

Interferential Wood Filters with Chemical Pure Quartz from Maramures Area as Anisotropic Layer

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Preliminary XRD and optical studies regarding the purity and the transparence of some quartz samples provided from different Romanian mountains areas, conducted us to choose the quartz crystal from Maramures area in the design of some Wood interferential optical filters working in the visible range. The interferential Wood filter consists from an anisotropic layer between two crossed polarizers. For the selected quartz crystal, the birefringence dispersion can be neglected. Consequently, the value of the birefringence measured at $\lambda = 589.3\text{nm}$ was used in the simulation process. A decrease in the band-width of the transmission bands was evidenced when the thickness of the anisotropic layer increased.

Keywords: quartz, birefringence, XRD, transmission factor, Wood filter

Quartz is a very common mineral, a chemical compound of silicon and oxygen, silicon dioxide SiO_2 , commonly called silica. Quartz is a technically important material that is valued for the combination of certain electrical or optical properties with a great physical strength and chemical resistance [1, 2]. In a crystal the atoms are arranged in a regular and periodic manner that is specific for each mineral. The geometry of this arrangement of atoms is not only reflected in the symmetry properties of a crystal, but also in the isotropy or anisotropy of its physical properties. A substance with physical properties depending on the direction of an external force is called anisotropic. Different minerals are anisotropic to various degrees, and many of the physical properties of quartz show anisotropy. The chemical bonds in silica are covalent: they are based on molecular orbitals in which 2 electrons are shared between the atoms. The basic building block in almost all modifications of silica (the exceptions are very high pressure modifications) is the SiO_4 unit, in which a central silicon atom is surrounded by four oxygen atoms (fig.1).

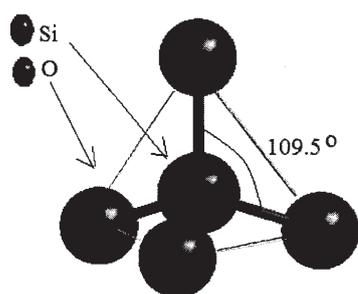


Fig. 1. SiO_4 Tetrahedron

The oxygen atoms occupy positions around the silicon atom that keep them at the greatest possible distance from each other, so they form the four corners of a tetrahedron. The angle of the central O-Si-O bonds is very close to the value in an ideal tetrahedron (109.5°). Each of the 4 oxygen atoms is linked to another silicon atom in a neighboring tetrahedron, so the SiO_4 tetrahedra share their oxygen atoms and the overall formula of quartz is SiO_2 . Quartz can thus be described as a network of interconnected SiO_4 tetrahedra [1]. It thus lends itself to the fabrication of very thin low order retardation plates. Quartz is a uniax anisotropic crystal and is characterized by [3]:

$$n_o = n_b = n_c \quad (1)$$

$$n_c = n_e \quad (2)$$

where n_a, n_b, n_c are the principal refractive indices of the media, n_o is ordinary refraction index and n_e is extraordinary refraction index [4].

The refractive index of the ordinary radiation, n_o , is the same for all directions of light passing through the crystal, but the refractive index of the extraordinary radiation, n_e , is dependent on the direction, so birefringence is an anisotropic property. In anisotropic minerals, optical axis lies parallel to the direction in which n_o is equal to n_e . The birefringence (Δn) of the uniax crystals is defined as being the difference between the extraordinary and ordinary refractive index:

$$\Delta n = n_e - n_o \quad (3)$$

When the birefringence is positive the crystal is uniax positive and if $\Delta n < 0$ the crystal is negative [5].

Experimental part

Samples

Crystals of quartz were collected from Romanian Mountains (Maramures area) (fig.2). and the principal aim was to characterize the quartz sample from the purity and transparency points of view. After XRD analyses the main refractive indices of the most transparent quartz crystal C were measured.

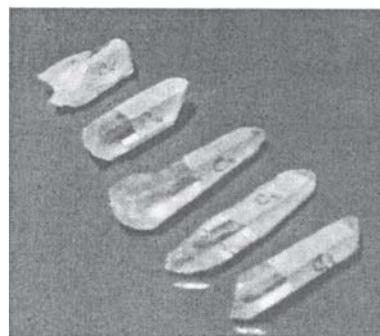


Fig. 2. Sample of quartz from Maramures area used for XRD analyses

Analytical methods

X-ray analyses

X-ray diffraction (XRD) is a powerful nondestructive technique for characterizing crystalline materials. It provides information on structures, phases, preferred crystal orientations (texture), and on other structural parameters, such as average grain size, crystallinity, strain and crystal defects [6].

X-ray diffraction peaks are produced by constructive interference of a monochromatic beam of X-rays scattered at specific angles from each set of lattice planes in a sample. The peak intensities are determined by the atomic decoration within the lattice planes. Consequently, the X-ray diffraction pattern is the fingerprint of periodic atomic arrangements in a given material [7-9].

The X-ray diffraction analyses were performed by Panalytical Diffractometer, model X'Pert Pro using $\text{CuK}\alpha$ radiation ($\lambda = 1.5406\text{nm}$), 45kV, 30mA, division slit 0.25° . All the diffractograms were investigated in the range $5 - 90^\circ$, 2θ degrees, step size 0.004 at room temperature.

In parallel with the measurements, searching on professional literature [10] one found the characteristically peaks positions on 2θ for standard NIST (*National Institute of Standards and Technology* from USA) of quartz. This source provides only 4 characteristically peaks of quartz at 2θ :

$$\begin{aligned} &20.841^\circ \pm 0.018; \\ &26.618^\circ \pm 0.020; \\ &50.098^\circ \pm 0.019; \\ &59.905^\circ \pm 0.018. \end{aligned}$$

The X'Pert HighScore Program offers the possibility to make the comparison between the data base peaks of the program and the peaks presented in the diffractogram pattern of the sample.

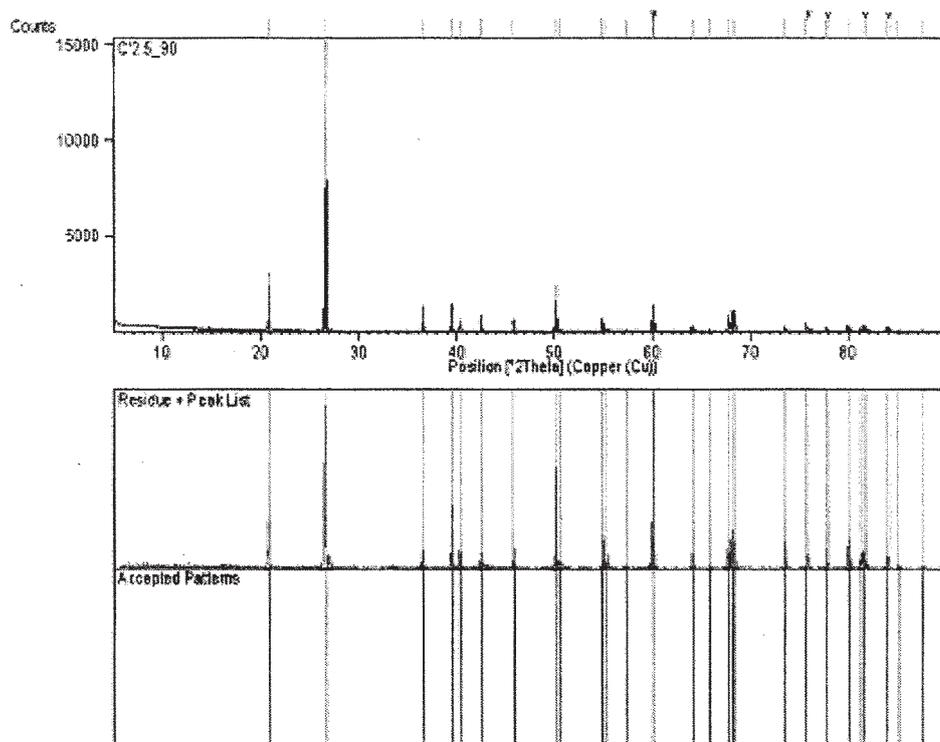


Fig. 3. The comparison of C sample X-ray diffraction pattern and X-ray diffraction pattern of the quartz from the data base of X'Pert High Score Plus Program

Table 1
MAIN REFRACTIVE INDICES AND BIREFRINGENCE OF QUARTZ CRYSTAL COLLECTED FROM MARAMURES AREA

Sample	n_e	n_o	$\Delta n = n_e - n_o$
Quartz (C)	1.5535	1.5445	0.0090

Birefringence determination

The main refractive indices were determined with Rayleigh interferometer standardized in the monochromatic yellow radiation of a Na lamp. The propagation direction is parallel to a main direction different from the optical axis of the studied sample [11].

The refractive indices n_o and n_e were calculated by means of the relation [12]:

$$n_i = n_g + \frac{k\lambda}{L}, i = o, e \quad (4)$$

where n_i is ordinary (o) /extraordinary (e) refractive index, k represents the order of the monochromatic mobile fringe which coincides with the zero-order fringe from the fixed system of fringes, L is the thickness of the anisotropic plate, $\lambda = 589.3\text{ nm}$ and n_g is the refractive index of the compensatory glass plate.

The main values of the refractive index were determined by means of the polarizer placed in the measuring beam having the transmission direction oriented in parallel, respectively, perpendicularly, on the optical axis of the anisotropic layer [13].

Results and discussions

XRD analyses conducted to the quartz diffractogram. The comparison between the X-ray diffraction pattern of known quartz from data base program and the crystal from Maramures area with X'Pert High Score Plus Program can be made by analyzing figure 3. We can observe a perfect correspondence between the data base peaks and C-crystal peaks.

The sample was analyzed from the optical point of view and in the table 1 are presented the main refractive indices and the birefringence of the Maramures quartz crystal.

From table 1 it results that birefringence of the quartz crystal is positive so the quartz sample is uniax positive.

Applications

Let's consider a device made up of a layer of anisotropic substance with a constant thickness L placed between two crossed polarizers P_1 and P_2 having the main transmission directions at 45° in relation to the transmission directions of the polarizers (fig. 4. and fig. 5.). This device can be considered as being a Wood type polarization interferential filter. In this paper a Wood filter with quartz as anisotropic layer is simulated.

The transmission factor of Wood interferential filter varies with the wavelength of incident light presenting alternating maxima and minima. The number of transmission maxima within a given spectral range depends on the birefringence of the material and the thickness L of the anisotropic layer.

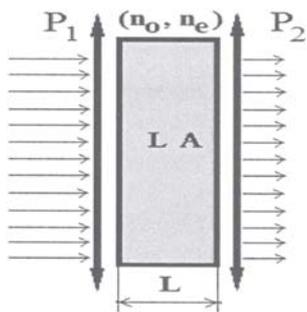


Fig. 4. Structure of a Wood filter

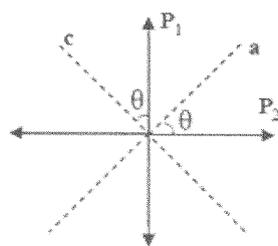


Fig. 5. Relative orientation of basic directions of the anisotropic crystal in relation to the transmission directions of the polarizers

If the anisotropic layer (LA) in the device from figure 4 is transparent and the losses through reflexion on the separation surfaces can be neglected, the transmission factor $T(\lambda_0)$ [14, 15] is given by the relation:

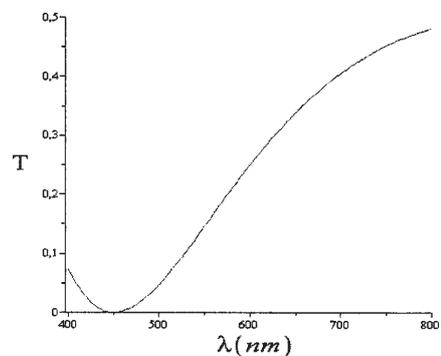
$$T(\lambda_0) = \frac{1}{2} \sin^2 \frac{\pi \cdot \Delta n \cdot L}{\lambda_0} \quad (5)$$

where λ_0 is the wavelength in vacuum of the radiations.

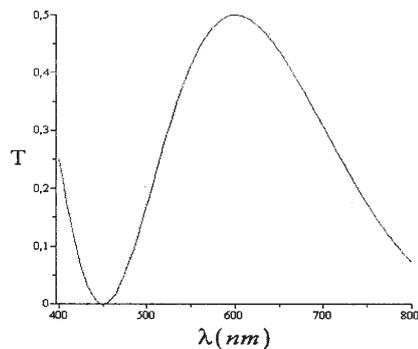
Function (5) depends on the wavelength of the radiations both directly and through the dispersion of the birefringence (Δn), so that the recorded spectrum in the visible range with a spectrophotometer contains successive minima and maxima [13].

Using the Maple 13 program, the transmission factor was simulated for various Wood filters according to the light wavelength or the thickness of the anisotropic layer. For simulation purposes were used experimental data for the purest quartz sample for which the transmission factor is maximum. In the visible range the quartz variation of the birefringence dispersion can be neglected. The simulations allow the change of the birefringence and/or the thickness of the anisotropic layer aiming to obtain a lesser number of transmission bands in the visible range. The results of simulation permit to estimate for each anisotropic layer (with known birefringence) the wavelength of radiations crossing the Wood filter with maximum intensity.

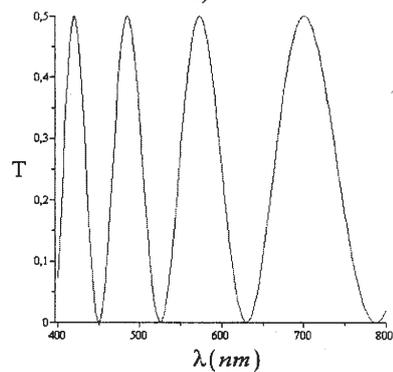
The simulations show that the number of channels increases when the LA thickness increases. For the thickness of about $50 \mu\text{m}$, all radiations with $\lambda > 600 \text{ nm}$ are transmitted by the device (fig. 6. a). For the thickness of about $100 \mu\text{m}$ one transmission band having the half-



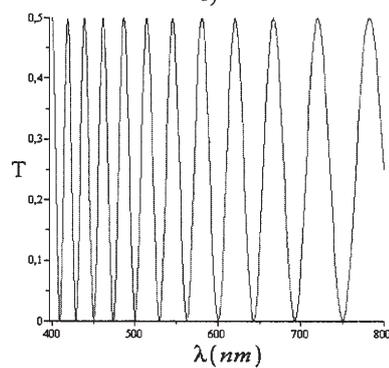
a)



b)



c)



d)

Fig. 6. Variation of the transmission factor according to the wavelength for the device made of a quartz layer ($\Delta n = 0.009$)
a) $L = 50 \mu\text{m}$, b) $L = 100 \mu\text{m}$, c) $L = 350 \mu\text{m}$, d) $L = 1 \text{mm}$

width of approximate 200 nm was obtained for Wood interferential filter. The spectral half-width of the transmission bands decreases when the thickness of LA plate increases (fig. 6. c and d.).

Conclusions

The chemical pure quartz crystal from Maramures area is characterized by a high transparency in the visible range. The birefringence of the sample is in accordance with the birefringence of quartz from other geographical area. The

variation of the birefringence dispersion can be neglected in the visible range. The simulations evidence the decrease of the band-width of the transmission band when the thickness of the anisotropic layer increases.

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