Hands-on Accelerator Experiments I, Soft X-ray Spectroscopy

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I. THEORY

I.1. Introduction

Soft X-ray spectroscopy is an advanced technique that provides detailed information about the electronic and magnetic properties of materials by analyzing their interaction with soft X-rays. This technique is widely used for studying materials employed in cutting-edge devices, such as AI semiconductors and rechargeable batteries. The method is capable of probing both the electronic structure and the magnetic properties of materials, which are essential for the development of next-generation technologies.

I.2. X-ray Absorption Spectroscopy (XAS)

X-ray Absorption Spectroscopy (XAS) is a widely used technique to explore the electronic structure and local geometric arrangement of atoms in a material. When a material is exposed to X-rays, the energy of the incident X-rays is absorbed by the material, leading to the excitation of electrons from core levels to unoccupied states in the material. The absorption process provides information about the local electronic environment, oxidation states, and the chemical bonding of the material.

XAS is divided into two main regions: the X-ray Near-Edge Structure (XANES) and the Extended X-ray Absorption Fine Structure (EXAFS). The XANES region provides insights into the oxidation state and symmetry of the atoms, while the EXAFS region is primarily used for studying the local atomic structure, such as atomic distances and coordination numbers.

In practice, XAS is used to investigate materials for semiconductor devices, energy storage systems, and materials with specific magnetic properties. By analyzing the absorption edge, researchers can gather information on the material's composition and its electronic and structural characteristics.

I.3. X-ray Magnetic Circular Dichroism (XMCD)

X-ray Magnetic Circular Dichroism (XMCD) is a technique that measures the difference in absorption of left- and right-handed circularly polarized X-rays in the presence of a magnetic field. This effect is due to the interaction between the magnetic moments of the material and the polarization of the X-rays. XMCD is particularly useful for studying the magnetic properties of materials, as it provides information about the spin and orbital contributions to the total magnetic moment.

XMCD is highly sensitive to the magnetic properties of a material and can be used to distinguish between spin and orbital magnetic moments. This makes it an essential tool for studying ferromagnetic, antiferromagnetic, and other magnetic materials, as well as their applications in spintronic devices and AI-based memory technologies.

One of the key advantages of XMCD is its ability to provide element-specific information, allowing researchers to investigate the magnetic properties of specific elements within complex materials. This technique is crucial for understanding the fundamental properties of magnetic materials and their behavior in various technological applications.

I.4. Experimental Setup for XAS and XMCD

The XAS and XMCD experiments are typically conducted at synchrotron radiation facilities, where X-rays are generated by accelerating electrons through a storage ring. These X-rays are then directed through beamline optics, such as elliptically polarized undulators or wigglers, which produce intense X-ray beams for the experiments.

In the experimental setup, various detectors are used to record the X-ray absorption spectra. For XAS, the transmitted intensity, electron yield, and fluorescence yield are measured to obtain detailed information about the electronic structure and local environment of the material. In the case of XMCD, the difference in absorption between left- and right-handed circularly polarized X-rays is measured to study the magnetic properties of the sample.

I.5. Applications of XAS and XMCD

X-ray Absorption Spectroscopy (XAS) and X-ray Magnetic Circular Dichroism (XMCD) have numerous applications in material science and device development. They are extensively used for investigating the electronic and magnetic properties of materials, which is essential for the advancement of technologies in areas such as AI semiconductors, rechargeable batteries, and spintronics.

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XAS provides crucial information about the electronic structure and local geometry of materials, making it indispensable in the study of semiconductor devices and energy materials. XMCD, on the other hand, plays a vital role in understanding the magnetic properties of materials, enabling the development of next-generation spintronic devices and memory technologies.

These techniques are used to probe the fundamental properties of materials, offering insights into their behavior at the atomic level, which are crucial for the design of more efficient and advanced devices.

II. EXPERIMENT

I will list the photos taken in the training class first and then provide additional explanations.

I will explain a few things before proceeding with the experiment.

Ultra-high vacuum (UHV) should not be higher than -6 square. Only states below that are handled, and in particular, vacuum states of -10 and -11 square are mainly used.
If I use soft X-ray in this UHV, I can measure more "precisely", and if I use hard X-ray, I can measure more "roughly".

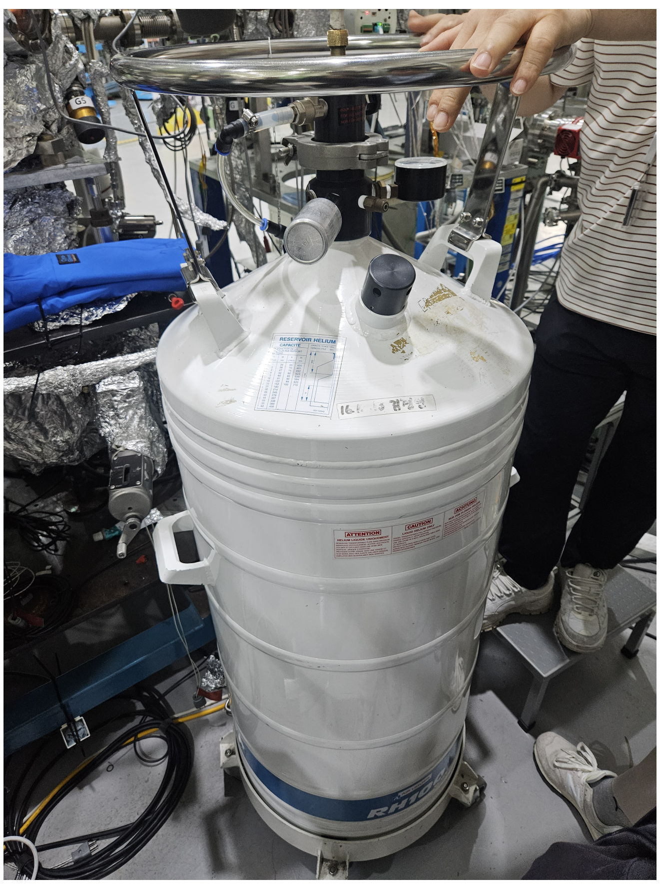

FIG. 1.

FIG. 2.

FIG. 1 is a picture of liquefied helium, and FIG. 2 is a part of the experimental setup. I heard that the chamber's left tube in the center of the picture is in charge of temperature and the right tube is in charge of signal.

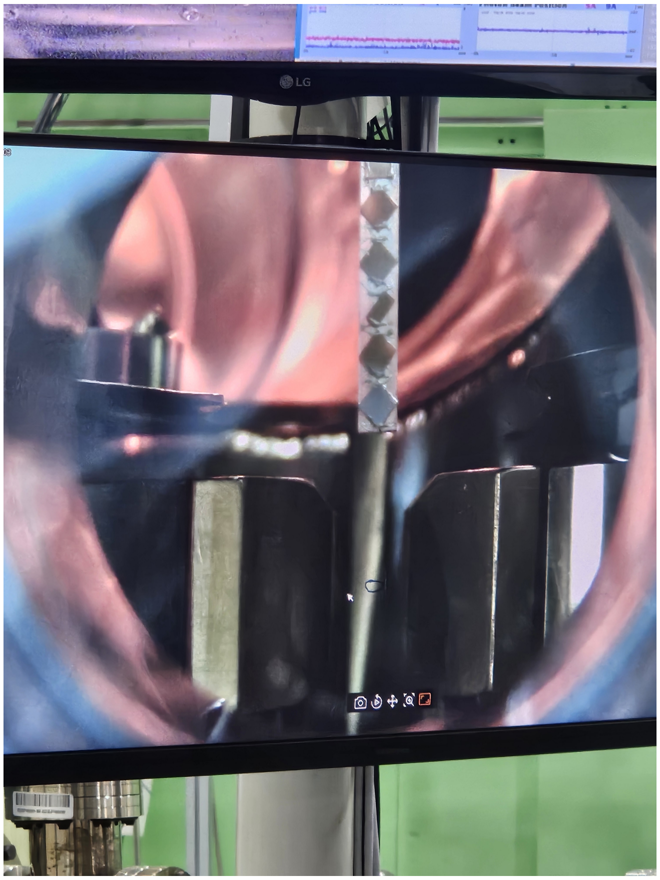

FIG. 3.

looking closely at the center of the picture, there is a small ellipse, which is the space where the beam enters. Up there are experimental samples, diamond-shaped ones are samples, and oxygen and nickel compounds are present here.

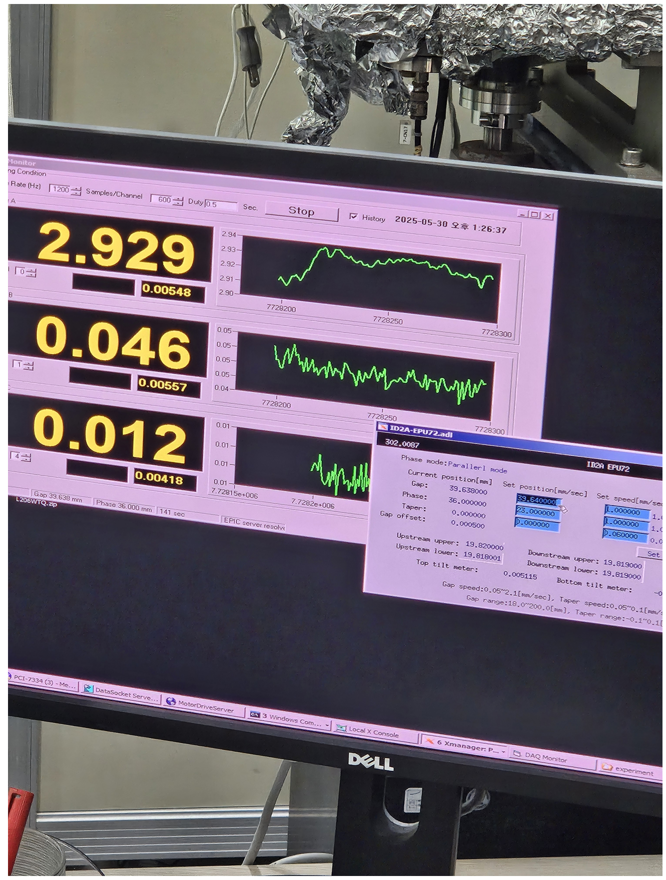

FIG. 4.

Three numbers will be visible in the upper-left tab, with the top beam signal indicating the state of the beam and the middle beam changes when it fits the sample. Measure by adjusting the 'gap' and 'phase' of the lower right tab. Here, the 'gap' means the gap of the undulater.

To briefly explain this experiment, there are different compounds in each sample, and the sample that is curious about how much oxygen is present is stopped, measured by changing the energy, and displayed as a graph. And by looking at the 'peak' of the graph, I can check whether the corresponding element is present or not. The table shows which elements come out well from which energy.

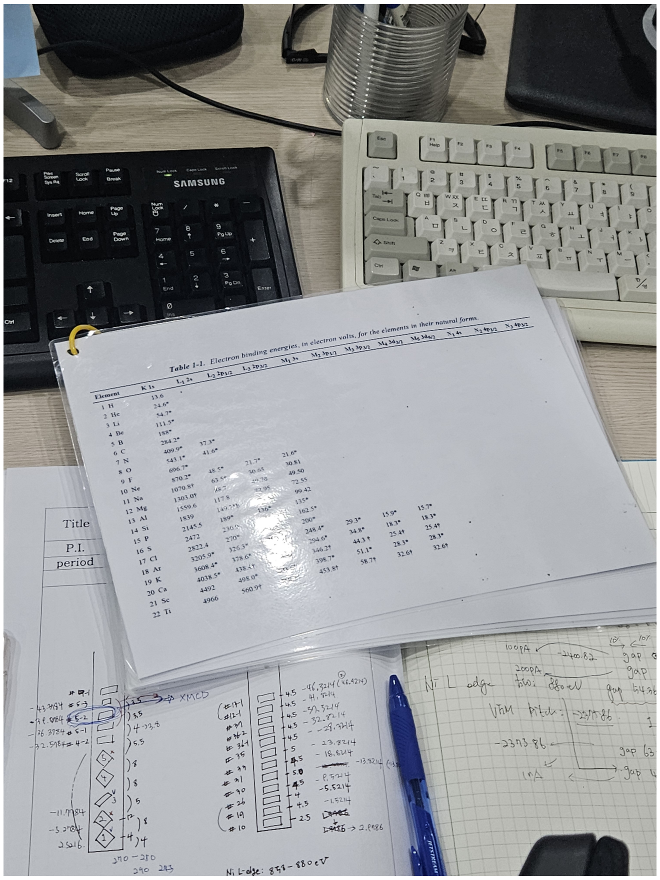

FIG. 5.

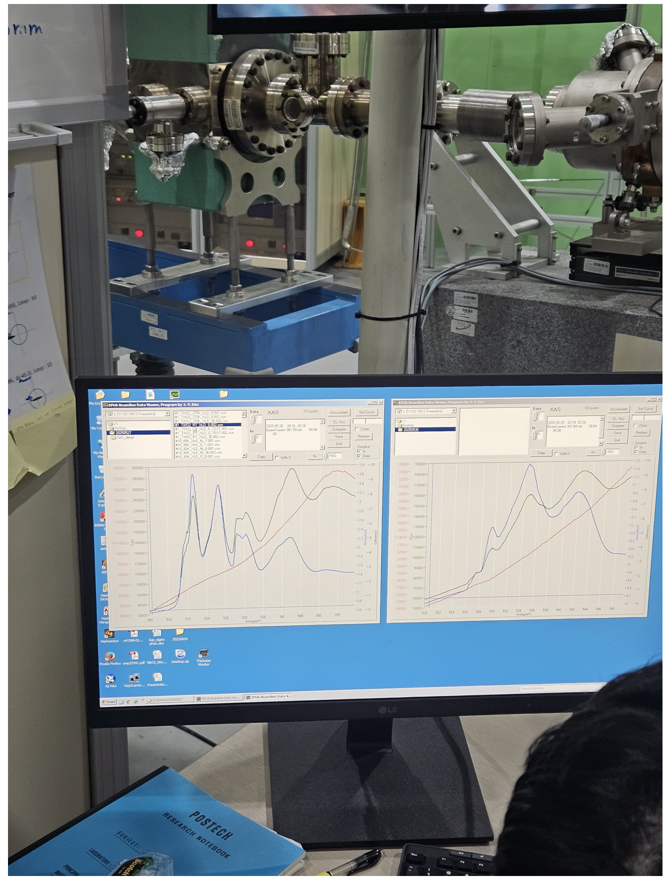

FIG. 6.

This is the table, and for example, if the oxygen-producing energy is 530, I can change the energy from 500-550 to take a picture.

The x-axis of this graph is energy. Compare the 'peak' in the left and right graphs to see if the element (oxygen) is exist or not. I'm trying to find exists in the compound.

FIG. 7.

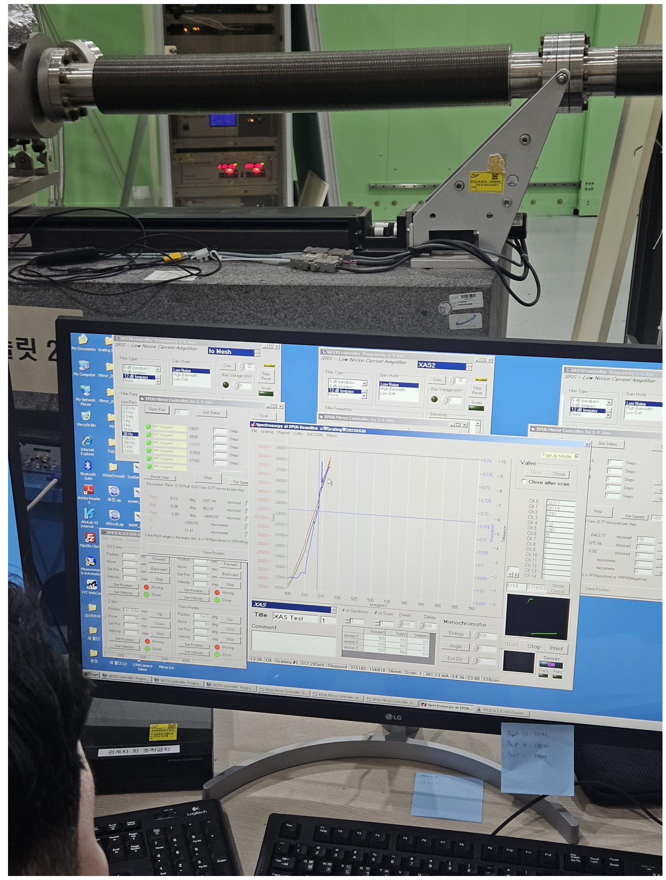

FIG. 8.

The picture above shows a 90° rotation of the sample. If you look closely at this sample, there is fluorescent material on the left, and the reason for the 90° rotation is that if you take it "normally" with the beam, the result comes out better.

Below is a picture of the results and during the experiment.

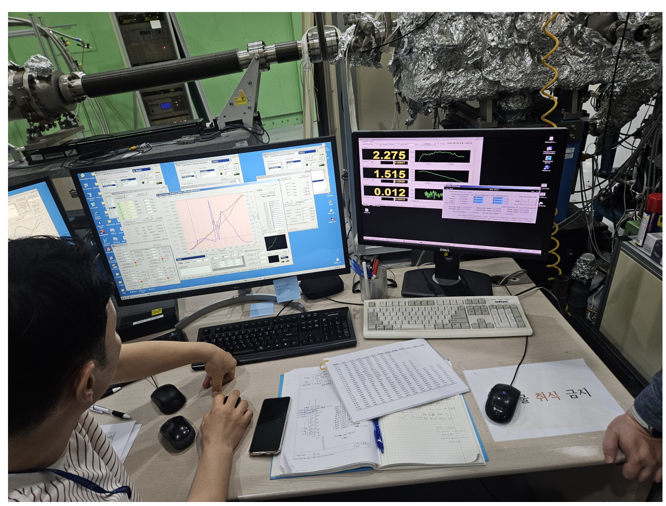

FIG. 9.

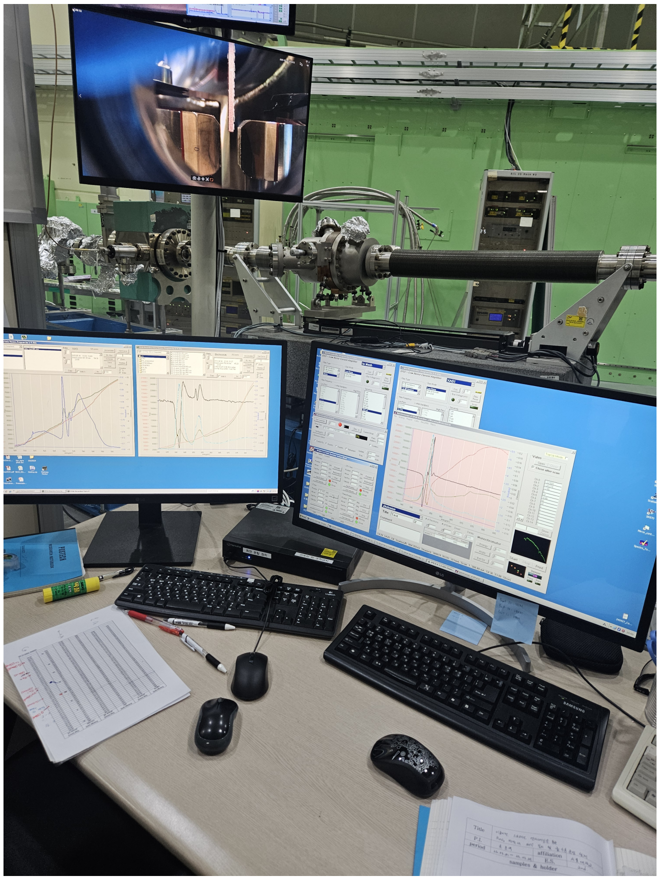

FIG. 10.

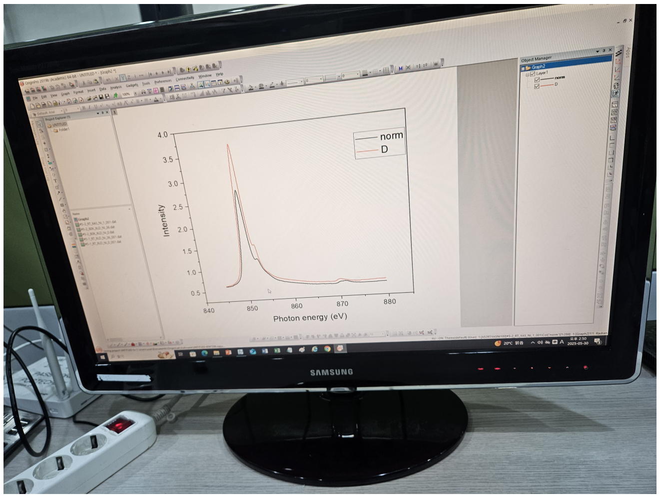

FIG. 11.

In the pictures above, there will be graphs in red, green, and blue, respectively, representing beam strength, sample signal, and (green)/(red) values.

In fact, the oxygen gap was incorrectly set in the first experiment, but there was no problem in the experimental results. I discussed the reason with my research colleagues, and 'gap' is a value involved in the 'flux' of light, and if this 'flux' value is not very strange, it is interpreted that it does not significantly affect the shape of the graph.

In addition, when light is irradiated to the sample, electrons will be emitted (photoelectric effect), and the amount of electrons is checked and measured.

FIG. 12.

FIG. 13.

The Dr. Kim explained the two pictures above, but I can't remember them well. I think he said that if the ratio of the two instrument panels in the middle of FIG. 12, the N pole and the S pole of the undulator change (not accurate).

Finally, I will conclude with the group photo of the "Hands-on Accelerator Experiments I" members.

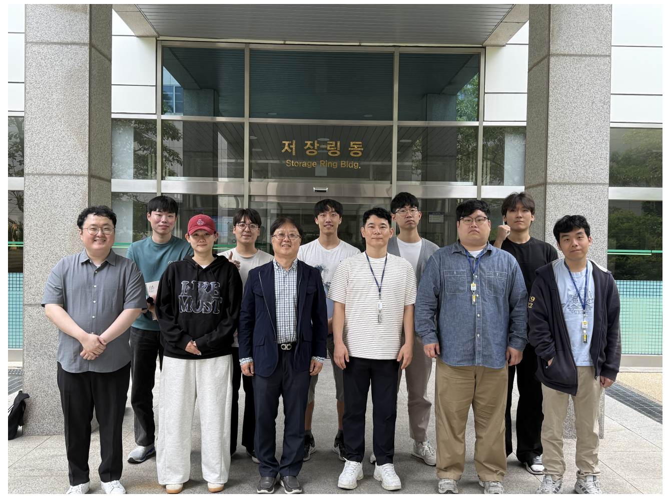

FIG. 14.

III. REFERENCE

[1] 김영학, "Soft X-ray Spectroscopy for Next-Generation Devices: Applications to AI Semiconductors and Rechargeable Batteries", *POSTECH*, 2025, pp. 1-36.