the chemical states in microscale real space using XAS spectra.

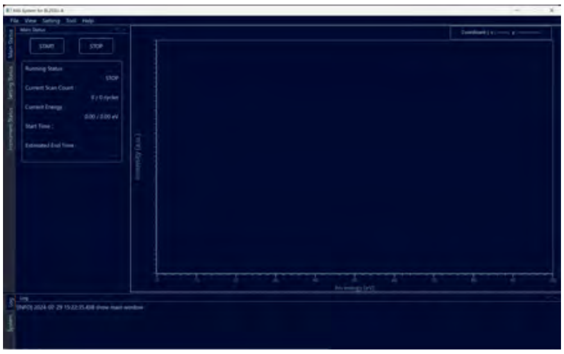

Fig. 2. Soft X-ray absorption measurement program for resonant photoemission spectroscopy.

2-4. Renewal of standard samples for incident photon energy calibration at B-branch

B-branch is mainly used for XMCD experiments. In this branch, the energy calibration was previously performed using the X-ray absorptions of $CaCO_3$, MnO, $Sr_3Fe_5O_{12}$, CuO, Gd_2O_3, and SiO_2 powders. To obtain a more accurate calibration curve at the higher photon energy side (>1000 eV), Al_2O_3 and

P_2O_5 powders are newly installed.

2-5. Electromagnet-type XMCD spectroscopy (B-branch end-station)

Electromagnet-type XMCD is a versatile XMCD apparatus that provides various experimental conditions. One of three types of sample holder can be attached to its manipulator: that for low temperature, that for high temperature, and that for measurements under electric force or current flow. The method of signal detection can also be selected from among total electron yield (TEY), partial fluorescence yield (PFY), and transmission modes. A high-precision manipulator introduced in FY2020 allows measurements of microscopic areas. In FY2022, to cope with the recent surge in the helium price, manipulator cooling using liquid nitrogen was tested. As a result, although operation at the fully cooled temperature (77 K) was achievable, setting specific temperatures was not successful due to insufficient heater output. Further improvements are currently under consideration.

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