Estimation of refractive index of monocrystalline sapphire by polarization measurement using MSV-5000 series

Introduction

The MSV-5000 series microscopic spectrophotometer is for transmission and reflection measurements of a sample as small as 10 μmϕ in a wide wavelength range from ultraviolet to near-infrared. The MSV-5000 has a built-in the Glan-Taylor polarizer as standard and can obtain optical constant such as refractive index(n) and extinction coefficient(k) by measuring reflectance spectrum of small monocrystalline having birefringence. This time, the monocrystalline sapphire(measurement area size: 50 μm in diameter), which has two types of crystal axis (c-axis or a-axis) and whose refractive index is already known, was measured and the dispersion of the refractive index was calculated.

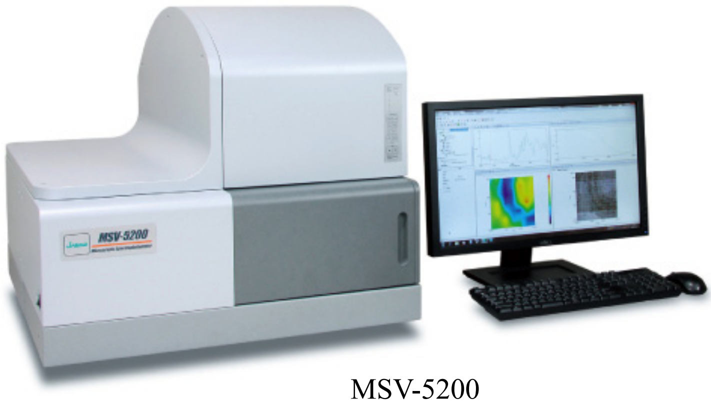
Keywords: microscope, polarized light, refractive index, birefringence

Measurement system

MSV-5200	UV/Vis/NIR Microscopic spectrophotometer
VWML-791	Multi-layer analysis program

Sample

Monocrystalline sapphire



MSV-5200

Measurement/Analysis

- Measurement

(1) Baseline: Two baselines of Al vapor deposited mirror were measured with polarizer angle at 0 and 90 degrees as a reference.

(2) Determination of crystalline axis: Under the condition of the polarizer angle at 0 degree and wavelength at 550 nm, the sample was rotated to find the angle of sample where the sample showed maximum reflectance. Then c-axis was determined by this angle and as orthogonal of c-axis, a-axis was determined as.

(3) Sample Measurement: After determination of c-axis, the reflection spectra were measured at polarizer angle at 0 and at 90 degree respectively.

(4) Conversion into absolute reflectance: The absolute reflectance spectrum of the sample was calculated by multiplying the obtained relative reflectance by the absolute reflectance spectrum of Al vapor deposited mirror.

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- Analysis

Two kinds of calculation methods were used for obtaining the refractive index and the results were compared.

(1) Method using [UVVIS K-K Conversion] Program:

The refractive index(n) is expressed by specular reflectance spectrum(R) and phase change(Φ) (Equation 1). Since the Kramers-Kronig(K-K) equation can be applied to specular reflectance spectrum(R) and phase change(Φ) (Equation 2), phase change(Φ) was calculated by K-K conversion of specular reflectance spectrum (R) and then, the refractive index(n) was calculated.

$$n = \frac{1-R}{1+R-2\sqrt{R}\cos\phi} \qquad \text{Equation 1}$$

$$\phi(\omega) = \frac{2\omega}{\pi} P \int_0^\infty \frac{\ln\sqrt{R(\omega')}}{\omega'^2 - \omega^2} d\omega' \qquad \text{Equation 2}$$

(2) Method using [Multi-layer Analysis] Program (Application of Fresnel equation):

Reflectance spectrum is expressed by the refractive index of the air and the sample(n_1, n_2), the incident angle(θ_1) and the reflection angle(θ_2) (Equation 3). By applying this equation, the wavelength dispersion of the refractive index was calculated using [Multi-layer Analysis] Program by fitting the calculated reflectance spectrum using Equation 3 to the measured spectrum.

$$R = \frac{1}{2}\left\{\left(\frac{n_1\cos\theta_1 - n_2\cos\theta_2}{n_1\cos\theta_1 + n_2\cos\theta_2}\right)^2 + \left(\frac{n_1\cos\theta_2 - n_2\cos\theta_1}{n_2\cos\theta_1 + n_1\cos\theta_2}\right)^2\right\} \qquad \text{Equation 3}$$

Parameters

Spectral bandwidth:	5.0 nm	Scan speed:	200 nm/min
Response:	Slow	Data interval:	0.1 nm
Accumulation:	3 times		
Cassegrain objective :	16 times	Incident angle:	23 degree
IN aperture:	50 µmϕ	OUT aperture:	50 µmϕ
Angle of polarizer:	0, 90 degree		

Measurement Results

Absolute reflectance spectrum of monocrystalline sapphire is shown in Fig. 1. Reflectance of ordinary light (c-axis) is approximately 0.15% higher than that of extraordinary light (a-axis).

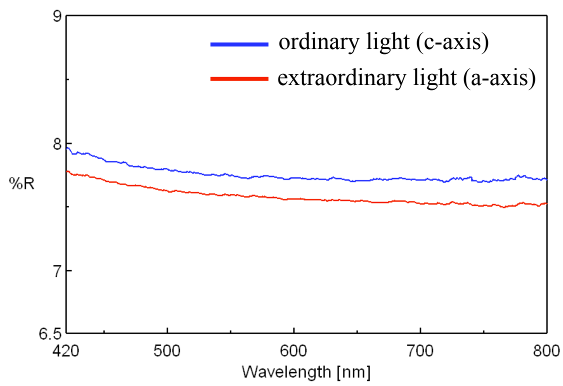

Fig. 1. Absolute reflectance spectra of monocrystalline sapphire

Analysis Results

By using [UVVis K-K Conversion] and [Multi-layer Analysis] Program, the wavelength dispersion of the refractive index was obtained (Fig. 2). Table 1 shows the result compared with the literature value of the reflective index of ordinary light and extraordinary light. The refractive index was determined with precision of two decimal places in a small area of several tens of microns, by either calculating method.

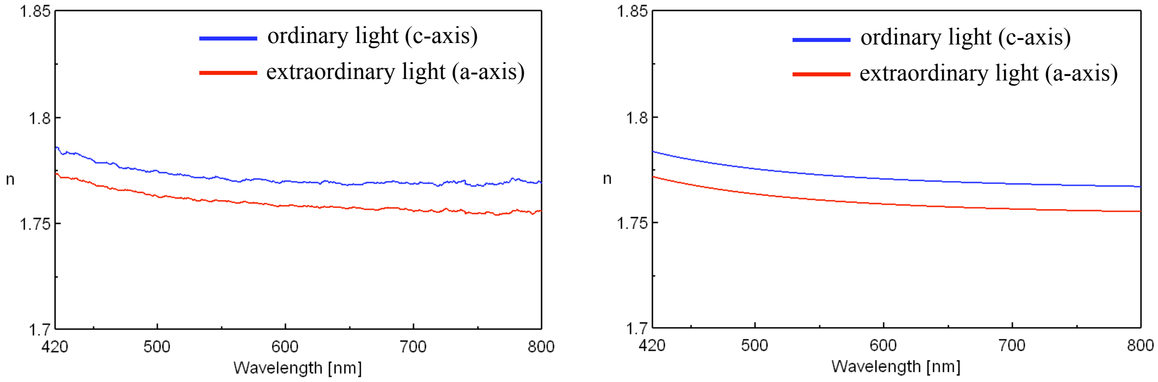

Fig. 2. Wavelength dispersion of refractive index of monocrystalline sapphire
(left: left: by using [UVVis K-K Convesion] Program, right: by using [Multi-layer Analysis] Program)

Table 1 Comparison with literature value of the refractive index of monocrystalline sapphire
(left: by using [UVVis K-K Conversion] Program, right: by using [Multi-layer Analysis] Program)

Wavelength [nm]	Literature value	K-K transform		Multilayer analysis	
	Refractive index	Refractive index	Error	Refractive index	Error
632.8	1.766	1.770	0.0037	1.769	0.0036
589.3	1.768	1.770	0.0016	1.771	0.0028
546.1	1.771	1.772	0.0012	1.773	0.0018
532.0	1.772	1.771	-0.0005	1.773	0.0015
514.5	1.773	1.773	-0.0005	1.774	0.0011
488.0	1.775	1.775	-0.0005	1.776	0.0007

Wavelength [nm]	Literature value	K-K transform		Multilayer analysis	
	Refractive index	Refractive index	Error	Refractive index	Error
632.8	1.758	1.757	-0.0005	1.758	-0.0003
589.3	1.760	1.758	-0.0015	1.759	-0.0011
546.1	1.763	1.761	-0.0017	1.761	-0.0020
532.0	1.764	1.761	-0.0030	1.761	-0.0022
514.5	1.765	1.762	-0.0032	1.762	-0.0026
488.0	1.767	1.764	-0.0028	1.764	-0.0030

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