BL 43IR
Infrared Materials Science

1. Introduction

BL43IR is dedicated to infrared (IR) microspectroscopy in the wavenumber region from 10,000 to 150 cm^{-1}. The beamline has three microscopes: a high-spatial-resolution microscope, a long-working-distance microscope, and a magneto-optical microscope. The microscopes are used with a Fourier transform spectrometer. We are developing new instruments for microspectroscopy to upgrade equipment already in operation, as well as to recruit new users for various sample environments.

2. Measurement and analytical method of magneto-optical Kerr effect

The magneto-optical microscopy station is designed for microspectroscopy under magnetic fields, and it consists of a superconducting magnet with a maximum field of 14 T combined with an IR microscope. Such equipment is currently operational only at BL43IR among infrared beamlines in the world. In this section, a new method to measure and analyze the magneto-optical Kerr effect (MOKE) in the IR region, developed by Dr. Iguchi and his collaborators [1], is reported.

The MOKE is a powerful tool for obtaining information regarding spin orders, such as the topology of electronic bands, spin-orbit interaction, and magnetic domains and so on, in a noncontact and nondestructive manner. For isotropic materials, the MOKE signal allows determination of the off-diagonal dielectric components, providing detailed insight into their properties. However, for anisotropic materials, such understanding had been limited. The reason is described below. When linearly or circularly polarized light is led to a magnetic crystal, the reflected light becomes tilted and elliptically polarized, which is represented by the Kerr rotation θ_K and the Kerr ellipticity η_K. This phenomenon is the MOKE, which results from the off-diagonal components of the dielectric tensor of the material. If a crystal is isotropic, the off-diagonal dielectric constant can be obtained from θ_K and η_K. If a crystal is anisotropic, however, the analysis is difficult because the spectrum due to birefringence and linear dichroism overlaps the MOKE spectrum. The birefringence and linear dichroism optical effects result from diagonal components of the dielectric constant, and the signal intensity is about 100–1000 times higher than that of the MOKE signal. To correctly measure the MOKE and obtain the off-diagonal dielectric constant, we developed the IR MOKE spectral measurement system by combining a photoelastic modulator (PEM) and a Fourier transform IR (FTIR) spectrometer at BL43IR.

The optical layout of the magneto-optical microscopy station is shown in Fig. 1. The IR light emitted from the storage ring passes through the FTIR interferometer and is then led to the magneto-optical station. Mirrors labeled P1 and P2 in Fig. 1 are parabolic mirrors and their focal lengths are 300 and 25.4 mm, respectively. The beam size is reduced to approximately 1/12 by the set of parabolic mirrors. A sample is placed on the bottom of the cold shaft in the cryostat, and only the reflection configuration is possible. IR light is focused onto the sample by a Cassegrain mirror.

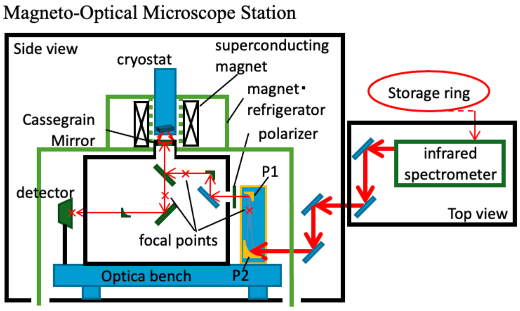

Fig. 1. Schematic illustration of optical layout of magneto-optical microscope station.

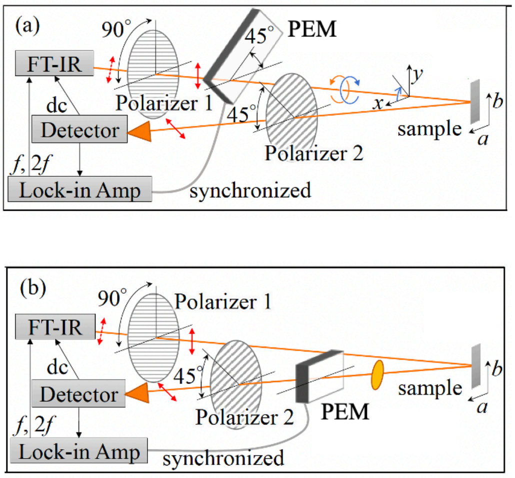

Fig. 2. Schematic diagrams of optical systems where PEM is placed (a) before and (b) after the sample. The lock-in amplifier is synchronized to the PEM modulation frequency f.

Figure 2 shows an illustration of the MOKE measurement configuration. The oscillation direction of the electric field of 0° polarized light is defined as horizontal in Fig. 2. The PEM is placed (a) before and (b) after the sample. Because of the difference in the position of the PEM, the incident light to the sample is (a) circularly and (b) linearly polarized. The typical MOKE configuration is (a). The magnetic field is applied perpendicular to the *a*–*b* plane of the sample. The a-axis of the sample is set to the *x*-axis of the optical configuration, as shown in Fig. 2(a). The lock-in amplifier is synchronized to the PEM modulation frequency f (about 50 kHz). The detected dc signal is returned directly to the FTIR interferometer, and the 1f and 2f signals are returned via the lock-in amplifier. A detailed explanation of the analytical method using a mathematical formula is described in the reference [1]. In this report, we only outlined the analytical method. The observable quantities are the spectra of the dc, f, and 2f signals. Our goal is to derive the wavenumber dependence of the off-diagonal component of the complex dielectric constant from these spectra. Using the Jones method, which is suited to describing and calculating polarized optics, the electric field of light is calculated from the incident light through the sample reflection and multiple optical elements to the detector. In the configuration shown in Fig. 2(a), only when the crystal is isotropic can the diagonal components be rearranged and the off-diagonal components determined. On the other hand, in the configuration shown in Fig. 2(b), the off-diagonal components can be determined even for an anisotropic crystal as follows.

$$\theta_{\mathrm{K}} = -\frac{I_2}{4J_2} \tag{1}$$

$$\eta_{\mathrm{K}} = -\frac{I_1}{4J_1} \tag{2}$$

θ_{K} is Kerr rotation and η_{K} is ellipticity, which are the quantities obtained by MOKE measurement. J_1 and J_2 are Bessel functions. I_1 and I_2 are the normalized modulate coefficients $I_1 = {}^{I_{1f}}\!/_{I_{dc}}$ and $I_1 = {}^{I_{2f}}\!/_{I_{dc}}$.

The off-diagonal dielectric constant $\tilde{\varepsilon}_{xy}$ can be obtained as follows.

$$\tilde{\epsilon}_{xy} = \frac{\tilde{\theta}(1+\tilde{n}_x)(\tilde{n}_x+\tilde{n}_y)(\tilde{n}_y+1)}{2} \qquad (3)$$

Here, $\tilde{\theta}\,(= -\tilde{r}_{xy} = +\tilde{r}_{yx})$ is the off-diagonal component of the reflectance matrix $\tilde{r}$. The diagonal component of $\tilde{r}$ is $\tilde{r}_j$. The diagonal component of the refractive index matrix is denoted by $\tilde{n}_j$ in Eq. (3). $\tilde{n}_j$, $\tilde{r}_j$. and $\tilde{\theta}$ are expressed as follows.

$$\tilde{n}_j = \frac{1-\tilde{r}_j}{1+\tilde{r}_j} \qquad (4)$$

$$\tilde{r}_j = r_j + is_j \qquad (5)$$

$$\tilde{\theta} = -\frac{\tilde{\theta}_{\mathrm{K}|y}}{\tilde{r}_y} = \frac{\tilde{\theta}_{\mathrm{K}|x}}{\tilde{r}_x} = \tilde{\theta}_{\mathrm{K}|j} + i\tilde{\eta}_{\mathrm{K}|j} \qquad (6)$$

$j = a, b$. $\tilde{\theta}_{\mathrm{K}|y}$ and $\tilde{\theta}_{\mathrm{K}|x}$ in Eq. (6) are complex angles of the reflective light when linearly polarized light of the electric field $E \| y$ and $E \| x$ is incident on the sample.

This method enables MOKE measurements to be performed on various crystals, whether the crystals are anisotropic or isotropic.

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References:

[1] Iguchi, S. Ikemoto, Y. Kobayashi, H. Kitazawa, H. Itoh, H. Iwai, S. Moriwaki, T. & Sasaki, T. (2023). *Proc. 29th Int. Conf. Low Temperature Physics (LT29) JPS Conf. Proc.* **38**, 011148.