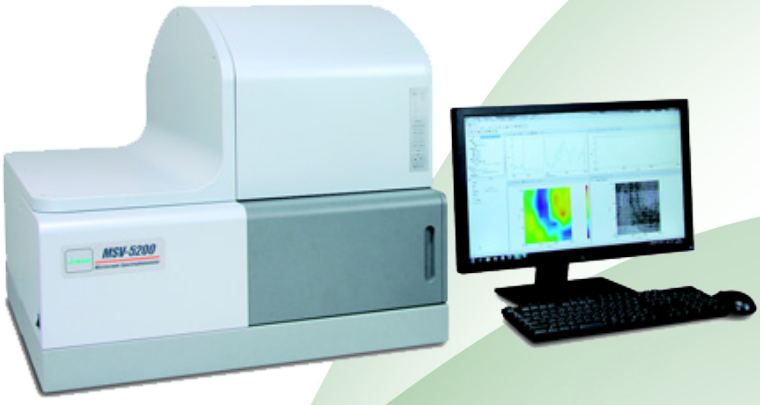
Application Note

Estimation of the Refractive Index of Monocrystalline Sapphire by Polarization Measurements using the MSV-5000 Series

Introduction

The MSV-5000 series micro-spectrophotometer is designed for transmission and reflection measurements of samples as small as 10 µm diameter over a wide wavelength range from the ultraviolet to the near-infrared wavelengths. The MSV-5000 has an integrated Glan-Taylor polarizer as standard and can obtain optical constants from sample materials such as the refractive index(n) and extinction coefficient(k) by measuring the reflectance spectrum of a small monocrystalline sample that exhibits birefringence. In this example, a monocrystalline sapphire sample (measurement area: 50 µm in diameter) was analyzed. This sample has two types of crystal axis (c-axis or a-axis) and the refractive index is already known, thus the polarization measurements were obtained for the sample and the dispersion of the refractive index was calculated from the measured data.



MSV-5000

Keyword: microscope, polarized light, refractive index, birefringence

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Measurement System

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

Sample: Monocrystalline sapphire

Measurement Conditions:

Spectral bandwidth (UV/Vis):	5.0 nm
Scan speed:	100 nm/min
Response:	Quick
Cassegrain objective:	16 times
Scanning speed:	1000 nm/min
Data pitch:	1 nm
Aperture:	50 mmf

Measurement

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

(2) Determination of crystalline axis: setting the polarizer angle to 0 degrees and the wavelength to 550 nm, the sample was rotated to find the angle of the sample where the sample showed a maximum reflectance. The c-axis was defined as this angle of sample rotation and the orthogonal of the c-axis, was defined as the a-axis.

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

(4) Conversion into absolute reflectance: the absolute reflectance spectra of the sample was calculated by multiplying the obtained relative reflectance spectra by the absolute reflectance spectra of the Al vapor deposited mirror, based on the relative polarization angles for the sample and reference data.

Analysis

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

(1)Method using [UV-VIS K-K Conversion] Program:The refractive index (n) is expressed by the specular reflectance spectrum (R) and the phase change (□) (Equation 1). Since the Kramers-Kronig (K-K) equation can be applied to the specular reflectance spectrum (R) and the phase change (□) (Equation 2), the phase change (□) was calculated by the K-K conversion of the specular reflectance spectrum (R) and then, the refractive index (n) was calculated.

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

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

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

The reflectance spectrum is expressed by the refractive index of the air and the sample (n1, n2), the incident angle of the source (□1) and the reflection angle (□2) (Equation 3). By applying this equation, the wavelength dispersion of the refractive index was calculated using the [Multi-layer Analysis] Program by fitting the calculated reflectance spectrum using Equation 3 to the measured spectrum.

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

Instrument Parameters:

Spectral bandwidth:	5.0 nm
Accumulation:	100 nm/min
Response:	3 times
Cassegrain objective :	16X
IN aperture:	50 μmf
Angle of polarizer:	0, 90 degrees

Scan speed:	200 nm/min
AcData interval:	0.1 nm
Incident angle:	23 degree
OUT aperture:	50 μmf

Measurement Results

The absolute reflectance spectra of monocrystalline sapphire is shown as Fig. 1. Reflectance of the ordinary light (c-axis) is approximately 0.15% higher than that of the extraordinary light (a-axis).

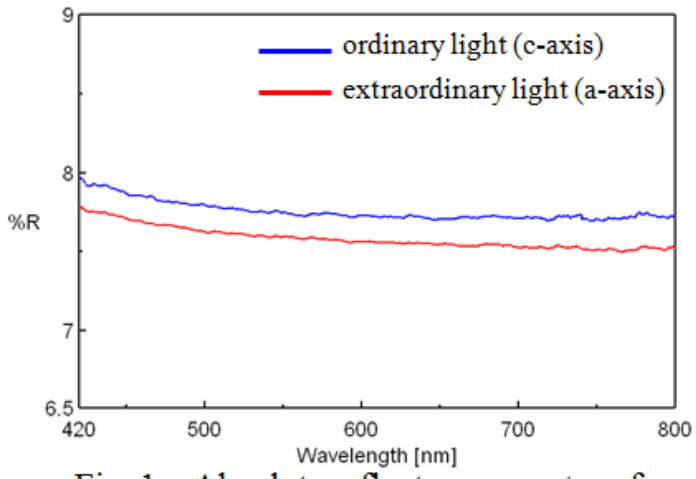

Fig. 1. Absolute reflectance spectra of monocrystalline sapphire

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Analysis Results

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

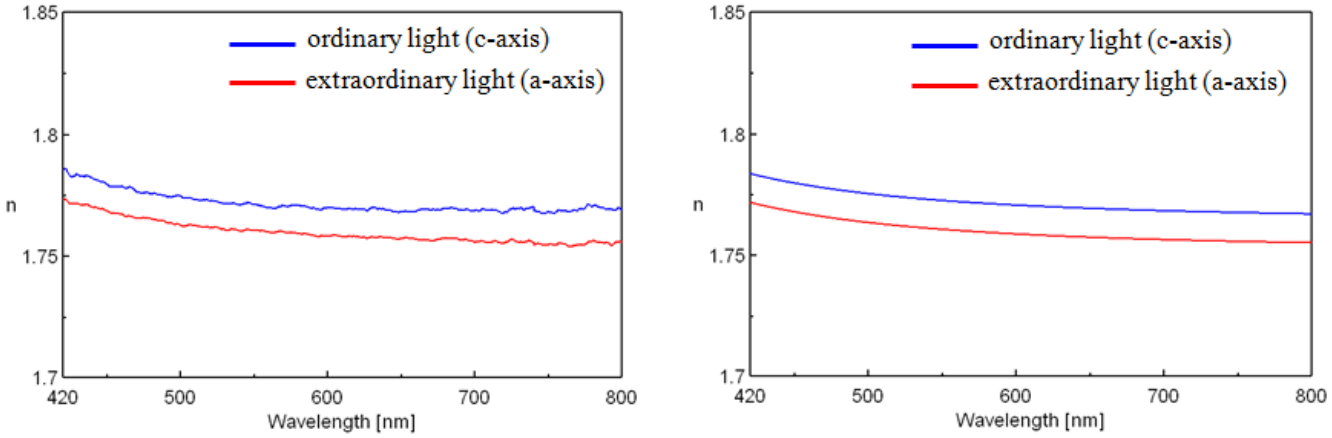

Fig. 2. Wavelength dispersion of refractive index of monocrystalline sapphire (left: left: by using [UV-Vis K-K Conversion] Program, right: by using [Multi-layer Analysis] Program)

Table 1 Comparison with literature value of the refractive index of monocrystalline sapphire (left: by using [UV-Vis 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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