INTERFERENTIAL METHOD TO DETERMINE THE OPTICAL ROTATORY DISPERSION OF CRYSTALLINE LAYERS

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The channeled spectra, obtained by interference of the left and right circularly polarized radiations emerging from an optically active anisotropic layer are used to determine the circular birefringence and the specific rotation in the visible range.

Keywords:

1. Introduction

The optically active substances (in crystalline of liquid phases) rotate the light polarization plane around the propagation direction. The inorganic crystals, organic molecules or polymers in solutions are optically active materials if they possess one or more asymmetric carbons in their structure. When a linearly polarized wave passes through transparent optically active materials, its polarization plane rotates around the propagation direction with angles dependent on the circularly birefringence, on the spectral range in which the recordings are made and also on the material nature, or on the solution concentration [1-4].

The phenomenon can be explained on the Fresnel theory basis. The Fresnel theory was developed on the basis of the equivalence between one linearly polarized wave and two circularly polarized (to right and to left) waves with amplitudes equal to the half of the linearly polarized wave amplitude, propagating on the same direction.

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The rotation angle (the angle between the azimuths at the entrance and at the exit from the optically active medium) can be determined by using a polar meter, but this device uses a small frequency range. The method of the channeled spectrum is preferred due to its rapidity, large frequencies ranges and a very little number of determinations.

This method asks for substances of high transparency in a large frequency domain and also for materials of high purity in order to avoid the light diffusion.

The proposed method is an extension of that one described in [5], where measurements at different wavelengths were combined with the rotating polarizer method [6] in order to identify optically active substances under the microscope.

In the present paper, the influence of the anisotropic layer's thickness along the optical axis on the optical rotatory dispersion of the Carpathian Quartz is analyzed.

2. Theoretical background

Let us write the equations of two circularly (to left –indexed by l - and to right-indexed by r -) polarized radiations propagating in positive sense of oz axis:

$$\bar{e}_x^l(z,t) = -\frac{E_0}{2}\bar{i}\sin(\omega t - k_l z + \varphi_{0l}) \text{ and } \bar{e}_y^l(z,t) = \frac{E_0}{2}\bar{j}\cos(\omega t - k_l z + \varphi_{0l}) \quad (1a,b)$$

$$\bar{e}_x^r(z,t) = \frac{E_0}{2}\bar{i}\sin(\omega t - k_r z + \varphi_{0r}) \text{ and } \bar{e}_y^r(z,t) = \frac{E_0}{2}\bar{j}\cos(\omega t - k_r z + \varphi_{0r}) \quad (2a,b)$$

In relations (1a,b) and (2a,b), the wave elongation (at distance z measured in the propagation direction and at moment t) is denoted by $\vec{e}(z,t)$ indexed for its orientation by x and y; the wave amplitude of the waves is $E_0/2$; ω is the angular velocity; k is the wave vector; φ_0 represents the initial phase of wave.

At the exit from the transparent optically active layer, at $z = L$, the two circularly polarized waves with different phases, recompose and give a linearly polarized radiation with azimuth θ:

$$\theta = \frac{k_l - k_r}{2}L = \pi\frac{n_l - n_r}{\lambda_0}L \quad (3)$$

In relation (3), n_l and n_r are the refractive indices of the anisotropic material measured with circularly polarized radiation to left, respectively to right and θ is named rotation angle.

The azimuth is measured relative to the initial orientation of the electric field intensity at the entrance of the anisotropic layer and depends on the material angle and on the thickness of the anisotropic layer, L. Its material dependence is given by the circular birefringence Δn, defined in (4):

$$\Delta n_c = n_l - n_r \quad (4)$$

Depending on the sign of the difference, Δn_c, the azimuth angle is positive or negative, resulting right or left rotation of the wave polarization plane at the exit from the anisotropic layer.

The birefringence is a dispersive parameter like the refractive indices for left (n_l) and right (n_r) circularly polarized radiations.

The rotation angle is dependent on the thickness of the optically active layer. The quantity:

$$[\theta] = \pi \frac{n_l - n_r}{\lambda_0} \tag{5}$$

is named specific rotation and represents the rotation angle determined by an anisotropic layer with unitary thickness.

The azimuth is the angle between the transmission direction of the first polarizer and the direction of the amplitude of the electromagnetic wave. The projection of the electric field intensity on the transmission direction of the second polarizer (perpendicular on the first) is expressed by $\sin\theta$. Consequently, the flux density at the exit of the device is proportional with $\sin^2\theta$ [3,4].

$$\Phi = \Phi_0 \sin^2 \frac{\pi\left(n_l - n_r\right)}{\lambda_0} L \tag{6}$$

The null minima in relation (6) are obtained for rotation angles equalizing an integer number of π and the maxima are obtained for an odd number of half π, respectively. In order to determine the circular birefringence Δn, its dispersion given by a constant parameter δ and the order of the channels, three equations expressing the condition for two consecutive minima and for the maximum between them (or for two consecutive maxima and the minimum between them) must be written, taking in consideration the decrease of the birefringence from the violet to red in the transparence range of the crystal [7-12].

The optical rotatory dispersion (ORD) caused by the rotation angle dependence on the light spectral composition [3,4,8] determines the apparition of a succession of maxima and minima in the emergent flux density from the optically active layer. The corresponding spectrum is named channeled spectrum.

$$\begin{gathered} \nu_{0k+1}\left(\Delta n + \delta\right) = \frac{k+1}{L} \\ \nu_{0k+\frac{1}{2}} \Delta n = \frac{k+\frac{1}{2}}{L} \\ \nu_{0k}\left(\Delta n - \delta\right) = \frac{k}{L} \end{gathered} \tag{7}$$

In (7), k is the order of channel, ν_{0k+1} and ν_{0k} are the wavenumbers of the channels and $\nu_{0k+\frac{1}{2}}$ is the wavenumber in the maximum between the two channels. The corresponding wavenumbers are estimated form the channeled spectrum and L is determined using an micrometer.

One can estimate the circular birefringence and its dispersion in the transparency domain of the studied crystal by solving the system (7) with three equations containing three unknown parameters.

A similar method can be used [8] to determine the linear birefringence of inorganic crystals or anisotropic polymer layers when the visible radiation propagates perpendicular to the optical axis of the layer.

3. Experimental

A special device [3,4] made from two crossed polarizers and the anisotropic optically active layer between them (see Fig. 1) must be introduced in the measure beam of the spectrophotometer, in order to obtain the channeled spectrum. Two identical polarizers having the transmission directions in parallel must be introduced in the compensatory beam of the spectrophotometer in order to compensate the visible absorption of the two polarizers from the measure beam.

The channeled spectrum represents a succession of maxima and null minima obtained for radiations with the rotation angle an integer number of π and an odd number of half π, respectively. The channeled spectrum obtained for L = 60 mm is illustrated in Fig. 2.

The channeled spectra of Carpathian Quartz were recorded for different thickness of the crystalline layers.

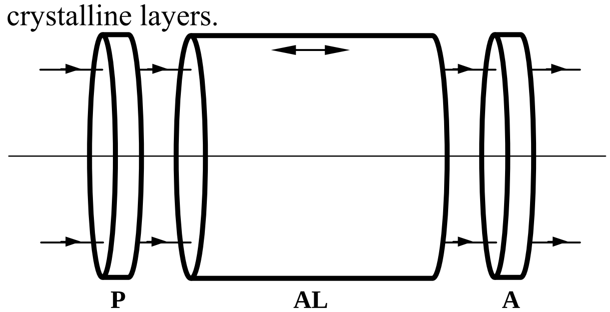

Fig. 1. Experimental device for optical activity measurements; P and A identical crossed polarizers, AL – uniax anisotropic layer

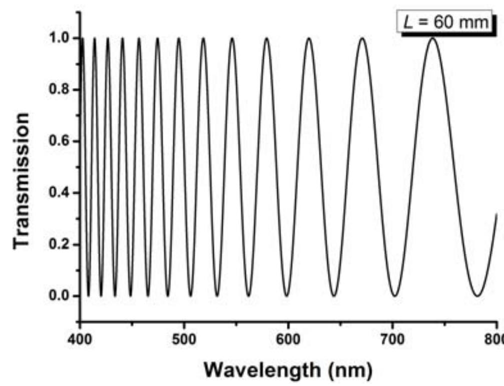

Fig. 2. Channeled spectrum of Quartz from Maramures area for L = 60 mm

4. Results and discussion

From the recorded channeled spectra (and also from relation (6)), it results that the number of the channels increases when the thickness of the optically active layer.

Channeled spectra for thickness L = 40, 60 and 80 mm were recorded and the birefringence, its dispersion and the order of the channels were estimated.

The wavelength dependence of the circular birefringence of the Carpathian quartz is plotted in Fig. 3. As it results from Fig. 3, the circular birefringence is independent on the thickness of the optically active layer.

As it results from Fig. 4, the birefringence dispersion δ linearly depends on the light wavelength. The slope of this dependence decreases with the increase of the optically active layer thickness. This fact is possible due to the increase in the distance between the channels with the thickness increasing.

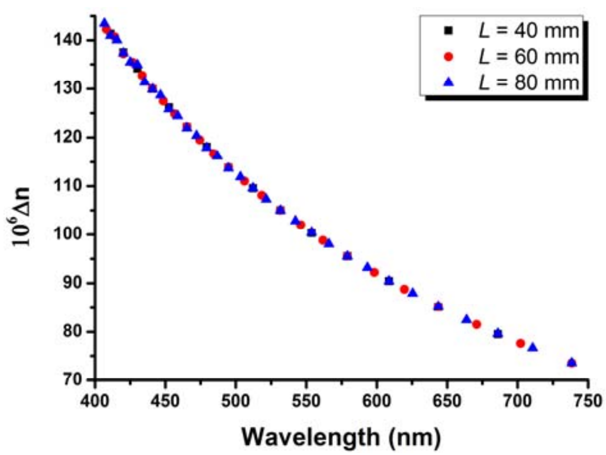

Fig. 3. Birefringence of the Carpathian Quartz

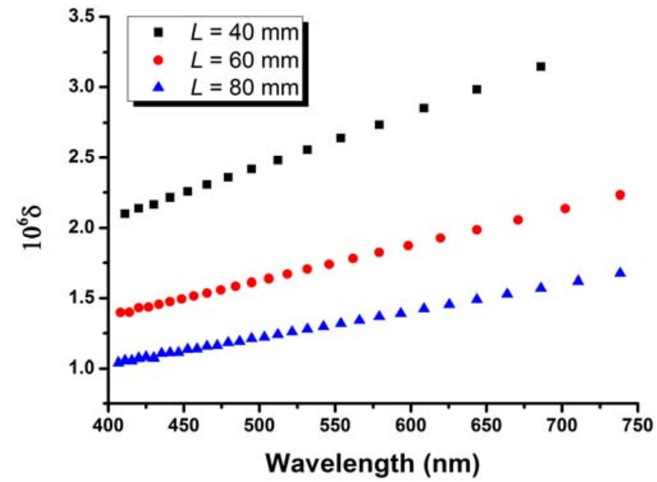

Fig. 4. Birefringence dispersion measured from channeled spectra obtained with different thickness of the Carpathian Quartz

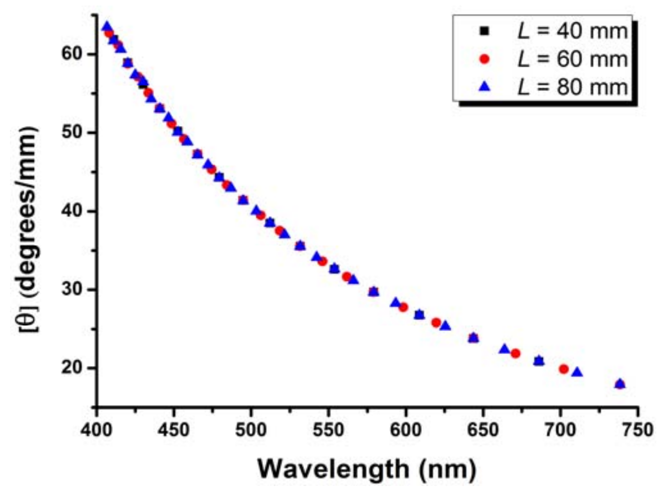

Fig. 5. Specific rotation of the Carpathian Quartz vs. wavelength of the visible radiations

The specific rotation of the Carpathian Quartz is the same for all studied samples having different thicknesses, as it results from Fig. 5. The specific rotation of the Carpathian Quartz decreases with the light wavelength increasing. The obtained results are in good agreement with those previously reported [13], where a polarimetric method and monochromatic radiations were used.

Knowledge on the linear or circular visible birefringence is important for the opticians working with total polarized light in the designing of interferential filters [14,15].

6. Conclusions

This method can be applied in the transparency range of the optically active either inorganic crystals, or polymer solutions. It represents a rapid and very precise method which permits to estimate the circular birefringence in large spectral ranges.

The obtained results prove that the accuracy of this method depends only on the precision in the wavelength determination and not on the thickness of the anisotropic layer.

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