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BIPOLARIZER – A CRYSTAL OPTICAL SPLITTER AND GROUPER OF THE LASER BEAMS

Abilhan Umbetovich Umbetov, Makhabbat Zhaksylykovna Umbetova
I.Altynsarin Arkalyk State Pedagogical Institute, Kazakhstan.
E-mail: Umbetov.a@mail.ru

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Abstract

Many accurate measurements, the role of which is rapidly increasing in the modern science and technology, are carried out by interference methods. The scope of interference devices has grown significantly, due to the creation of lasers and the development of electronics. There are two ways with the help of which the light wave that comes from the source can be divided into two or more parts, and then connected. The first of these is the separation of the wave by front and the second - by amplitude. For the separation of the light wave by front,several sections are distinguished on the wave surface bymeans of diaphragms, mirrors and other optical components. The beamsemerging from these sectionsmovein the interferometer in various ways and then are superimposed on one another. Among the interferometers of the second type, there are polarized interferometers, in which the separation of the light wave by amplitude is made with the use of the birefringentcrystal optical systems. The ray beam after passing through such a system is spatially separated into two beams polarized in two mutually perpendicular planes. These devices operate on the principle of shearing interferometers, in which the image formed by the beams of one polarization is superimposed with the shifted image formed by the beams of orthogonal polarization. The advantage of such devices is that the need for a reference surface is eliminated, and it is possible to study thewavefront at any point.

Keywords: bipolarizer, crystal optical element, uniaxial, Iceland spar, polarization, interference, laser, electromagnetic, wave, interferometer.

Introduction:

The laser measuring devices use the TCOE in two main modes: themode of spatial separation of the narrow light beam with orthogonal polarizations and the mode of interference of the light beams at the output of the system. The first mode is used to control laser radiation, optical resonators [1, 2] etc. The second mode of the TCOE operation is the basis of polarization shearing interferometers [3]. The light beam is split by the system into two orthogonally polarized beams, the fronts of which are shifted relative to each other. When the beams are moved with the help of an analyzer in the area of their superposition, the interference pattern appears. The shape of this pattern and its contrast make it possible to analyze the characteristics of the incident beam, the wavefront curvature and the degree of radiation coherence [4].

Briefly consider the application of the TCOEbythe laser measuring devices.

Laser deflectors

The operation of laserdigital deflectors is based on two effects: the birefringence effect and the longitudinal Pockels electro-optic effect. The deflector acts as a system of alternating birefringent crystals and Pockels cells. Birefringent crystals cleave each incident beam into two beams, and the Pockels cell transmits an ordinary (o) and extraordinary (e) beam depending on the voltage applied to it. N of such pairs, placed in series, provide 2^N states of the beam at the output of the system. Thedeflector provides a high scanning speed of up to 10^9 Hz, whereas the mechanical scanning provides the frequency of $10^4 \div 10^5$ Hz.

Selection of modes of the laser resonator [1, 2]

The size of resonators, used in lasers, is substantially higher than the optical wavelength, so that these resonators have a large number of closely spaced modes. When using lasers in optical communication systems, in the production of holograms with high resolution, in sensitive interferometry and in several other areas,a greater spectral frequency radiation is required. In this regard, an important question is the selection of the laser resonator modes and the obtaining of the single mode. The works by White (1986), Walther and Hall (1980) [3, 4] describe the production of the narrow-band generation with the help of a Lyot filter. This filter consists of a birefringent crystal with polarizers on both sides.Smith (1982) [2] describes three-mirror resonators in which thelight beam splitting is carried out by crystal optical systems, which are used as splitters. He also considers the application of a birefringent crystal for splitting the light beam into two parallel beams incident on different mirrors. Small losses are provided only for those frequencies at which the optical path length of one beam is different from that of the other beam by an integer of waves.

The known birefringent crystals [3] give a very small splitting, and the beams are located close to each other. This creates certain technical difficulties. It is more favorably to use crystal optical systems such as the Wollaston, Rochon and Sénarmontprisms [4,5], splitting the light beam into two beams lying at a certain angle to each other.

The main fields of application of polarization interferometers with the TCOE were considered by a number of domestic and foreign authors. Smith (1983) [15] provides an overview of the main optical schemes of polarization shearing interferometers and highlights the key areas of their application.

Research of isotropic objects [6-11].

Measurements are performed by the form of the interference pattern occurring at the intersection of wave fronts, deformed by the object under study, set before the TCOE. This method explores the quality of processing of optical parts, lenses and lens aberration, and carries out gas-dynamic studies, etc. One thing can be noted in the existing devices: the general disadvantage, which consists in the fact that the used TCOEs set a shift that cannot be changed depending on the experimental conditions.

Researchof resolution of optoelectronic devices and photographic materials, as well as the transfer functions of optical elements with the help of laser interference resolvometers.

Currently, for microelectronics, holography and other areas of science and technology, the transmitting television systems with high resolution have been created. The traditional methods for determining the resolving power, based on the design of test tables or line targets on the object under study, have a number of disadvantages [6,7].

The projection method also has a fundamental disadvantage,which consists in the fact that the picture contrast of the target generated by the lens decreases with the increase of spatial frequency. This phenomenon leads to the fact that the high numerical values of resolution obtained by the projection method may be significantly underestimated, since the test pattern itself has a reduced contrast.

These shortcomings determine the free interference method of formation of the test pattern. This method does not require the focusing optics, resulting in the decrease of contrast at high spatial frequencies. The method is applicable when working in a coherent light and gives the contrast of the interference pattern, almost independent of frequency. The uniform interference pattern can be formed over a large area, making it easier to study the resolving power at the photodetector field.

Research of geometrical parameters of the laser beams

For a precise processing of measurement results in quantum electronics devices with the use of laser radiation sources, it is necessary to know the geometric parameters of the laser beams to a high precision. Most methods of measuring the geometric parameters of the laser beams [8-12] are based on direct or indirect photometry of the beam intensity distribution. More accurate results can be obtained throughinterference methods. The image of the interference pattern depends on the radius of curvature of the radiation wavefront incident on the TCOE, which by the interference pattern helps to determine the radius of curvature of the wavefront in different sections of the beam, and to calculate the "neck" (where the wavefront is flat), the beam radius in the "neck" and the angular divergence.

Research of the degree of radiation coherence

The connection between the integrated radiation coherence and the contrast of the interference pattern helps to explore the degree of coherence by the interference method [13-15]. Smith (1993) [29] provides an overview of the interference methods for studying the degree of spatial coherence. The studies are conducted and considered by Young's method [16-19], with the Michelson interferometer [20], with the Mach–Zehnder interferometer [21], by the holographic method [22]. These methods have several drawbacks. The Young's interferometer has a low light intensity, and its resolution is limited by the size of the holes. The Michelson and Mach–Zehnderinterferometersare difficult to adjust and sensitive to vibrations.

Polarization shearing interferometers turned out to be simple and convenient in service [23-28]. In these interferometers, two images of the light source, which are shifted at a distance determined by the properties of the TCOE, are interfered. With the help of such a device there was studied the degree of spatial coherence of laser radiation[27], the degree of spatial illumination coherence ina microdensitometer [25-26], the spatial correlation functions of the field and the intensity of laser radiation [23-24], the phase transition in the formation of spatially coherent beams in a laser [28].

Implementation of selective amplitude modulation and spatial filtering

The TCOE of the anisotropic crystal (the Wollaston lens) can be used as an element performing a spatial encoding at the input of a spectral instrument and decoding at the output [43-44]. A. Girard [29] suggested the use of the Wollaston lens for spatial encoding and decoding in an interference spectrometer with selective amplitude modulation. The TCOE helps to realize the tunable spatial filter [30].

Dove prism of the uniaxial crystal

The TCOE considered by A.M. Stoeldarov [31] is a polarizing prism from the Icelandspar of the trapezoidal shape that allows for polarization measurements to be conducted in the ultraviolet spectrum. The combination of the two Dove prisms forms a bipolarizer, which was proposed by Eichenwald [37].

Materials and Methods:

In carrying out this work, the following tasks were set:

- To develop an effective method for the calculation of laser radiation passing through thetwo-component crystal optical element (TCOE) in the form ofa bipolarizer (BP);
- To obtain the expressions that are suitable for the analysis of properties of such systems and for engineering calculations;
- To investigate the interference mode of polarized beams at the output of the BP and to receive the expressions describing the interference pattern.
- To create the polarization interferometer on the basis of the BP for fixing and measuring small angular displacementsof objects.

Results and Discussion:

The purpose of this research is to develop an effective method for the calculation of laser radiation passing through the two-component crystal optical element (TCOE) in the form of a bipolarizer (BP), and to study the possibility of BP using in a polarization interferometer for measuring small angular displacements of objects.

The research objectives are as follows: a comprehensive, theoretical and experimental BP study, the study of interference of the polarized beams formed by the BP, the consideration of the possibility of BP using in a polarization interferometer for fixing the location and measurement of small angular displacements of objects.

Electromagnetic wave distribution in the BP

A bipolarizer (BP) represents a structure shown in Figure 1 (a) and (b). Two prisms from the Iceland spar with a cross section in the form of an isosceles trapezoid (the Dove prism) are bonded on large bases by the Canadian balsam layer. The Dove prism from $CaCO_3$ was considered in [33]. Unlike the designs discussed in [34], the orientation of the optical axes in the upper and bottom Dove prisms is such that theaxes are located in the vertical plane, parallel to each other, and form an angle of $\frac{\pi}{4}$with the plane of bonding (Figure 1b). This choice of axes orientation is convenient when using the BP to work with laser sources having a vertical orientation of the vector $\vec{E}$.Let the form (BP) be defined by the following parameters: the length of the common base is A_1A_2=2, and the length of the side face isA_1B_l=l, L($A_2A_1B_1$)=ψ (Figure 1b). The angle ψ is chosen in such a way that the circularly polarized beamwhen falling on the faceat a small angle to the normal of this face is divided in the BP into ordinary (o) and extraordinary (e), where the e-beam passes through the adhesive layer satisfying the expression $n_e < n_{cb} < n_0$, and the o-beamfeelsthe total internal reflection inthe place of bondingA_1A_2, and emerges through the face of A_2C_2. Similarly, the circularly polarized beam incident almost normally on the face of $A_1B_1$is divided into the o-beam that is completely reflected from thebonding ofA_1 A_2, and the e-beam that passes through the adhesive layer and emerges from the BP through the face of A_2C_2. The angle ψ satisfying the requirements is equal to 65º.

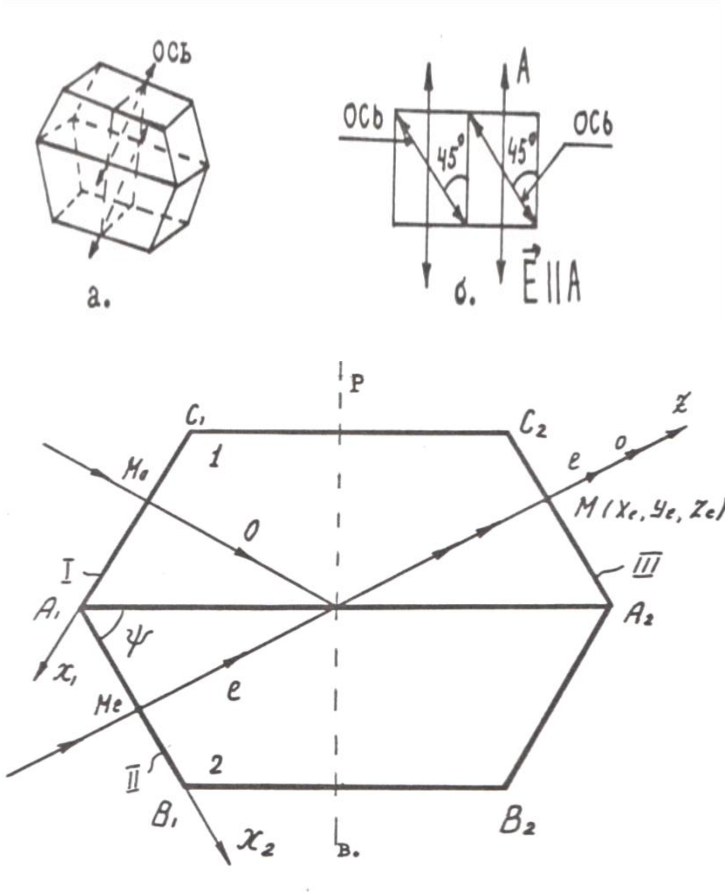

Figure 1.a) Bipolarizer in axiometry, b) Bipolarizer at the P section, c) Distribution of the o- and e-waves in the bipolarizer.

At the output of the BP, the o- and e-beams are mixing with the analyzer installed perpendicular to the edge of the BP and provide an interference pattern determined by the conditions of beam-forming on the faces of A_1C_1 and A_1B_1.

In the experiment, the circularly polarized beam was incident on the face of A_1, B_1, passing through the semi-transparent (ST) mirror, which gave the possibility of division into two beams of equal intensity. The beam reflected from the ST mirror with the help of another totally-reflecting (TR) mirror, fell to the face of A_1C_1. For a description of the passage of the two beams through the BP, introduce two coordinate systems - K and K^1, associated with the faces of A_1C_1 and A_1B_1(Figure 2), where the Z-axes coincide with the outer normals to these faces.

Suppose that the experiment applies a well-collimated laser beam with circular polarization. Let us first consider the conditions under which at the normal incidence of separated beams on the faces of A_1C_1 and A_1B_1, the light spots of both beams coincide at the outputBP face of A_2C_2 (consecutive beams). It is easy to see that the unit vectors of the optical axes in the K and K^1coordinate systems can be respectively written in the following form:

$$\vec{a} = \left\{ \frac{\sin\psi}{\sqrt{2}}; \frac{1}{\sqrt{2}}; \frac{\cos\psi}{\sqrt{2}} \right\};$$

$$\overrightarrow{a^1} = \left\{ \frac{\sin\psi}{\sqrt{2}}; \frac{1}{\sqrt{2}}; -\frac{\cos\psi}{\sqrt{2}} \right\} \qquad (1)$$

Let the center of the collimated beam falls on the face of A_1B_1in its geometric center. We are interested in the trajectory of the e-beam only. In the BP, it is determined by the direction of group velocity of the e-wave in the crystal. Let us define this direction as a unit vector$\vec{S}$ and the direction of the wave vector as a unit vector $\overrightarrow{K_1^e}$, which, according to the refractive conditions on the face of A_1B_1, is as follows:

$$\overrightarrow{K_1^e} = \left\{ \frac{\alpha}{n_e}; 0; 1 \right\} \qquad (2)$$

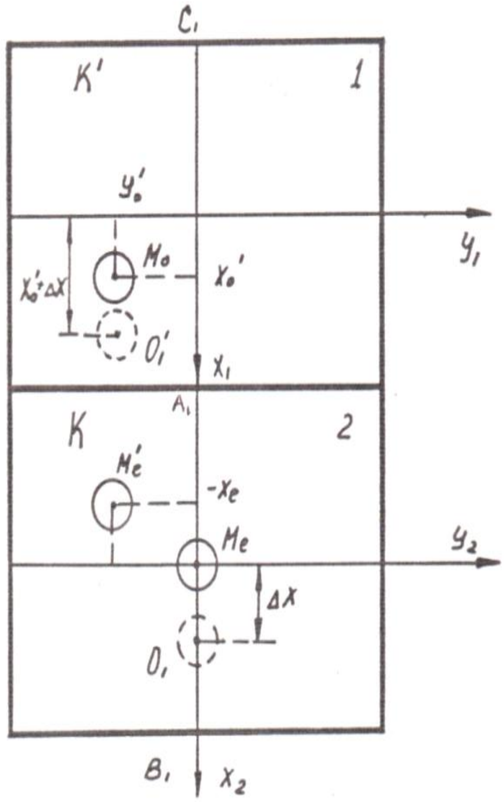

Figure 2. View of the bipolarizer |BP| in the section of B_1C_1.

It is known that

$$\vec{S} = \mu\vec{K} + \eta\vec{\alpha} \qquad (3)$$

The coefficient μ and η can be determined from the ratio:

$$\left(\vec{s}\vec{a}\right)^2 = \frac{n_e^4\left(\overrightarrow{K_1^e}\vec{a}\right)}{n_0^4 - \left(n_0^4 - n_e^4\right)\left(\overrightarrow{K_1^e}\vec{a}\right)^2} \qquad (4)$$

The equation (3) together with the condition $|\vec{S}| = 1$ gives the following expression for the unknown coefficients μ and η on the assumption that the vector $\overrightarrow{K_1^e}$ is either identical or differs little from the direction of the normal, and the magnitude $\frac{n_0^2 - n_0^2}{n_0^2}$ is small:

$$\eta = -\left(\frac{n_0^2}{n_0^2} - 1\right)(\vec{a}\vec{k}_1^{e}), \mu = 1$$

and

$$\vec{S} = \vec{K} + \left(1 - \frac{n_0^2}{n_0^2}\right)(\vec{a}\overrightarrow{K_1^e})\vec{a} \qquad (5)$$

The equation of the e-beam trajectory in the crystal is determined by the equations:

$$\frac{X}{S_x} = \frac{Y}{S_y} = \frac{Z}{S_z} \qquad (6)$$

where the center of the e-beam gets to the face of A_2C_2 at the point of M_e^1 (x_e, y_e, z_e) (the K coordinate system is used) and:

$$X_e = -a \sin\psi \left(1 - \frac{n_e^2}{n_0^2}\right) \sin\psi \cos\psi$$

$$Y_e = -a \sin\psi \left(1 - \frac{n_e^2}{n_0^2}\right) \sin\psi \cos\psi \qquad (7)$$

$$Z_e = 2a \sin\psi$$

Considering the passage of the o-beam in Figure 1, we can say that the beam should normally fall on the face of $A_1 C_1$ at the point of $M_0^1(x_0^1; y_0^1; 0)$, where (in the K' system):

$$X_0^1 = -a \sin^2\psi (1 - \frac{n_e^2}{n_0^2}) \cos\psi$$

$$Y_0^1 = -a(1 - \frac{n_e^2}{n_0^2}) \sin\psi \cos\psi \qquad (8)$$

Thus, the initial alignment of the beam that provides the coincidence of the light spots at the output face is as follows: on the face of A_2C_2 the beam 2 is directed properly to its geometric center, on the face of A_1C_1 with the help of an auxiliary mirror the beam 1 is directed normally to the point with coordinates (6), displaced from its geometric center. As will be shown, the BP can be used to measure very small angular displacements (of the order of arcsecond units), and the conditions (8) determine the alignment of the light beams at the output of the BP. If the BP is perfectly manufactured, the spot at the output of the BP has a uniform illumination.

Consider the pattern of the beam paths when turning the BP at a small angle α around the Y-axis, which lies in the plane of bonding A_1A_2, passing through the geometric center of the BP and the normal plane of the drawing in Figure 1. It is easy to define that this turn will shift the X-coordinate of entry points of the beams on the faces ofA_1B_1 and A_1C_1 at the following distance:

$$\Delta X = \frac{\alpha \iota}{2} tg\psi \qquad (9)$$

Formulating, as before, the equation for the e-beam axis with the use of the formula (6) and the vector (2) (sizes of the α^2 order are neglected again), for the intersection of this axis with the output face of A_2C_2 we will get the point $M_e^{'}(X_e^{'}, Y_e^{'}, 2\alpha \sin\psi)$ with coordinates (in the K system):

$$X_e^1 = \frac{\alpha \iota}{2} tg\psi + \alpha \sin\psi \left[\frac{\alpha}{n_e} - \left(1 - \frac{n_e^2}{n_0^2}\right) \frac{\sin\psi \cos\psi}{2} \right] \qquad (10)$$

$$Y_e^1 = -h\left(1 - \frac{n_e^2}{n_0^2}\right)\frac{\cos\psi}{2} + \frac{\alpha}{n_e}\frac{\sin\psi}{2}$$

A direct geometric consideration with the help of Figure 1 gives the corresponding point of intersection of the o-beam axis with the output face of A_2C_2 - $M_e^{'}(X_e^{'}, Y_e^{'}, 2\alpha \sin\psi)$, where:

$$X_0^1 = -a\left(1 - \frac{n_e^2}{n_0^2}\right)\sin^2\psi \cos\psi - \frac{\alpha \iota}{2} tg\psi + \frac{2\alpha \sin\psi}{n_0} \qquad (11)$$

$$Y_0^1 = -a\left(1 - \frac{n_e^2}{n_0^2}\right)\sin\psi \cos\psi$$

This gives the condition confining the upper limit of the measured angles. In fact, to ensure that there is an appropriate interference pattern, the e- and o-beams must be crossed at the output face of A_2C_2. If the radius of these beams is r_o, there should be $M_eM_o<2r_o$ or:

$$\alpha \prec \frac{r_0 ctg\psi}{\sqrt{\left(1 + 2\alpha \cos\psi \left(\frac{1}{n_e} - \frac{1}{n_0}\right)\right)^2 + \alpha^2 \sin^2\psi \cos^2\psi \frac{1}{n_e^2}\left(1 - \frac{n_e^2}{n_0^2}\right)2}} \qquad (12)$$

The limit conditions can be increased, if the BP is aligned in the position of the divergent o- and e-beams at the output face.

This can be done if the point (9) at the input face is slightly shifted along the X^I-axis of the K^I system. However, this method is good only when the direction of the angular deviation of the beam is already known.

For the parameters used in the experiments with the BP (l = 11 mm, α = 11.7 mm, ψ = 68^0), from (13) at r_o= 3mm we obtain α <3^0, which is in a qualitative agreement with the experiment.

Interference of the polarized beams in the BP

The interference pattern that occurs at the intersection of the beams at the output of the BP can be described as follows. Figure 3 shows the trajectories of the o- and e-beams, obtained after the above-described adjustment of these beams and the subsequent rotation of the BP at an angle α. The primary set of the BP corresponds to the normal passage of the o- and e-beams towards the faces of A_1B_1 and A_1C_1. At the same time, the o- and e-beam falls normally on the face of A_2B_2 at one point with the coordinates (9), and when turning the BP at an angle α, the falling points of the o- and e-beams on the face of A_2C_2 are different, the point belonging to the o-beam moves parallel to the X-axis, and the point belonging to the e-beam - along the line described by the equation.

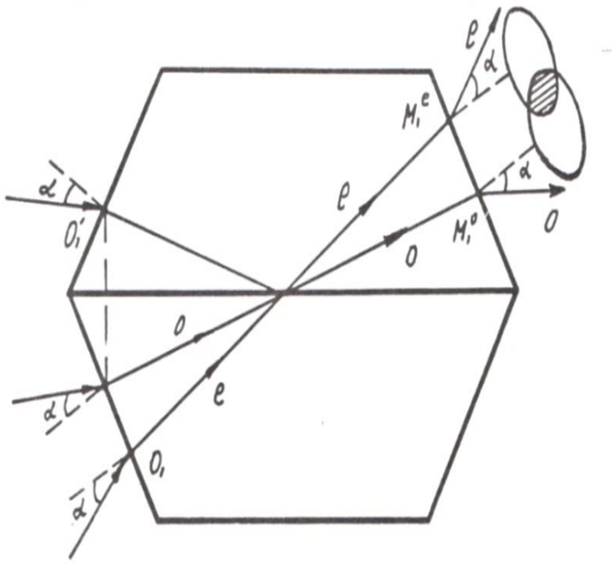

Figure 3. Bipolarizer |BP| activity in the mode of interference of the o- and e-waves

$$Y - Y' = (x - x_0)\frac{\frac{\cos^2\psi}{n_e}\left(1-\frac{n_e^2}{n_0^2}\right)}{\frac{\iota}{2a}+\frac{2\cos\psi}{n_e}} \qquad (13)$$

The angle between the wave vectors of the o- and e-beams emerged from the face of A_2C_2 is equal to 2α.

When describing the wave field in the beams by the plane waves, then, for example, for the electric vector of the wave after it passes through the analyzer, one can write the following expressions in the K coordinate system:

$$\overrightarrow{E_0} = \overrightarrow{E^0} e^{-i\frac{w}{c}\sin ax + i\frac{w}{c}\cos az}$$

$$\overrightarrow{E_e} = \overrightarrow{E^0} e^{-i\frac{w}{c}\sin ax + i\frac{w}{c}\cos az + i\Delta} ,(14)$$

where $\overrightarrow{E^0}$ is the complex amplitude, which for simplicity is taken equal for the o- and e-wave with orthogonal polarization (this can always be done by turning the analyzer at the angle of 45°), Δ – the optical path difference between the o- and e-beams. The intensity at the intersection of the o- and e-beams is given by the following ratio:

$$I = |\overrightarrow{E_0} + \overrightarrow{E_e}|^2 = 4|\overrightarrow{E^0}|^2 \cos^2 \frac{w}{c}\sin ax + \frac{\Delta}{z} \qquad (15)$$

The condition for maximum is defined by the following ratio:

$$\frac{w}{c}\sin ax + \frac{\Delta}{2} = \pi S , \qquad (16)$$

where S is the integer.

The interference pattern presents a system of Haidinger fringes parallel to the Y-axis with the distance between the fringes, defined by (17):

$$\Delta x = \frac{\lambda}{2a} , \qquad (17)$$

where λ is the wavelength of radiation.

The resolving limit of lines of the interference pattern will be determined by the resolving power of the microscope, through which the interference pattern is observed, and the wavelength of radiation.

The BP experimental results

The interference mode of the BP is as follows. The laser beam and the prisms, giving two beams polarized in two mutually perpendicular planes (birefringent prisms), shown in Figure 4, entering the input face of the BP are split into two beams of orthogonal polarization: ordinary (o_1) and extraordinary (e_1). The BP is designed so that the principal axes of both Dove prisms are parallel to each other, lie in a plane perpendicular to the BP side faces and bases, and form an angle of 45^0 with the bases of the Dove prisms. This is convenientfor using laser sources, in which radiation is polarized in the vertical plane, i.e. the light beam incident on the BP has oscillations of the electric vector parallel to the face of the BP. This creates a condition for the formation of the o-and e-beams of equal intensity required to produce an interference pattern with the highest contrast. The ordinary beam (o_1) emerges from the BP, undergoing total internal reflection on the Dove prism bonded by the bases. Bonding is made with a thin layer of Canada balsam, as far as Canada balsam has an intermediate refractive index: $n_e < n_{cb} < n_0$.

The extraordinary beam (e_1) passes through the BP without undergoing deflection. The laser beam 2 (Figure 4), entering the input face of the BP, is also divided into two beams of orthogonal polarization: (o_2) and (e_2). Thus, at the output of the BP there are four (o_1, e_1, o_2, e_2) polarized beams. Between the beams o_1 e_2 and e_1 o_2, photo displacement is performed with the analyzer (A) in two measurement channels. The interference pattern is obtained in the form of fringes of the equal width, parallel to the side faces of the BP. Any slight rotation of the BPresults in a mutual displacement of interference fringes in bothcircuit arms.

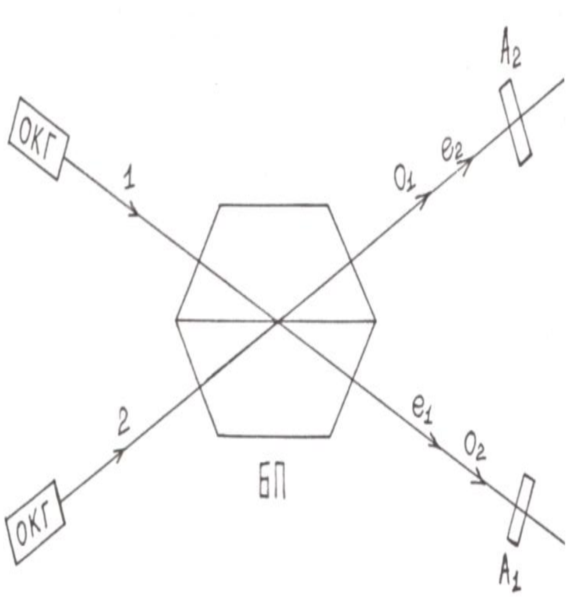

Figure 4. Mode of operation of the bipolarizer (BP)

The dependence of the spatial frequency of the interference raster on the angle of light incidence on the input faces of the BP was experimentally investigated. The experimental results are presented in Figure 5. The experiment showed that the interval of the measured angles is $\alpha \cong \pm 70^1$.

Figure 6 shows the workflow of the BP in the "splitter of the laser beam" mode. The collimated laser beam with a cross-sectional diameter of ~ 5mm passes through the Dove prisms bonded by the base, and at the output of the BP there are eight beams polarized by four beams in orthogonal planes. The beams 1, 2, 4 and 4^1 are ordinary and 1^1, 2^1, 3^1 и 3 - extraordinary. The beams 1 and 2 as well as 1^1 and 2^1 extend parallel to each other (as shown in Figure 5). The last of the investigated modes, although not specific to the BP, but can be applied in a number of cases for replicating the laser beam by eight channels. The two-channel mode with the possibility of obtaining interference in each channel and a subsequent photodetection of the resultant signal should be considered the most common mode of the BP. In such a mode, the BP can be recommended as a device outputting the laser beams in the laser gyroscope of a triangular type.

γ, lp/mm

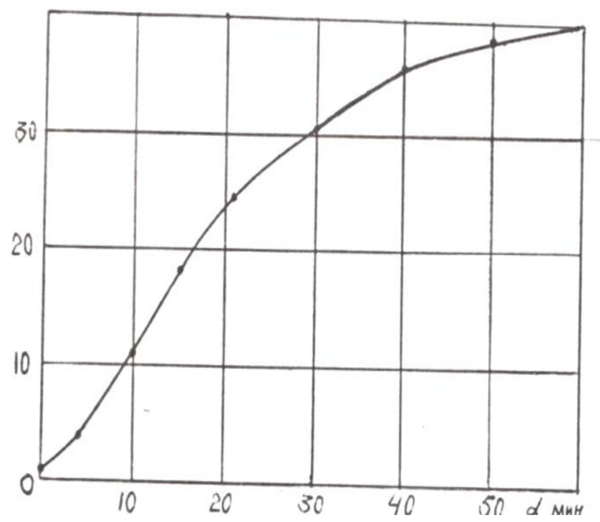

Figure 5. The dependence of the spatial frequency of interference fringes in the BP on the rotation angle α

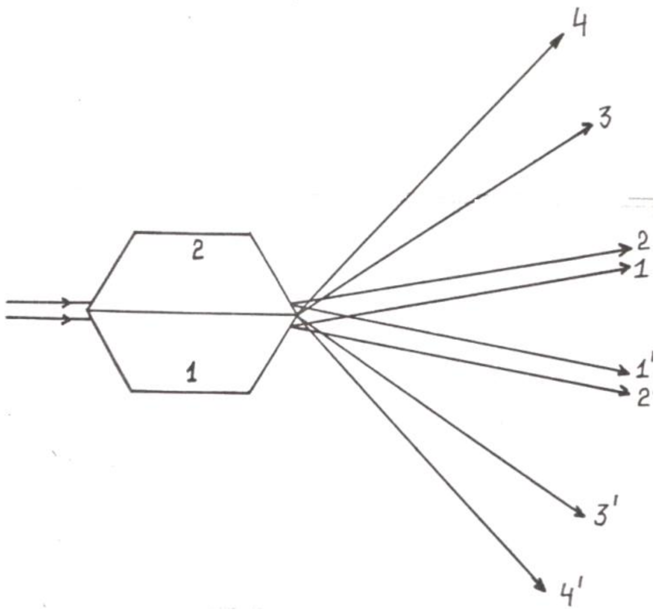

Figure 6.The bipolarizer |BP| workflow in the "splitter of the laser beam" mode. |1,2,4,4^1| – o-beams, |1^1,2^1,3^1,3 – e-beams

The laser polarization interferometer in the bipolarizer (BP) for the measurement of small angular displacements

On the basis of the developed theory of the BP we have proposed [35] the polarization interferometer with the use of the BP. As it follows from the expression (18) there is a dependency of the spatial frequency of the interference pattern at the output of the BP on the angle of incidence of the laser beam on the input face of the BP, which makes it possible to use the BP for tracking or measuring small angular displacements of the object.

In the known devices [36-37], several types of birefringentplates are used simultaneously or separately to solve these problems. The precision of measurement of small angular displacements of the object in the known devices is not high (of the order of several tens of arcseconds).

The design of the BP makes it possible to construct a circuit, which can be used to measure small angular displacements of objects with high accuracy (of the order of tenths of an arcsecond). One of such possible circuits is considered below (Figure 7).

The device operation is as follows. The light beam from the source of polarized radiation I, after being expanded and formed into a parallel beam through the collimator (2) consisting of a microlens and a long-focus lens in the focal position,is separated by the beam splitter 3 into two beams of equal intensity. One of them is directed to the flat mirror 4, mounted on the object, and being reflected, falls on the BP 5, and the other beam passes through the beam splitter 2, and also falls on the BP 5. At the same time, both beams are normally incident on the input face of the BP. Each of the beams incident on the output faces of the BP is split into two beams of orthogonal polarization: ordinary (o) and extraordinary (e) (Figure 7).

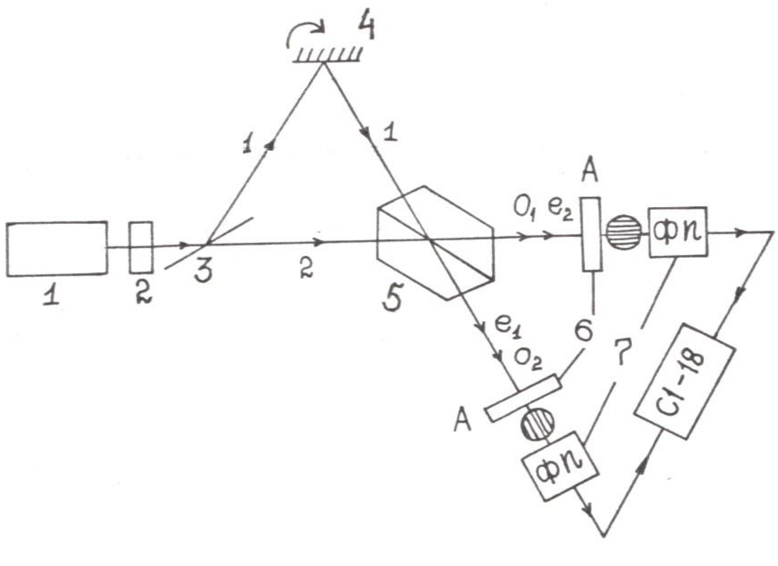

Figure 7. The polarization interferometer for measuring small angular displacements of the object

The BP is designed so that the principal axes of both Dove prisms are parallel to each other, lie in a plane perpendicular to the BP side faces and bases, and form an angle of 45^0 with the bases of the Dove prisms. This is convenient for using laser sources, in which radiation is polarized in the vertical plane, i.e. the light beam incident on the BP has oscillations of the electric vector parallel to the face of the BP. This creates a condition for the formation of the o- and e-beams of equal intensity required to produce an interference pattern with the highest contrast. The ordinary beam (o_1) emerges from the BP, undergoing total internal reflection on the Dove prism bonded by the bases.

Bonding is made with a thin layer of Canada balsam, as far as Canada balsam has an intermediate refractive index: $n_e < n_{cb} < n_{0.}$

The extraordinary beams ($e_{1,}$ e_2) emergefrom the BP, undergoing deflection. At the output of the BP, between the beams o_1 e_2 and e_1 o_2, there is a need for photo displacement in two measurement channels. For this purpose, the analyzers 5 are put into both interferometer arms, oriented perpendicular to the face of the BP, and the photodetectors 6 record signals in channel outage. Any slight rotation of the flat mirror 4 results in a mutual displacement of interference fringes in both arms of the polarization interferometer. The difference signal, recorded from the photodetectors 7, is a measure of the angular displacement of the flat mirror 4 installed on the object.

The sensitivity of the proposed device can be characterized by the expression (18). Preliminary tests of the interferometer layout have shown that for the interval of the measured angles$\alpha = \pm 70^1$,theaccuracy of measurementsof the order of anarcsecond is achieved. With increasing requirements for vibration resistance, the measurement of displacements of the interference pattern can be performed with an accuracy of 1/10 of the fringe, which is equivalent to the angular displacement of the object of the order of a tenth of an arcsecond.

The proposed device has the following advantages as compared with the known analogs:

1) improves the accuracy of the measurement of small angular displacements of objects.

2) simplifies the design of the interferometer.

Conclusions:

The method of calculating the passage of electromagnetic waves in the TCOE-bipolarizer (BP) from the uniaxial crystal has been developed. The expressions that are suitable for the analysis of properties of the BP have been received.

We have considered the workflow of the BP in the mode of interference of polarized beams at the output of the BP and determined the dependence of the spatial frequency of interference fringes generated by the BP on the angle of incidence of the laser beams on the input faces of the BP.

It is shown that it is possible to use the BP for measuring small angular displacements of objects in the polarization interferometer. The proposed polarization interferometer helps to very accurately fix and measure small angular displacements of objects and simplifies the design of the interferometer.

References

1. W. Kulcke, K. Kosanke, E. Max, H. Fleisher, T. J. Harris. Convergent Beam Digital Light Deflector.MIT Press. Cambridge 1965.
2. P.W.Smith. 1982. Proc. IEEE. Vol.10.pp.422.
3. A.D. White.1986. Tech J. Vol.45. pp.22-28.
4. H.Walther, J.L.Hall.1970. Applied Physics Letters.Vol. 17. pp.239-242.
5. L.Cirkovic,H.Y.Evans,H.Y.Forrest,J. Katrenstein.1988. Appl.Opt.Vol.7. pp.981.
6. Yu.V.Kalamiytsov. Interferometers. Leningrad. Mechanical engineering 1986.
7. L.Csillag,M.Janossy, K.Kantor.1986. Phys. Lett. Vol.20. pp.626.
8. J. Svetlik.1984. Appl.Opt. Vol.13. pp.1275
9. O. Bryngdahe.1986. Progress in Optics. Vol.4.pp.38.
10. J.F. Ebersole.1985. Optical Engineering. Vol.14.pp.38.
11. T.A. Tsuruta.1983. Appl.Opt.Vol.2. pp.371.
12. W.Martienssen, E.Spiller.1980. Amer.J.of Phys. Vol.32. pp.919.
13. J.B.Saunders.1980.Appl.Opt. Vol.19. pp.1623.
14. W. Merzkirch. 1984. Appl.Opt. Vol.13. pp.409.
15. F.D. Smith.1983. Appl.Opt. Vol.2. pp.335.
16. V.A. Zverev.Radio-optics. Moscow. Soviet Radio 1985.
17. J. Grudman. Introduction to Fourier - optics. Moscow. Mir 1990.
18. A.Papoulis. Theory of systems and changes in optics. Moscow. Mir 1995.
19. K. Preston. Coherent optical computers. New York. McGraw-Hill 1972.
20. A.A. Akayev,S.A. Mayorov. Coherent optical computers. Leningrad. Mechanical Engineering 1997.
21. G.Ya. Kosov.1997.Electronic Engineering.Vol.3. pp.659-682.
22. V.S. Gdalin. Measurement of parameters of television transmitting and receiving tubes. Moscow. Soviet Radio 1998.
23. E.P. Semenov.1987. Opto-Mechanical Industry. Vol. 12. pp. 68-75.
24. R.Bruscaglioni.1986. Optica. Vol.1. pp.3-13.
25. G.A. Ashulov, M.D. Khukhrina.1985. Optics and Electronics. Vol. 4. pp. 106.
26. R.E.Nopking, F.R.Clapper.1988.JosA. Vol.38.pp.661.

27. J.B. Saunders.1990. Appl. Opt. Vol.19. pp. 1623

28. W. Merzkirch. 1994.Appl. Opt. Vol.13. pp. 409.

29. F. Smith.1993. Appl. Opt. Vol.2. pp.335

30. N.M.Borovitskaya, I.Ya. Brusin,V.G. Gavrilenko. Experimental radio optics. Moscow. Nauka1989.

31. V.A. Zverev.Radio-optics. Moscow. Soviet Radio 1985.

32. J. Grudman. Introduction to Fourier - optics. Moscow. Mir 1990.

33. S.I.Bychkov, D.P. Dukyanov, A.I. Bakalyar.Laser gyroscope. Moscow. Soviet Radio 1975.

34. A.S.Batyrakov, M.M. Butusov,G.P. Grechka. Laser measurement systems. Moscow. Radio and Communication 1981.

35. A.I.Bakaliyar, D.P. Lukyanov. Basics of the theory of ring laser gyroscopes and their application in navigation complexes. Leningrad. A.F. Mozhaisky LIVIKA 1988.

36. K.A. Barsukov, Yu.V.Osipov, V.N. Popov,V.S. Firsov. Laser interference resolvometer and its use for testing electro-optical systems. Third All-Union School on Optical Information Processing. Scientific conference abstracts. Riga 1980.

37. L.G. Nazarova.1970. Optics and Spectroscopy. Vol.29.pp. 757.

38. M.Bass, C. Decusatis.Handbook of Optics. Volume II: Design, Fabrication and Testing, Sources and Third Edition. The McGraw-Hill 2010.

39. Bass M., Enoch J.M. Handbook of Optics. Volume Third Edition. — The McGraw-Hill, 2010. — 1250 p.

40. M.N. Berberan-Santos. Fluorescence of Supermolecules, Polymers.Springer 2008.

41. N.Berova, P.L.Polavarapu, K.Nakanishi, R.W.Woody. Comprehensive Chiroptical Spectroscopy, Applications in Stereochemical Analysis of Synthetic.Wiley 2012.

42. C.W. Billings, J. Tabak Lasers: The Technology and Uses of Crafted Light. Wiley2006.

43. L.N.Binh. Guided Wave Photonics: Fundamentals and Applications with MATLAB.CRC Press. Taylor & Francis Group 2012.

44. L.N.Binh, N.Q.Ngo. Ultra-Fast Fiber Lasers: Principles and Applications with MATLAB Models.CRC Press 2010.

45. S.Jr.Boggs, D.Krinsley. Application of Cathodoluminescence Imaging to the Study of Sedimentary Rocks.Cambridge University Press 2006.

46. G.D.Boreman. Basic Electro-Optics for Electrical Engineers The Society of Photo-Optical Instrumentation Engineers. Wiley 1998.
47. R.W. Boyd.Nonlinear Optics. Elsevier 2008.
48. R.W. Boyd. Nonlinear optics.Second Edition. Elsevier Science/AP 2010.
49. F.Bretenaker, N.Treps. Laser: 50 Years of Discoveries.World Scientific Publishing Co 2015.
50. W.S.C.Chang. Principles of lasers and optics.Cambridge University Press 2005.