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Short Note

Laboratory Extreme-Ultraviolet Faraday-Rotation Apparatus Using Multilayer Polarizers

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A laboratory apparatus for Faraday-rotation measurement in the extreme ultraviolet (EUV) region (50–70 eV) has been developed, using Al/YB$_6$ multilayers as both polarizers and analyzers. The light source was a laser-produced plasma. A magnetic field was generated by Sm–Co permanent magnets. The Faraday-rotation angle of 2.7° (absolute value) for a 21-nm-thick Ni film at 65.3 eV could be easily measured, coinciding well with the result using synchrotron radiation.

KEYWORDS: Faraday rotation, extreme ultraviolet, laser-produced plasma light source, multilayer polarizer, Ni $M_{2,3}$ absorption edges

Measurements of magneto-optical effects in core absorption are effective tools for estimating the magnetic moments of incomplete shells of magnetic atoms, because the initial states (core levels) have well-defined symmetries. The estimation of magnetic moments is very important not only in basic research, but also in the characterization of magnetic materials such as magnetic multilayers. These effects have been studied by magnetic circular dichroism (MCD) measurements using circularly polarized synchrotron radiation.[1)] Multilayers have recently been developed not only as high-reflectivity mirrors, but also as polarizers of high efficiency, enabling polarimetry in soft X-ray and extreme ultraviolet (EUV) regions.[2)] Kortright *et al.* reported Faraday-rotation measurements on Fe $L_{2,3}$ edges (700–720 eV).[3)] They used high linearly polarized undulator radiation and a reflection multilayer as an analyzer. We performed the Faraday-rotation experiment around Ni $M_{2,3}$ edges (60–70 eV) using transmission multilayers as polarizers,[4–6)] which make monochromatized synchrotron radiation high linearly polarized.[7)] On the basis of these experiments, it was verified that the Faraday-rotation measurements are as useful in soft X-ray and EUV regions as the MCD measurements. The above-mentioned measurements for the estimation of magnetic moments are urgently required to be made in laboratories for sample preparation procedure without the need for synchrotron radiation facilities. In laboratories, MCD measurements in soft X-ray and EUV regions have not yet been realized, because it is very difficult to generate circularly polarized light. Therefore, the purpose of this study is to develop a laboratory Faraday-rotation apparatus which operates in the EUV region, for which reflection polarizers with high reflectivity have been developed.

The optical system used in this study is shown in Fig. 1.[8)] The entire apparatus is accommodated in four chambers evacuated by two turbo-molecular pumps. The pressure is typically 2×10^{-6} Torr. The light source is a laser-produced plasma. The YAG laser (DCR-2A) was delivered by Quanta Ray. The wavelength is 1064 nm, the maximum power is 1 J/pulse and the maximum repetition frequency of the pulse is 10 Hz. The laser is focused on a spot of 0.2 mm diameter on the surface of a Sm target through a lens with a focal distance of 100 mm. The EUV light was focused by a spherical pre-mirror onto the entrance slit of the monochromator. The monochromator is of a constant-deviation (166°) type

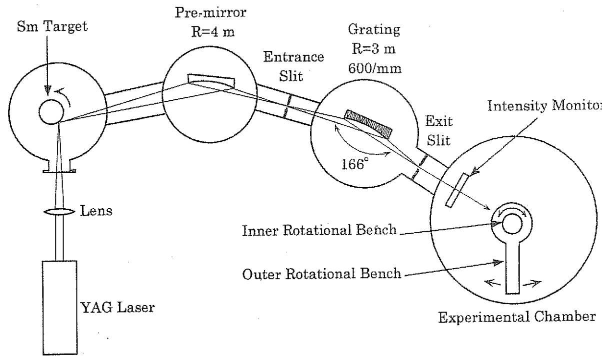

Fig. 1. Top view of laboratory EUV spectrometer.

with a spherical grating of radius 3 m and a groove density of 600/mm. The width of both the entrance and exit slits were 0.2 mm. The resolving power at a wavelength of 25 nm was 240.

The Faraday-rotation apparatus is accommodated in the experimental chamber as shown in Fig. 2. There are inner and outer rotational benches in the chamber, and they can be rotated independently around the same vertical axis. When the inner bench is rotated by θ, the outer bench can be rotated by 2θ. Since the EUV light from the laser-produced plasma is unpolarized, the polarizer is necessary for the generation of linear polarization. We mounted a reflection polarizer at the center of the inner rotational bench. A magnet system, a sample holder and a rotating analyzer unit were mounted on the outer rotational bench. A magnetic field of 0.82 T was generated by four Sm–Co permanent magnets in the direction of the light at the sample position. The polarization was measured using an analyzer unit rotating around the optical axis. The detector used was a micro channel-plate (MCP).

The reflection polarizer and analyzer consisted of Al/YB$_6$ multilayers with a period of 18.5 and periodic length of 13.8 nm.[5)] They were fabricated by a magnetron sputtering instrument (ANELVA SPL-500) on Si wafers. The polarizer was used in the photon energy range of 7 eV centered at 65 eV with polarizance of above 0.95. The angle of incidence was adjusted to around 42° (quasi-Brewster angle) in order to achieve its maximum reflectance (~20%) at each photon energy. The angle of incidence to the analyzer was fixed at 42°. The MCP was applied with a high voltage of 1.6 kV. Signals from both the intensity monitor and the MCP were amplified first by a pre-amp and secondly by a main-amp, and transferred to the computer through an A/D converter and I/O in-

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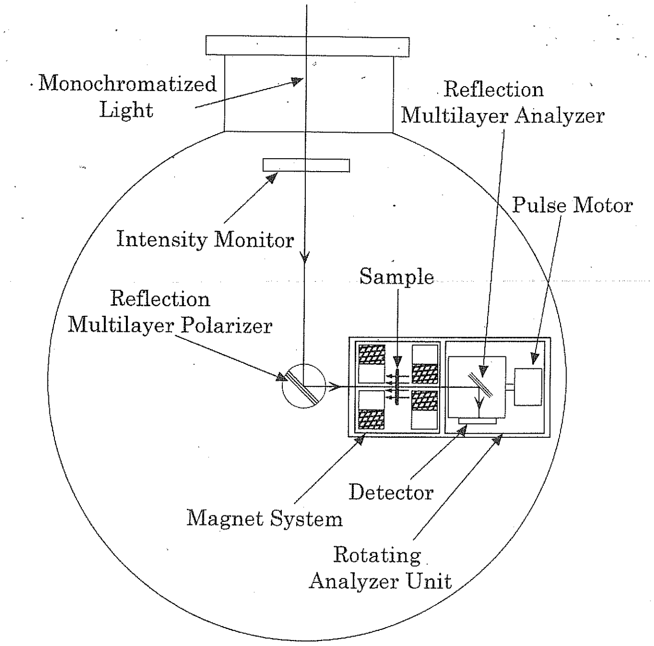

Fig. 2. Setup for Faraday-rotation measurement.

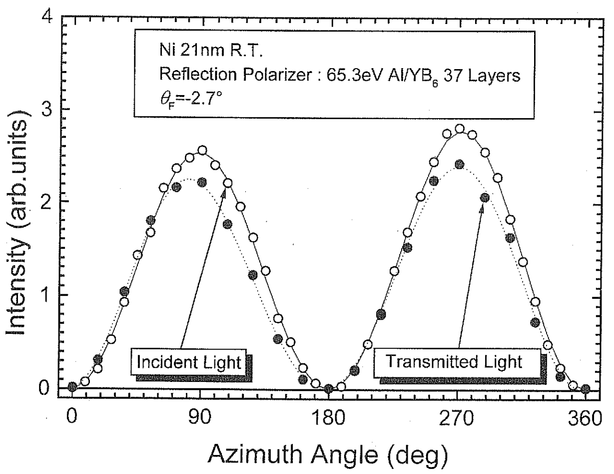

Fig. 3. Signals from the rotating analyzer unit at 65.3 eV. Open and closed circles indicate the signals of the incident light and the transmitted light through a magnetized 21-nm-thick Ni film, respectively.

terface. The signal from the MCP was normalized with that from the intensity monitor to suppress the shot-to-shot fluctuation. The polarization measurement was carried out at the azimuth angle of the rotating analyzer with a step of 18°. At each azimuth angle of the analyzer, the signals for 24 shots of laser pulses were accumulated.

The sample was a 21-nm-thick Ni film deposited on a substrate of collodion film supported by a Cu mesh screen. The transmittance of the sample was 10–20% at around 65 eV, while the transmittance of the substrate was about 40%. The Faraday-rotation measurement was performed at room temperature.

Figure 3 shows an example of the polarization signals of the incident light and transmitted light through the sample, measured at 65.3 eV by the rotating analyzer unit. The ordinate gives the intensities from the detector, and the abscissa, the azimuth angle of the analyzer. The two sinusoidal curves represent the results of fitting. The fitting procedure was the same as that described in the previous paper.[7]

Figure 4 shows the spectra of the Faraday-rotation angle. The closed circles indicate the results at 64.3, 65.3, 65.9, 66.5 and 65 eV obtained in the present experiment. The Faraday-rotation angle was −2.7° for a 21-nm-thick sample at 65.3 eV. The open circles indicate the results obtained using synchrotron radiation.[7] Though the S/N ratio of the former was not as good as the latter, both spectra coincide well. This is the first measurement of EUV magneto-optical effects in a laboratory, which proves that it is possible to estimate magnetic moments in laboratories. We will improve the premirror system to include both horizontal and vertical planes to obtain EUV light of greater intensity and improve the multilayer structure to achieve a higher reflectivity close to the theoretically designed value,[5] and obtain signals with a better S/N ratio.

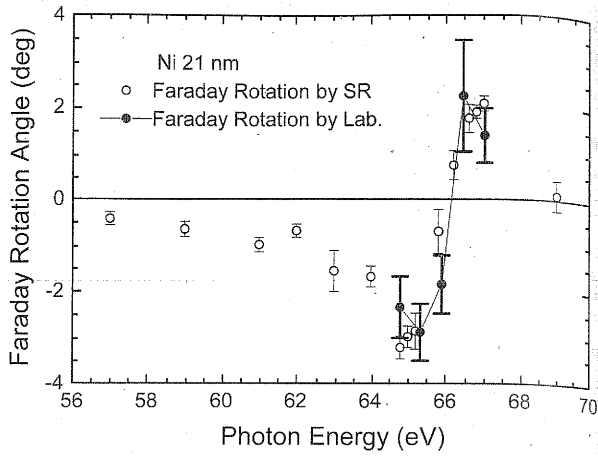

Fig. 4. Spectra of Faraday-rotation angle of Ni around $M_{2,3}$ absorption edges. Open and closed circles indicate the results measured using a laboratory light source (present results) and synchrotron radiation,[7] respectively.

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