BL39XU
Magnetic Materials

1. Introduction

BL39XU is a hard X-ray beamline dedicated to the study of magnetic materials and strongly correlated electron systems. Techniques include X-ray absorption spectroscopy (XAS), X-ray magnetic circular dichroism (XMCD), X-ray emission spectroscopy (XES), and resonant X-ray magnetic scattering. Recent developments have focused on X-ray spectroscopy measurements under multiple extreme and complex conditions and scanning XAS/XMCD imaging using a nano-focused X-ray beam. These techniques are available for user experiments, and further developments are ongoing.

In FY2020, two projects were mainly undertaken. (1) The helium (He)-flowing-type cryostat was combined into a new electromagnet installed in FY2019. (2) Three types of spherical-focusing analyzer crystal were installed to extend the energy range of the X-ray emission spectrometer.

2. Experimental station for X-ray spectroscopy under multiple extreme conditions

Experimental hutch 1 located at the upstream position is mainly used in the XMCD measurements under extreme conditions and in the XES measurements. In FY2020, (1) an actualization of low-temperature measurements for the XMCD using a high-field electromagnet and (2) a supplementation of analyzer crystals for the XES measurement were undertaken.

2-1. High-field electromagnet with a large sample space

A high-field electromagnet has been installed to extend a magnetic field range up to 3.5 T (@ 5 mm in a pole-piece gap) in FY2019. The magnet has a large sample space (e.g., 1.6 T @ 40 mm gap) to enhance the advantage of the experimental setup. However, currently, the electromagnet can only be used at room temperature. In FY2020, to actualize a complex sample condition of high magnetic field and high/low temperature, a He-flowing-type cryostat was combined into the electromagnet. Figure 1 shows a photograph of the electromagnet combined with the He-flowing-type cryostat. The sample position can be controlled in horizontal and vertical directions by using two motor stages. The gap of the electromagnet can be in the range of 5–

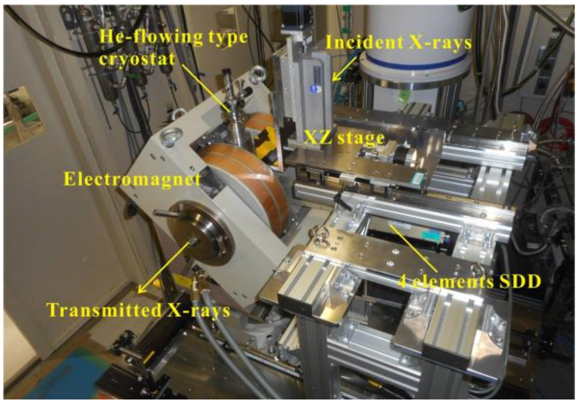

Fig. 1. New XMCD spectrometer with combination of a high-magnetic-field electromagnet and a He-flowing-type cryostat.

Table 1. Some conditions of the sample environment. Relationship between magnetic field and gap of pole piece of electromagnet.

Gap (mm)	5	20	45
Mag. field (T)	3.5	2.4	1.5
Temp. (K)	300	11–500	11–500
Press. (GPa)	A.P.	A.P.	A.P.–40

50 mm in response to sample size or environment. Table 1 shows some conditions of the magnetic field depending on the gap of the pole piece.

2-2. X-ray emission spectrometer with multiple analyzer crystals

High energy resolution fluorescence detection XAS (HERFD-XAS) measurements using the XES method are actively performed [1, 2]. However, there are still unavailable energy regions for the XES spectrometer. In FY2020, to extend the energy range of the X-ray emission spectrometer, three types of analyzer crystal, namely, InSb 111, InSb 220, and SiO_2 11-24, were installed. Figure 2 shows the types of analyzer crystal and the emission energy range available for the XES spectrometer. These crystals mainly cover energy ranges of 5.01–5.76, 6.68–7.05, 8.18–8.82, and 10.55–12.34 keV and can provide the X-ray emission spectrum with high sensitivity. In particular, the elements of V $K\beta_{1,3}$, Cr $K\alpha_{1,2}$, and Pr~Sm $L\alpha_{1,2}$ emissions are available owing to the expansion in a region of lower energy. Table 2 shows the relationship of available energy range with each crystal and its reflection plane. The addition of these analyzer crystals reduced the dead energy zone for the emission, and almost all elements and their emission can be used.

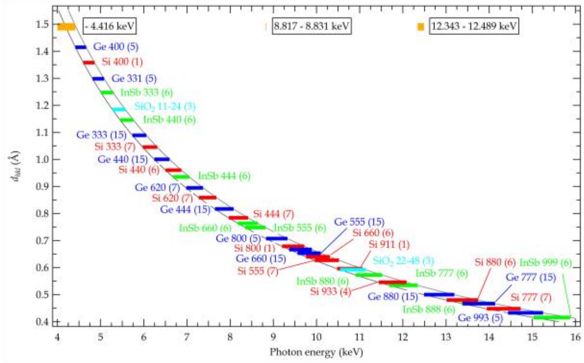

Fig. 2. Analyzer crystals available for the XES spectrometer. The number in parentheses represents the quantity of crystals. Orange thick lines denote the unavailable energy range.

Table 2. Available energy range due to each crystal and its reflection plane.

Crystal	Reflection	Energy (keV)
InSb 111	333	5.01–5.29
	444	6.68–7.05
	555	8.35–8.82
	777	11.67–12.34
	888	13.36–14.11
	999	15.03–15.87
InSb 220	440	5.45–5.76
	660	8.18–8.64
	880	10.91–11.52
SiO_2 11-24	11-24	5.27–5.57
	22-48	10.55–11.14

3. Experimental station for X-ray nanospectroscopy

Since FY2011, a scanning hard X-ray nanoprobe has been developed for XAS/XMCD microscopy at the X-ray nanospectroscopy station in experimental hutch 2 [3]. Kirkpatrick and Baez (KB) mirror optics are used to generate a circular polarized and focused X-ray beam with a typical spot size of 100 nm × 100 nm in an energy range of 5–16 keV.

Currently, X-ray nanoprobe XMCD is mainly used in this station. Two types of electromagnet are available depending on the purpose: (1) for high magnetic fields up to 2.2 T and (2) for the computed tomography (CT) of XMCD. In particular, the latter magnet has a large space above the sample, although the gap of the pole piece is narrow and the applied magnetic field is small (< 1.0 T). Therefore, additional sample environments such as electric field or laser can be assembled for the XMCD measurements.

In contrast, a highly efficient imaging method using X-ray fluorescence (XRF) and XAS is also conceivable with the effective use of a nano-focusing X-ray beam. An XRF/XAS imaging system will be facilitated in the near future.

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