# Accurate measurement of the main refractive indices and thermo-optical coefficients of the calcite crystal

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The main refractive indices of calcite crystal are measured by the means of auto-collimation, and the thermo-optical coefficients are calculated. The coefficient expression of Sellmeier equation is obtained by solving Sellmeier equation strictly and the refractive indices of different wavelengths are calculated, which accord with experimental results very well. The measured main refractive indices of calcite at 488-nm wavelength are identical with the values obtained by Sellmeier equation.

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The calcite crystal has become a kind of ideal optical polarizing materials because of its many advantages such as large birefractive indices ($n_{\rm e} - n_{\rm o}$), the stable optical performance, the wide transmission range (0.25—2.8 $\mu$m), etc.[1−3]. The refractive indices and the thermo-optical coefficients are the important physical parameters of crystal devices, the divergence angle and the deviant angle of polarizing devices made of calcite crystal are changed because of the refractive indices and the thermo-optical coefficients varying with temperature. So the main refractive indices of crystal at different wavelengths and different temperatures must be known accurately. Li has provided several refractive indices and the thermo-optical coefficients of the fixing wavelength at particular temperature[4]. The theoretical calculation at different wavelengths and different temperatures was only operated[5,6], however, experimental measurement has not been carried out.

In this paper, the main refractive indices and thermo-optical coefficients are measured at different temperatures using different laser sources by the means of auto-collimation[7−10]. The main refractive indices of different wavelengths at different temperatures are calculated by Sellmeier equation, which accord with experimental result very well.

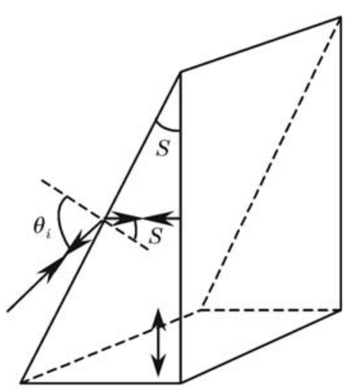


Fig. 1. Prism used to measure principal refractive indices and thermal coefficients.

The high-quality calcite right prism used to measure two main refractive indices is shown as Fig. 1. Optical axis is parallel strictly to the long right-angle side, and the deviation is smaller than 1′. The inclined plane and large right-angle plane are polished, the flatness is superior to $\lambda/10$, its cutting angle $S$ is measured to be 29.876°.

When the laser beam reaches the inclined plane of the prism with the smallest incident angle $\theta_i$, it is divided into o-light and e-light. Under auto-collimation condition, we have

$$n_i = \sin\theta_i / \sin S, \quad (i = {\rm o}, {\rm e}) \qquad (1)$$

where $n_i$ stands for the refractive index of the linearly polarized light while $S$ stands for the structure angle of the prism.

The experimental setup is shown in Fig. 2. Right angle calcite prism is put into temperature control device LT-1 with the accuracy of 0.1 °C and adjustable range of −20—+80 °C. Put the temperature control device in the center of rotor platform of instrument, one can measure angle and make 360° rotation in the level plane. Rays sent out from light source are exposed at the prism on the temperature control device through diaphragm. Rotating the platform instrument can measure angles, measuring the minimum deviation angles of o-light and e-light and taking it into Eq. (1) can obtain the refraction indices $n_{\rm o}$ and $n_{\rm e}$.

The structure angle varies with temperature, the structure angles of the prism at different temperatures are

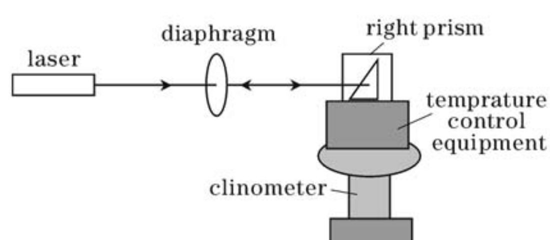


Fig. 2. Experimental setup.

 

firstly measured in order to get the refractive indices accurately. The relationship[11,12] between structure angle and temperature is shown in Fig. 3.

The different wavelength lasers at 473, 532, 670, and 633 nm are used as the light sources separately, whose maximum directional variations are smaller than 30 $\mu$rad in the scope of ±3 °C. The method described above is used to measure the minimum deviation angles of o-light and e-light ($\theta_o$ and $\theta_e$) at different temperatures. The refraction indices at different temperatures and wavelengths are calculated from Eq. (1). The results are listed in Table 1.

In order to calculate the main refraction indices of o-light and e-light for each wavelength at different temperatures, the modified Sellmeier equation[13,14] is used,

$$n_i^2 = A_i + \frac{B_i}{\lambda^2 - C_i} - D_i\lambda^2. \quad (i = \mathrm{o}, \mathrm{e}) \qquad (2)$$

From Eq. (2) and Table 1, the four parameters of $A_i$, $B_i$, $C_i$, and $D_i$ of Sellmeier equation at different temperatures are got and listed in Table 2.

Using Sellmeier equation (2) and the values of $A$, $B$, $C$, $D$ listed in Table 2, we can obtain the main refraction indices, as shown in Table 3.

From Tables 1 and 3, we can see clearly that the values

**Table 1. Principal Refractive Indices of Calcite Crystal at Different Wavelengths and Temperatures Obtained from Eq. (1)**

| Principal Indices | Temperature (°C) | Wavelength 473 nm | 532 nm | 633 nm | 670 nm |
|---|---|---|---|---|---|
| $n_o$ | 23.0 | 1.67005 | 1.66277 | 1.65578 | 1.65367 |
| | 30.1 | 1.67006 | 1.66281 | 1.65585 | 1.65370 |
| | 39.5 | 1.67009 | 1.66285 | 1.65587 | 1.65375 |
| | 48.0 | 1.67014 | 1.66289 | 1.65593 | 1.65379 |
| | 60.7 | 1.67018 | 1.66293 | 1.65595 | 1.65382 |
| $n_e$ | 23.0 | 1.49173 | 1.48841 | 1.48535 | 1.48423 |
| | 30.1 | 1.49185 | 1.48848 | 1.48541 | 1.48432 |
| | 39.5 | 1.49192 | 1.48857 | 1.48549 | 1.48439 |
| | 48.0 | 1.49209 | 1.48869 | 1.48558 | 1.48449 |
| | 60.7 | 1.49215 | 1.48878 | 1.48576 | 1.48462 |

**Table 2. Constants of the Sellmeier Equation at Different Temperatures**

| Temperature (°C) | 23.0 | 30.1 | 39.5 | 48.0 | 60.7 |
|---|---|---|---|---|---|
| $A_o$ | 2.7685 | 2.7737 | 2.7700 | 2.7730 | 2.7713 |
| $B_o$ | 0.0035 | 0.0029 | 0.0034 | 0.0030 | 0.0032 |
| $C_o$ | 0.1433 | 0.1502 | 0.1443 | 0.1489 | 0.1460 |
| $D_o$ | 0.1008 | 0.1086 | 0.1026 | 0.1070 | 0.01044 |
| $A_e$ | 2.2312 | 2.2296 | 2.2303 | 2.2303 | 2.2338 |
| $B_e$ ($\times 10^{-4}$) | 2.1381 | 3.0378 | 2.8890 | 3.0916 | 1.3179 |
| $C_e$ | 0.1989 | 0.1926 | 0.1934 | 0.1924 | 0.2068 |
| $D_e$ | 0.0648 | 0.0614 | 0.0623 | 0.0620 | 0.0674 |

**Table 3. Main Refractive Indices of Calcite Crystal at Different Temperatures Obtained from Eq. (2)**

| Principal Indices | Temperature (°C) | Wavelength 473 nm | 532 nm | 633 nm | 670 nm |
|---|---|---|---|---|---|
| $n_o$ | 23.0 | 1.67007 | 1.66280 | 1.65581 | 1.65370 |
| | 30.1 | 1.67009 | 1.66283 | 1.65587 | 1.65373 |
| | 39.5 | 1.67011 | 1.66287 | 1.65590 | 1.65376 |
| | 48.0 | 1.67017 | 1.66291 | 1.65595 | 1.65381 |
| | 60.7 | 1.67020 | 1.66295 | 1.65597 | 1.65386 |
| $n_e$ | 23.0 | 1.49176 | 1.48846 | 1.48538 | 1.48427 |
| | 30.1 | 1.49191 | 1.48852 | 1.48545 | 1.48438 |
| | 39.5 | 1.49197 | 1.48858 | 1.48552 | 1.48442 |
| | 48.0 | 1.49212 | 1.48871 | 1.48560 | 1.48453 |
| | 60.7 | 1.49215 | 1.48882 | 1.48579 | 1.48465 |

**Table 4. Thermal Refractive Index Coefficients of Calcite Crystal**

| Wavelength (nm) | 473 | 532 | 633 | 670 |
|---|---|---|---|---|
| $dn_o/dT$ | 0.3130 | 0.2730 | 0.2140 | 0.1920 |
| $dn_e/dT$ | 1.2520 | 1.2280 | 1.1910 | 1.1760 |

**Table 5. Principal Refractive Indices of Calcite Crystal at Different Temperatures (488 nm)**

| Temperature (°C) | | 23.0 | 30.1 | 39.5 | 48.0 | 60.7 |
|---|---|---|---|---|---|---|
| Measured Values | $n_o$ | 1.66852 | 1.66854 | 1.66856 | 1.66862 | 1.66865 |
| | $n_e$ | 1.49035 | 1.49041 | 1.49047 | 1.49052 | 1.49056 |
| Calculated Values | $n_o$ | 1.66849 | 1.66852 | 1.66853 | 1.66859 | 1.66860 |
| | $n_e$ | 1.49033 | 1.49038 | 1.49042 | 1.49048 | 1.49053 |

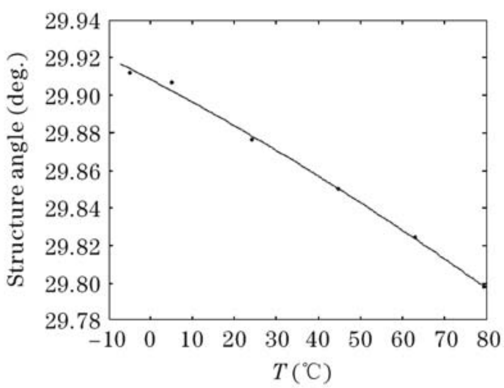


Fig. 3. Structure angle of the sample prism varying with temperature.

in two tables can be compounded well, and the accuracy can reach to $10^{-4}$, which illustrates that Sellmeier equation reflects the dispersion relationship between the principal refraction index of calcite crystal and wavelength very well.

The thermo-optical coefficients of calcite crystal calculated from Table 3 are shown in Table 4.

In order to prove the accuracy of the measured results, another light source (488 nm) is used to measure the indices of o-light and e-light. The measured results are coincided with the calculated ones by Sellmeier equation, as shown in Table 5.

In conclusion, the main refraction indices of calcite crystal at different temperatures in the range of visible light are measured with the method of autocollimation, then Sellmeier equations parameters of different wavelengths are obtained. And the main refraction indices at different wavelengths and different temperatures can be got. The main refractive indices of calcite by Sellmeier equation are consistent with the experimental results. The main refractive indices of o-light and e-light at 488-nm wavelength are measured, they are identical with the values by Sellmeier equation, which illustrates that the measured results are accurate.

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