Ellipsometer Equipped with Multiple Mirrors for Element-selective Soft X-ray Experiments

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Received: 1 May, 2020; Accepted: 19 May, 2020; Published: 20 June, 2020

We developed the ellipsometer unit with a switchable mirror holder that can mount two mirrors and switch them without breaking vacuum. The vacuum unit, combined with a differential pumping rotary flange, rotates smoothly with the help of two roll-stands, keeping the optical path stable during an experiment of ellipsometry. The system allows one to efficiently make the measurement at two different photon energies of soft X-ray. Thus, it is useful, for example, in experiments of the resonant magneto-optical Kerr effect on a multi-element magnetic material with an X-ray free electron laser. Moreover, our set-up provides a simple technical tip to rotate a heavy vacuum unit that is attached to a vacuum chamber from the side.

Keywords Ellipsometry; Multilayer mirror; Soft X-rays; Extreme UV; X-ray free electron laser

I. INTRODUCTION

A beam of soft X-rays has been a significant probe to examine electronic and chemical states of a material [1−10]. Furthermore, variations of polarization by light-matter interaction can provide magnetic information through measurements of, for example, X-ray magneto-optical Kerr effect (XMOKE) [5−10]. In the XMOKE experiments, it requires linearly polarized light and, thus, it matches with the beam generated at a facility of an X-ray free-electron laser (XFEL), such as SPring-8 Angstrom Compact free electron Laser (SACLA) [11−13]. Tuning the photon energy of the (soft) X-ray beam at absorption edges of a material, XMOKE signals can be element-specific. The analysis, so-called resonant MOKE, has successfully traced both static and dynamics behavior in magnetic multi-element compounds [5−10].

A measurement of XMOKE has been carried out by tuning photon energy to the absorption edges of a sample (the resonant effect) and by the ellipsometry technique to measure magneto-optical Kerr rotation angle with element-selectivity [5−10]. Figure 1(a) illustrates a schematic drawing of the ellipsometry measurement with soft X-ray. An optical beam is reflected on the sample surface, followed by reflection on a mirror (analyzer), and reaches a detector (micro-channel plate, MCP). A set of a mirror and a detector rotates with angle, χ, with respect to the optical axis between the sample and the mirror. Functioning as a soft X-ray polarization analyzer, it is necessary to use a multilayer mirror that is customized for the light reflection of a specific photon
energy, i.e., the absorption edges, demanded in the experiment. To guide the soft X-ray beam, all the optical components and the operation must be kept in vacuum. In the case of a sample that is composed of more than one element, it is necessary to change the multilayer mirror to conduct resonant experiments for different elements. This process has required breaking vacuum and subsequent pumping of the system, which has wasted much time during the valuable XFEL beamtime. In the present technical note, we report our development of an ellipsometer unit equipped with the multiple mirrors that enables the mirror-switching under the vacuum condition. The unit is compact enough to be mounted at any ConFlat flange (ICF70, which corresponds to CF 2-3/4) of a vacuum chamber and makes the precise rotation without disturbing the optical alignment. Moreover, our technique provides a cheap and easy tip for researchers who want to control a heavy vacuum unit.

II. SYSTEM

The ellipsometer unit was developed at the SACLA SXFEL beamline, as shown in Figure 1(b). The beamline, a measurement chamber, and the ellipsometer unit are composed of vacuum chambers, and they are connected with each other by vacuum tubes. The soft X-ray beam from the XFEL beamline is reflected at a sample and is guided to the unit, as indicated by red arrows in Figure 1(b).

The \( \chi \)-rotation of the heavy unit is made by the DPRF (differential pumping rotary flanges) with the support by roll-stands, indicated in Figure 1(b). Figure 2 shows a photo of two roll-stands that support the unit chamber, while Figure 3 gives that of the individual ones. A roll-stand is commercially available as a pipe support that can hold a material that weighs up to 60–70 kg.

The \( \chi \)-rotation keeps the vacuum condition in the unit by a differential pumping rotary flange (DPRF) B, shown in Figure 2. A rotary motion of the DPRF is motorized and its angular resolution is 0.0008°. Figure 4 illustrates connections to the DPRF B. We additionally introduce a pinhole spacer (inset in Figure 4) before the DRPF B to ease the optical alignment. The pinhole has a size of \( \varnothing 1 \) mm and the surrounding fluorescent agent enables one to check a position of the soft X-ray beam in vacuum through the attached viewport. Based on the beam position on a pinhole spacer, the optical beam can be easily optimized by adjusting an energy.
X-Y stage or a sample manipulator, shown in Figure 1(b). Thanks to a combination of the DPRF and the two roll-stands, the $\chi$-rotation can be made precisely without disturbing the practical optical alignment of the ellipsometry measurement.

In resonant soft X-ray experiment of multi-element samples, it is necessary to change the photon energy to absorption edges of different elements in the material. Thus, it is required to change multilayer mirrors during experiment. To replace the mirrors without breaking vacuum, we developed the ellipsometer equipped with multiple mirrors. Figure 5 provides anatomical drawing of the ellipsometer unit with details of the composing parts. The whole unit is designed compact so that it can be additionally attached to an ICF 70 (CF 2-3/4) flange of a vacuum chamber. The system has the following features:

i. An ICF114 (CF 4-1/2) flange is adopted for a mirror holder of two mirrors (10 mm $\times$ 10 mm each) to be installed.

ii. A mirror holder can accommodate two mirrors on the front and back sides, and two mirrors can be switched by the rotary motion provided by converting the perpendicular rotary motion of the transfer rod through two gears.

iii. As shown in an inset of Figure 5, a stopper is installed on the mirror stage for the two mirrors in order to secure the reflection angle at $45^\circ$ with the accuracy better than 0.1°.

iv. Several viewpoints are installed at flanges of ICF70 (CF 2-3/4) and ICF34 (CF 1-1/3) to ease an optical alignment.

v. A reflected beam can be guided to the viewports by rotating the mirror stage by DRPF A.

It is of note that more than two mirrors can be installed by the same system of rotational-switching. However, it requires a much larger UHV chamber and a new switching mechanism to secure the different mirror angles.

III. CONCLUSION

We developed an ellipsometer unit equipped with two mirrors that reversibly switched in vacuum. Adopting more than one multilayer mirror, it is useful for soft X-ray resonant experiment that requires different photon energies. For example, one can trace ultrafast spin dynamics of different magnetic elements in a material by XMOKE measurement at the SXFEL beamline [14]. It is of note that the system significantly saves time during the XFEL beamtime by eliminating the venting/pumping time that is generally required for replacing mirrors. Through our research, we also made usage of roll-stages for precisely rotating the heavy vacuum unit that is additionally attached to the chamber from the side.

Acknowledgments

The research was made under the SACLA Basic Development Program 2018–2019. MA and JM acknowledge Vacuum & Optical Instruments, REX INDUSTRIES CO., LTD., and MCC Corporation for kind cooperation in publication. The development was also performed at the facilities of the Synchrotron Radiation Research Organization in the University of Tokyo.

Appendix

A movie of smooth rotation of the vacuum unit supported by the two roll-stands is available in Supplementary Material at https://doi.org/10.1380/ejssnt.2020.231.
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