Research Article

Conformity Check of Thickness to the Crystal Plate $\lambda/4(\lambda/2)$

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This work demonstrates that if crystal plates are identical in thickness in the direction of radiation, the intensity at the output of the polarizer-crystal-crystal-analyzer system equals zero. This means that it is possible to control the difference in thickness between the reference crystal plate (e.g., plates of $\lambda/4$ or $\lambda/2$) and the examined plate by the intensity of the transmitted radiation. Further, it shows that if nonmonochromatic radiation is used, then the spectrum of radiation at the output is determined by the relative orientation of the optical elements and their sizes. The paper gives the theoretical model for calculations of profile of spectra for the number of important cases of orientation of elements.

1. Introduction

When carrying out measurements using certain types of optical instruments, polarized light is used. The results of using such optical instruments depend on the type and degree of light polarization [1]. To control the degree of polarization, $\lambda/4(\lambda/2)$ phase plates are generally used. The technological manufacture of such phase plates is time consuming, making the cost of the plates high. Strict quality control of the plates is a necessary condition for their manufacture.

Physical phenomena occurring during the propagation of light in an anisotropic crystal can be used to control the polarization of light. Changing the phase difference between the orthogonal components of the light field changes the polarization state of the light wave [2, 3]. This effect is the basis of the action of the phase plates which controls the polarization of light.

Many works are devoted to the control of light polarization. In Konstantinova et al. [4], a polarizing system with the properties of a quarter-wave plate, with an additional optical activity based on two birefringent plates of arbitrary thickness, is considered theoretically and implemented experimentally. Pikoul [5] provides a comparative analysis of the polarization properties of the crystal plate with a different arrangement of the optical axis. Constituent phase plates, which act as quarter- and half-wave, are often used. A number of papers are devoted to the theory of the optical properties of composite plates [6–10].

Quarter- and half-wave plates are often used in physical experiments. For example, the former are used to convert the linear polarization of light into a circular in laser systems, while the latter are used to rotate a 90° polarization plane of linearly polarized light wave. Vityazev et al. [10] note that for small changes in the azimuth of the incoming radiation or the amount of phase difference, the ellipticity and the azimuth of the radiation at the exit of the plate change dramatically in a wide range of values.

When light passes successively through several similarly oriented phase plates, the result of their action is the sum of the phase shifts in each plate. If the axes of plates are crossed, the result of their combined effect on the light passing through them is equal to the difference between the phase shifts in each of them [6, 7, 11, 12].

Some optical properties of the two plane-parallel plates cut from the crystal are described in Syuy et al. [13]. Syuy shows that on the transition point from the line spectrum to a continuous spectrum, it is possible to control the position of the crystal optical axis in the optical system.

This paper theoretically considers a system of two crystal plates placed between a crossed polarizer and analyzer. The crystal plates have orthogonal orientation of the optical axes. The main section of the first crystal plate is oriented at an angle of 45° to the plane of the polarizer's transmission. The purpose of the paper is to develop an optical scheme for identifying the correspondence between the investigated crystal plate and the quarter-wave (half-wave) plate, according to the intensity of the transmitted radiation.

FIGURE 1: The experimental setup. P = polarizer; A = analyzer; λ , $\lambda/4$ or $\lambda/2$ = standard crystal plate; CP = investigated crystal plate; PMP = photomultiplier.

FIGURE 2: The orientation of the optical axes of crystal plates in relation to the planes of polarizer and analyzer transmission. P = transmission plane of polarizer; A = transmission plane of analyzer; z_1, z_2 = optical axes of the first and second crystal plates, respectively; $\alpha = \gamma = 45^\circ$; $\beta = 90^\circ$.

2. Methods

Consider an optical system consisting of a polarizer, two crystal plates, and an analyzer (Figure 1). The orientation of the optical axes of the crystal plates and a transmission plane of the polarizer and the analyzer are shown in Figure 2. The direction of the reference angle is clockwise. Quartz crystals were chosen as the object of research because quartz is usually used for the manufacture of quarter-wave (half-wave) plates. The Gaussian profile has been used to model the intensity distribution of the cross-section of the light beam.

FIGURE 3: The dependence of the relative intensity of the difference between the thicknesses ($d_2 - d_1$) of the quartz plates for helium-neon laser radiation.

First, the light beam transmitted through the polarizer is divided into two beams in the reference crystal plate with orthogonal polarizations (e and o). Then, the e and o rays also divide inside the investigated crystal plate (ee , eo , oe , and oo). The phase acquired by the beams at the output of the crystal will be

$$\begin{aligned}\varphi_{ee} &= \frac{2\pi}{\lambda} (d_1 + d_2) n_e, \\ \varphi_{eo} &= \frac{2\pi}{\lambda} (d_1 n_e + d_2 n_o), \\ \varphi_{oe} &= \frac{2\pi}{\lambda} (d_1 n_o + d_2 n_e), \\ \varphi_{oo} &= \frac{2\pi}{\lambda} (d_1 + d_2) n_o,\end{aligned}\tag{1}$$

where d_1 = standard thickness, d_2 = thickness of the investigated sample, and n_o, n_e = indicators of the ordinary and extraordinary rays, respectively.

By projecting the electric field vectors of the light waves ee , eo , oe , and oo onto the transmission plane of the analyzer according to the law of cosines and taking into consideration the fact that $I \sim E^2$, the following equation is formed:

$$\begin{aligned}I = I_0 &\left[\cos^2 \alpha \cos^2 \beta \cos^2 \gamma + \cos^2 \alpha \sin^2 \beta \sin^2 \gamma \right. \\ &+ \sin^2 \alpha \sin^2 \beta \cos^2 \gamma + \sin^2 \alpha \cos^2 \beta \sin^2 \gamma \\ &\left. - 0.5 \cos 2\alpha \sin 2\beta \sin 2\gamma \cos \left(\frac{2\pi}{\lambda} d_2 \Delta n \right) \right]\end{aligned}$$

FIGURE 4: (a) The transmission spectrum of the polarizer-crystal-crystal-analyzer system quartz crystals; $d_1 = d_2 = 2.127$ mm; $\alpha = 60^\circ$; $\beta = 0^\circ$; $\gamma = 90^\circ$. (b) The transmission spectrum of the polarizer-crystal-crystal-analyzer system quartz crystals; $d_1 = d_2 = 2.127$ mm; $\alpha = 60^\circ$; $\beta = 0^\circ$; $\gamma = 30^\circ$. (c) The transmission spectrum of the polarizer-crystal-crystal-analyzer system quartz crystals; $d_1 = d_2 = 2.127$ mm; $\alpha = 30^\circ$; $\beta = 30^\circ$; $\gamma = 30^\circ$. (d) The transmission spectrum of the polarizer-crystal-crystal-analyzer system quartz crystals; $d_1 = d_2 = 2.127$ mm; $\alpha = 60^\circ$; $\beta = 0^\circ$; $\gamma = 60^\circ$.

$$\begin{aligned}
 & - 0.5 \sin 2\alpha \sin 2\beta \cos 2\gamma \cos \left(\frac{2\pi}{\lambda} d_1 \Delta n \right) \\
 & - 0.5 \sin 2\alpha \cos^2 \beta \sin 2\gamma \cos \left(\frac{2\pi}{\lambda} (d_1 + d_2) \Delta n \right) \\
 & + 0.5 \sin 2\alpha \sin^2 \beta \sin 2\gamma \cos \left(\frac{2\pi}{\lambda} (d_2 - d_1) \Delta n \right) \Big], \\
 \end{aligned} \tag{2}$$

where I_0, I = the light intensity at the entrance and exit of the optical system, respectively, d_1 = standard thickness, d_2 = thickness of the sample, and Δn = birefringence of the crystal.

3. Results and Discussion

At $\alpha = 45^\circ$, $\beta = 90^\circ$, and $\gamma = -45^\circ$, we have only eo and oe beams with the respective phases (1), and the expression (2) will be

$$\begin{aligned}
 I = I_0 \Big[& \cos^2 \alpha \sin^2 \beta \sin^2 \gamma + \sin^2 \alpha \sin^2 \beta \cos^2 \gamma \\
 & + 0.5 \sin 2\alpha \sin^2 \beta \sin 2\gamma \cos \left(\frac{2\pi}{\lambda} (d_2 - d_1) \Delta n \right) \Big]. \tag{3}
 \end{aligned}$$

For $\alpha = 45^\circ$, $\beta = 90^\circ$ and $\gamma = -45^\circ$, if the difference in thickness between the standard and the test sample is

$$(d_2 - d_1) = \pm \frac{m\lambda}{\Delta n}, \quad (m = 0, 1, 2, 3, \dots), \quad (4)$$

the intensity at the output of the optical system is zero, which corresponds to the quarter-wave (half-wave) plate. For helium-neon laser radiation ($\lambda = 0.63$ micron) and the sample quartz plate ($\Delta n = 0.009$), the thickness difference ($d_2 - d_1$) must be a multiple of 70 microns. If the thickness difference between the standard and the test sample is different from condition (4), this sample does not correspond to the quarter-wave (half-wave) plate.

Figure 3 shows the dependence of the relative intensity of the thickness difference $(I/I_0)(d_2 - d_1)$ on quartz plates using helium-neon radiation. The form of the polarized spectrum of the transmission for the researched system is determined by the angles γ , β , and α (Figure 4). The spectrum's shape can be a line (Figure 4(b)), continuous (Figure 4(a)) or mixed (Figures 4(c) and 4(d)). The frequency of the line spectrum is defined by the ratio of the angles α and β and the thickness of the crystal plates. The smaller the effective thickness of the plates, the greater the spectral peaks, and vice versa.

4. Conclusion

Theoretically it was found that using a polarizer-crystal-crystal-analyzer system where one of the crystals is the standard, it is possible, according to the intensity of the transmitted radiation, to control the compliance of the sample to a quarter-wave (half-wave) plate. For such control, two pairs of orthogonal transmission planes (polarizer-analyzer) and the main sections of crystalline plates (Figure 2) must be oriented at an angle of 45° (in this case, $\alpha = \gamma = 45^\circ$, $\beta = 90^\circ$). Further, the spectrum at the output of the optical system is determined by the mutual orientation of the optical elements and the thickness of the crystal plates, which can be used to control a wide spectrum range.

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