PHYS719P REPORT NO.6:
MAGNETIC SPECTROSCOPY BEAMLINE

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Abstract

Magnetic spectroscopy beamlines play a cruial role in characterizing the magnetic properties of materials. Utilizing undulator radiation sources, these beamlines generate polarized X-ray beams that enables techniques such as X-ray absorption spectroscopy (XAS) and X-ray magnetic circular dichroism (XMCD). The optical configuration including spherical grating mirrors and focusing mirrors ensure precise energy selection and polarization control. This report presents an overview of magnetic spectroscopy beamlines, their optical systems, and practical methodologies on XAS measurements for materials like nickel oxide.

I. INTRODUCTION

Magnetic spectroscopy beamlines enable the investigation of magnetic properties of materials. Under the influence of an external magnetic field, the spin states of electrons tend to align. By probing the response of spin states of electrons in a material, information on the physical parameters such as the orbital and spin magnetic moments, as well as electron-specific contributions to the total magnetic moment can be derived.

Radiation source commonly employed in these beamlines is an undulator. One of the critical features of undulator radiation is the ability to tune the polarization. Especially in magnetic spectroscopy circularly polarized X-rays enable differential absorption measurements required to distinguish spin orientations in a material.

Among the tools employed in the magnetic spectroscopy beamline, X-ray magnetic circular dichroism (XMCD) and X-ray absorption spectroscopy (XAS) are actively used in the PLS-II 2A beamline, which is shown in figure 1. XAS provides element-specific information about the electron structure by measuring absorption as a function of incident proton energy. Detection methods such as total electron yield (TEY) and fluorescence yield (FY) are used to probe surface (depth ~ 150 Å) and bulk properties (depth ~ 1000 Å) respectively. TEY is particularly applied to evaluate surface properties of semiconductors, and FY is applicable to evaluating battery materials. XMCD measures the difference in absorption of left- and right-circularly polarized light in the presence of a magnetic field, enabling analysis of both orbital and spin magnetic moments via sum rules.

In this report, the composition and hands-on practice of magnetic spectroscopy beamline at PLS-II will be introduced. Section II presents the composition of optical system, and practical measurements with XAS will be presented in section III. Section IV provides the conclusion and summary of this report.

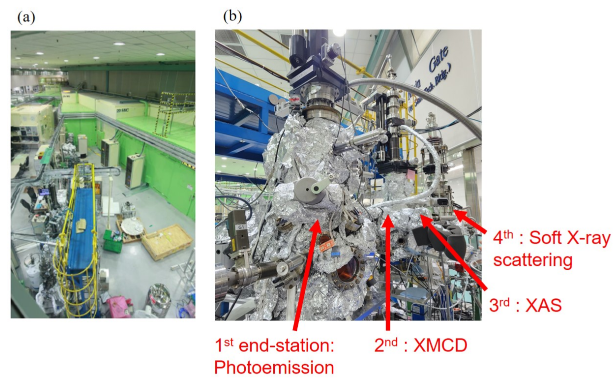

Figure 1: (Adopted from ref. [1]) (a) Bird's view of 2A beam line and (b) end station

II. OPTICAL SYSTEM

The optics for a magnetic spectroscopy beamline should be designed to ensure delivering monochromatic, and polarization-controlled X-ray beams to the sample. To achieve this, various optical components are employed. The spherical grating mirror reflects and diffracts the incoming polychromatic beam, while focusing the desired wavelength onto the sample. By selecting the diffraction order or density of the grating, the energy resolution and range can be selected for specific spectroscopy measurements.

Horizontal focusiong mirrors (HFMs) and vertical focusing mirrors (VFMs) are also integrated into the optical path for precise control of beam focusing. The mirrors not only shape the beam, but also tailors the polarization properties of the reflected beam. For instance, selecting appropriate reflecting and mirror coatings allows one to preserve or modify the polarization.

III. PRACTICE ON XAS MEASUREMENT

Implementation of X-ray absorption spetroscopy in the soft X-ray region requires UHV conditions due to the high absorption of low-energy protons by air. Preparing the UHV environment (10^{-8} – 10^{-9} Torr) takes approximately 18 hours, which includes pump-down and chamber baking. This long preparation ensures the minimization of signal attenuation and contamination of sample.

During the measurement, the sample is mounted between a pair of magnets as shown in figure 2. Here the relative orientation between the photon spin and magnetic moment of sample can be controlled. Since the change of X-ray helicity in the soft X-ray region is technically demanding, reversing the direction of magnetic field is often employs as an equivalent means of altering the polarization interaction.

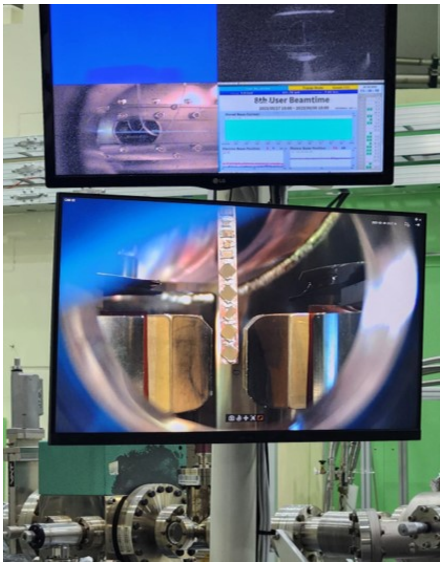

Figure 2: Sample placed in a magnetic field for XAS measurements. The camera is viewing the sample for aligning the beam.

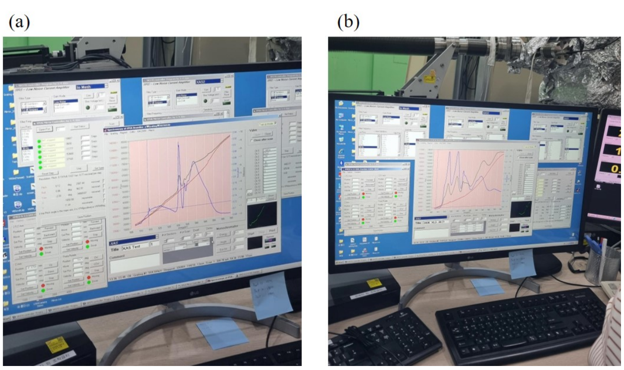

Figure 3: XAS spectrum of (a) oxygen and (b) nickel in the NiO sample.

Phosphor materials are often embraced onto the sample holder to align the X-ray beam with the sample.

Measurement with a nickel oxide (NiO) sample is conducted as a practical example of XAS. The raw absorption signal detected from the sample contains both of the intrinsic absorption and fluctuation in the incident beam intensity. Therefore, the raw signal should be subtracted with the contribution of beam intensity. Figure 3 shows the absorption spectrum of oxygen and nickel. The peaks in the XAS spectrum provide information on the unoccupied electronic states of oxygen or nickel. Therefore, by comparing the spectrum with the pre-measured reference, the chemical state such as bonding and oxidation states of the sample can be confirmed.

IV. CONCLUSION AND SUMMARY

Magnetic beamlines offer a powerful platform for investigating material-specific magnetic characteristics using polarized synchrotron radiation. Techniques such as XAS and XMCD rely heavily on precise beam conditioning and control of polarization, which are achieved through an array of components including spherical grating mirrors, horizontal and vertical focusing mirrors. Through practical examples on XAS with NiO sample, we have learned insight on the importance on beam alignment and vacuum preparation in obtaining reliable spectroscopic data. These methods are crucial in the characterization of semiconductors, magnetic materials, and energy storage systems.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Y. H. Kim, *Lecture note on Soft X-ray spectroscopy and application to AI semiconductors and rechargeable batteries*, Division of Advanced Nuclear Engineering (DANE), POSTECH, Pohang, Korea, May. 2025