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INCREASING THE SENSITIVITY OF COMPUTER-INTEGRATED THERMAL IMAGERS IN THE STUDY OF THERMOELECTRIC PHENOMENA AND REMOTE OBSERVATIONS

The work is devoted to the substantiation of the choice of optical polarizing elements for thermal imaging remote observations and measurements. A comparative analysis of the main methods of obtaining polarization images was performed, namely using polarizer rotation, phase plate rotation, and using combined infrared matrix receivers with micro polarizers. Simplified mathematical models of signal transformation in the main optical elements of polarimetric thermal imagers – linear polarizers and phase (quarter-wave) plates - were used for the analysis. The advantage of wire polarizers compared to polarizers based on reflection is shown. It is also substantiated that among the various physical effects causing phase delays – birefringence, total internal reflection and reflection of radiation at the air-metal interface, diffraction on a wire diffraction grating – the use of the latter effect is most acceptable. Bibl. 21, Figs. 7.

Key words: polarimetric thermal imagers, Stokes vectors, polarizer, quarter-wave plate.

Introduction

Thermoelectric phenomena are widely used in various spheres of human activity. One of the relevant scientific and applied problems, for instance, is the utilization of waste heat using thermoelectricity [1]. A complete set of means for technical implementation of energy conversion processes requires many components, including measurement technologies. To control the quality of thermoelectric energy converters, computerized methods of absolute measurements using thermocouples are being developed [2]. More generalized monitoring of physical phenomena related to thermal contrasts is possible using thermal imagers. Classical thermal imagers allow observing the thermal radiation contrast of energy brightness (intensity) between the object and the background [3]. With a low radiation contrast of the observation object, the efficiency of using classical thermal imagers may not be high. In order to increase the radiation contrast of images of objects on a uniform background, some countries have begun research on the creation of thermal imagers, in which the carrier of information is the polarization properties of infrared (IR) radiation of the target and the background (obstacles) [4, 5, 6]. Such polarimetric thermal imagers (PT) measure the polarization characteristics of radiation from the object and background, namely: intensity, degree of polarization, and azimuth and ellipticity of polarization [7, 8]. These characteristics make it possible to measure the complex refractive index, which combines the optical and electrical parameters of the medium under study.

The PT optical system consists of an IR polarizer, a quarter-wave retarder, and an IR lens located in series on the optical axis [9, 10]. A number of monographs and articles [11, 12] are devoted to the study of such an optical system, where the polarization elements (IR polarizer and quarter-wave plate) are considered, which perform the appropriate transformations of the optical signal to obtain the polarization parameters of radiation from the observation object and the background. Also, great attention is paid to PT calibration [13]. At the same time, there is no information on the study of PT optical system in order to substantiate the choice of infrared polarizer and phase plate for improving the operational characteristics of the thermal imager.

The purpose of this work is to research and substantiate the choice of infrared polarizer and phase plate to match their parameters, which will improve the operational characteristics of polarimetric thermal imagers.

Physical and mathematical model of the optical-electronic system of the polarimetric thermal imager

The polarization characteristics of radiation, which change during propagation and reflection, can be expressed by the Stokes vector, the Jones vector, or the Mueller matrix [14, 15]. The Stokes vector was proposed to study partially polarized, as well as unpolarized and fully polarized light. The four parameters of the Stokes vector $\vec{\boldsymbol{S}} = \{S_0, S_1, S_2, S_3\}$ describe information about the polarization state of the observation object. The four-segmentation method of the modulation of the matrix radiation receiver (MRR) by the polarization state of the radiation for the measurement of the Stokes vector has become the most widespread [4, 5, 9].

Fig. 1 shows a diagram that explains the operating principle of such a PT based on modulation [10]. To simplify the study, we will assume that monochromatic radiation is considered. The investigated partially polarized radiation with amplitude $\vec{E}_{pp}$ passes through a polarizer, a quarter-wave plate, which can change the polarization angle θ and the phase difference ε between the components E_x and E_y of the vector $\vec{E}_{pp}$ using mechanical rotation, or continuous periodic modulation. The infrared MRR forms a group of output radiation values, which are used to obtain four parameters of the Stokes vector of the polarization image by changing the angles θ and ε.

The Stokes vectors make it possible to obtain the main parameters of radiation polarization: intensity, degree of polarization, polarization angle, and polarization ellipticity.

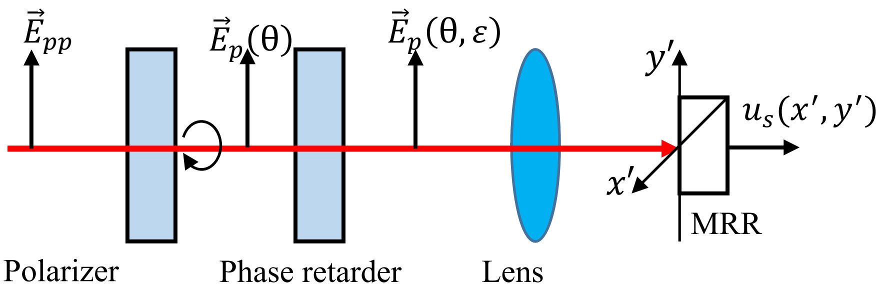

Fig. 1. Operating principle of polarimetric thermal imager

We will consider the PT optical system, which consists of an IR polarizer, a quarter-wave plate and an IR lens of a thermal imager located in series on the optical axis (Fig. 2). Let a parallel beam of natural or partially polarized radiation with amplitudes $\vec{E}_n$ or $\vec{E}_{pp}$, respectively, enter the input of the optical system. At the output of the polarizer, linearly polarized radiation with the vector $\vec{E}_{lp}$ is formed, which is oriented at an angle θ relative to the x axis. After passing through a quarter-wave plate, the optical axis of which is parallel to the surface of the plate and forms the angle α with the vector $\vec{E}_{lp}$ (polarization plane), as a result of birefringence in the plate, ordinary and extraordinary beams with amplitudes E_0 and E_e are formed. These beams spread in one direction and have a phase difference at the exit from the plate

$$\Delta\varphi = \varepsilon = k \cdot \Delta d = \frac{2\pi}{\lambda}(n_o - n_e)d, \tag{1}$$

where d is the thickness of the plate, n_o and n_e are the refractive indices for the ordinary and extraordinary beams, respectively.

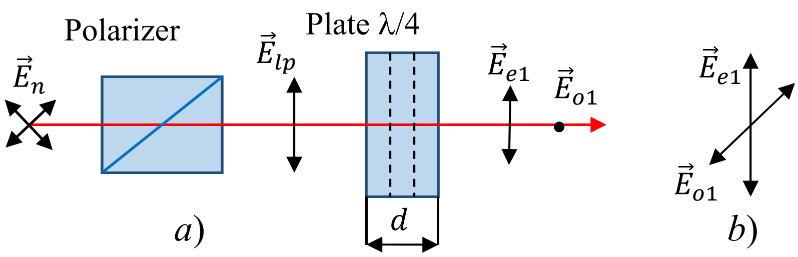

Fig. 2. Diagram for radiation polarization study (a) and its vector model (b)

In modern PTs, three methods of obtaining a polarized image are used: rotation of the polarizer, rotation of the phase plate, and the use of MRR, each pixel of which has a micro polarizer with a certain orientation of the polarization axis [16]. The first and second methods have limited use due to the presence of a mechanical system for rotating optical elements and the need to use three or four consecutive frames. Fig. 3 shows different polarization states of optical radiation, which can be fully described by the four Stokes parameters.

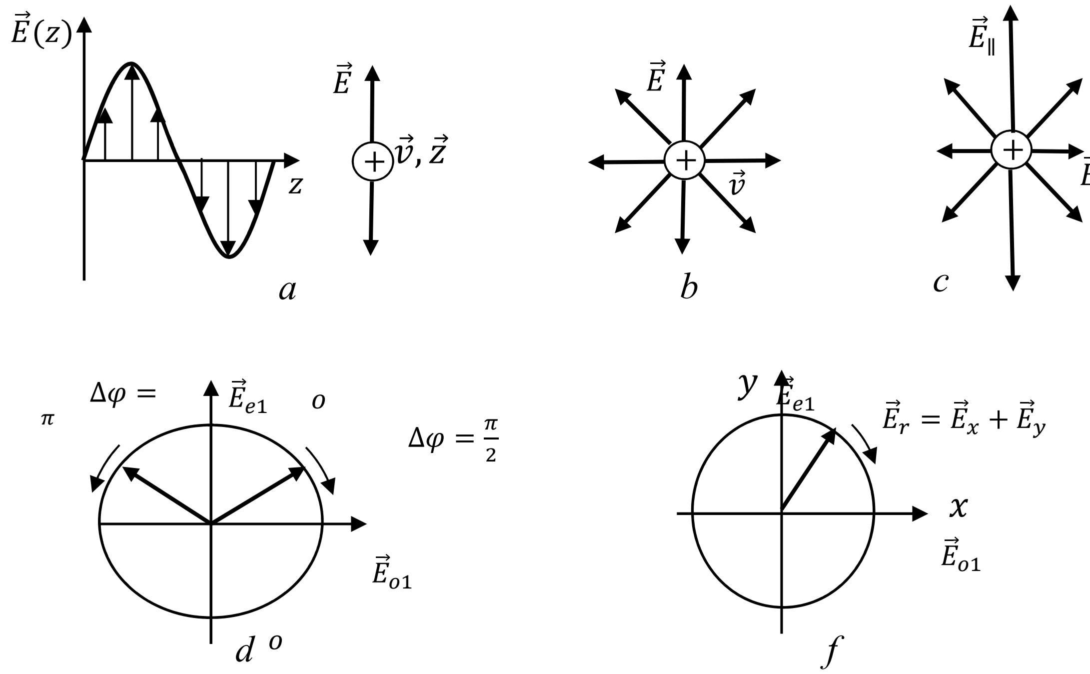

Fig. 3. State of radiation polarization: a – linearly polarized; b – natural; c – partially polarized; d – elliptically polarized; f – circularly polarized

The first Stokes parameter S_0 determines the total optical intensity. The second Stokes parameter S_1 determines the preference of the recorded optical signal for horizontal polarization over vertical polarization. The third Stokes parameter S_2 determines the preference of the recorded optical signal with linear polarization oriented along 45° over linear polarization along 135°, which are measured relative to the horizontal direction. The fourth Stokes parameter S_3 characterizes the superiority of right-circular polarization over left-circular polarization.

The Stokes parameters can be determined with the aid of two orthogonal electric radiation fields E_x and E_y, which are defined by the equations

$$E_x(t) = E_{x0}\exp[j(2\pi\nu t - \varphi_x)] \text{ i } E_y(t) = E_{y0}\exp\left[j(2\pi\nu t - \varphi_y)\right], \quad (2)$$

where E_{x0} , E_{y0} and φ_x , φ_y are constant amplitudes and initial phases of these fields, respectively; ν is radiation frequency. The electric radiation field that passed through a linear polarizer with the polarization axis in the θ direction and a phase plate with a delay by the angle $\varepsilon = \varphi_x - \varphi_y$, is determined by equation (3):

$$E_1(\theta, \varepsilon) = E_x \cos\theta + E_y \exp(j\varepsilon)\sin\theta. \quad (3)$$

Let us consider the features of using polarizers and phase plates in PT optical systems.

Polarizers for the IR region of the spectrum

A polarizing optical element is any optical element that changes the state of radiation polarization [15]. Polarizers and phase plates (phase retarders) are polarizing optical elements.

General provisions

A polarizer is an optical element designed to create light regardless of the properties of the incoming light. The desired state of polarized light can be linear, circular, or elliptically polarized (Fig. 3), and an optical element designed to create one of these states is called a linear, circular or elliptical polarizer. Polarizers use such optical phenomena as absorption, refraction, birefringence and diffraction of radiation.

The linear polarizer has two transmission parameters: the basic main transmittance T_1 and the secondary main transmittance T_2. The parameter T_1 is defined as the ratio of the intensity at the output of the polarizer $I_{p,max}$ to the intensity at the input I_0, when the incident beam is linearly polarized in the oscillation azimuth, which provides the maximum transmittance. Similarly, the parameter T_2 is determined for the minimum transmittance. Thus

$$T_1 = \frac{I_{p,max}}{I_0}; T_2 = \frac{I_{p,min}}{I_{,0}}. \quad (4)$$

The ratio $R_t = T_1/T_2$ is called *the main transmittance (extinction coefficient)* of the polarizer. For high-quality polarizers, this coefficient can reach 10^5. The average value of the main transmittances is called the total transmittance

$$T_t = \frac{T_1 + T_2}{2}. \quad (5)$$

The parameter T_t is defined as the ratio of the intensity at the output of the polarizer to the intensity of the input unpolarized beam.

For a perfect polarizer, Malus`s law has the form

$$I_{id}(\theta) = \frac{1}{2} I_0 \cos^2\theta. \quad (6)$$

For a real polarizer, Malus`s law is given by

$$I_r(\theta) = I_{90} + (I_0 - I_{90})\cos^2\theta. \quad (7)$$

Wire grid polarizers

In the IR region of the spectrum, polarizers in the form of a flat grid formed by parallel wires (wire grid polarizer, WGP) are widely used [15, 16]. Such a polarizer forms linearly polarized radiation in a plane perpendicular to the wires. The distance between the wires must be less than the wavelength. The wire grid is applied to the substrate, the surface of which has an anti-reflection coating. Radiation that is polarized parallel to the wires is reflected. The grating period of IR polarizers is usually 0.5 μm or more.

Since reflection and absorption losses reduce the transmittance of wire gratings, an anti-reflection coating is applied to the substrate. Therefore, its quality and achromacity are important factors in the production of wire gratings. Commercial wire grating polarizers have a basic transmittance (20 – 10000) for linear polarization of radiation in transmission mode in the spectral range from 1.5 μm to millimeter wavelengths.

Typical technical characteristics of wire polarizers are given in Table 1.

Table 1

Technical characteristics of a wire polarizer

Parameters at $\lambda = 5$ μm	Technical characteristics
Transmission efficiency, T_1, %	90
Transmission of unwanted radiation, T_2, %	0.4
Degree of polarization, $(T_1 - T_2)/(T_1 + T_2)$, %	99
Extinction ratio, T_1/T_2	225

In [17], an IR wire polarizer is considered, which consists of a grating with a period of 400 nm on a photocurable film 30 μm thick. The grating is made of gold using thermal spraying and film imprinting in high humidity conditions. The polarizer has a transverse magnetic transmission of more than 75 % in the range of wavelengths (4 – 5.5) μm and an extinction ratio of more than 20 dB in the range (2.5 – 7.5) μm. The maximum extinction ratio is more than 28 dB for a wavelength of 6.5 μm. Such a film polarizer with high transmittance is cheaper compared to conventional IR polarizers.

In [16], the process of manufacturing a wire polarizer for pixels of a micro bolometric (MBM) MRR is described. A wire grid made of gold is applied to a substrate that has low losses for the wavelength of the incident wave, that is, the small imaginary and real parts of the refractive index *n*, k [18] should have minimum values. The ideal solution to this problem is the mechanical placement of a gold grid in the air, which is technologically impossible. Therefore, substrates with different refractive indices were used (Fig. 4).

Numerical simulation of the propagation of TM and TE fields for various wire grids (period, metal thickness, substrate materials and wavelengths) was carried out using the theory of diffraction gratings [19]. If the electric field vector is parallel to the boundary between two media, then we speak about the TE-polarization of the wave. If the magnetic field vector is parallel to the boundary between two media, then the radiation is considered to be TM-polarized. The purpose of this simulation is to find the geometric dimensions of the grating, when the extinction ratio of the TM/TE field at the polarizer output exceeds 100:1, the TM transmission value exceeds 80 %.

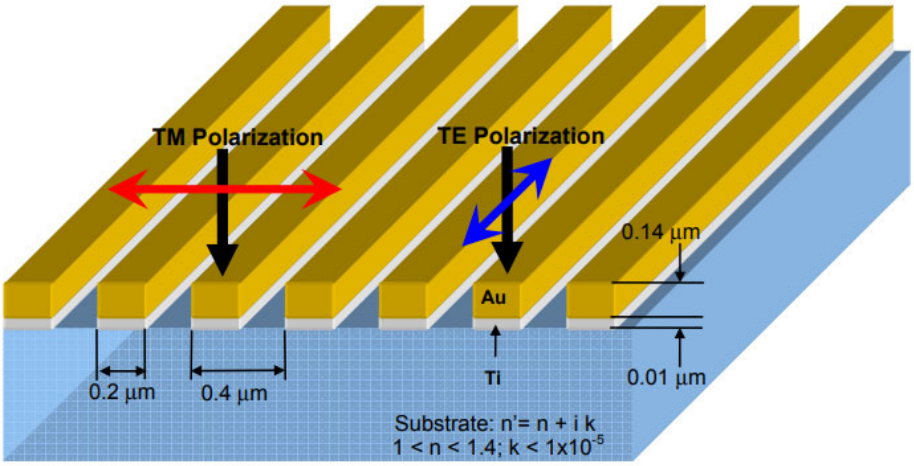

Fig. 4. Illustration of a gold wire grid polarizer on a substrate with a low refractive index for n and k and different geometric dimensions [15]

A simplified version of the PT optical system uses a rotating phase plate behind which a fixed linear polarizer is located, which allows obtaining several consecutive images to determine the Stokes parameters over the entire field of view. An alternative method is the field of view which is spatially divided into superpixels, in each of which the Stokes parameters are determined simultaneously. Each superpixel cell has a separate wire micro polarizer with a certain orientation of the polarization plane.

The key element of the PT optical system is a quarter-wave plate designed for the appropriate spatial division of the image. Various physical phenomena can be used in such plates: reflection at the Brewster`s angle, birefringence, diffraction of radiation on a wire grating with a small period. Such subwavelength gratings have an effective refractive index that depends on the polarization of the incoming radiation. This effect is known as birefringence and can be used to create a wave plate.

In [16], the results of a project at Sandia National Laboratories (Albuquerque, New Mexico, USA) to develop a long-wavelength infrared micro polarization device for polarimetric imaging are presented. Information about the polarization state of radiation from the object and the background can help detect and recognize objects of interest for various remote sensing tasks and for military applications. While traditional sequential polarimetric images create scenes with polarization information using a series of acquired images, the use of a MRR, each pixel of which has a polarizer with a certain orientation of the polarization plane, allows, through processing of pixel signals, to determine the distribution in the image plane of all four Stokes parameters simultaneously.

Fig. 5 shows the MRR superpixel model, which consists of four cells with separate micro polarizers with different orientations of the polarization plane. The orientation of the wires in each cell is different, which results in each cell forming a polarizer whose optical axis forms angles of 0°, 45°, 90° and 135° with the optical axis of the retarder. Thus, the use of a superpixel allows simultaneous reception of signals at the output of individual cells for different polarization angles in one frame. The processing of these signals makes it possible to calculate the components of the Stokes vector, which determines the polarization characteristics of the radiation of the observation object [16]:

$$S_0 = 1;\ S_1 = \{2I(0°, 0) - [I(0°, 0) + I(90°, 0)]\}/[I(0°, 0) + I(90°, 0)];$$

$$S_2 = \{2I(45°, 0) - [I(0°, 0) + I(90°, 0)]\}/[I(0°, 0) + I(90°, 0)];$$

$$S_3 = \{2I(135°, \pi/2) - [I(0°, 0) + I(90°, 0)]\}/[I(0°, 0) + I(90°, 0)].$$

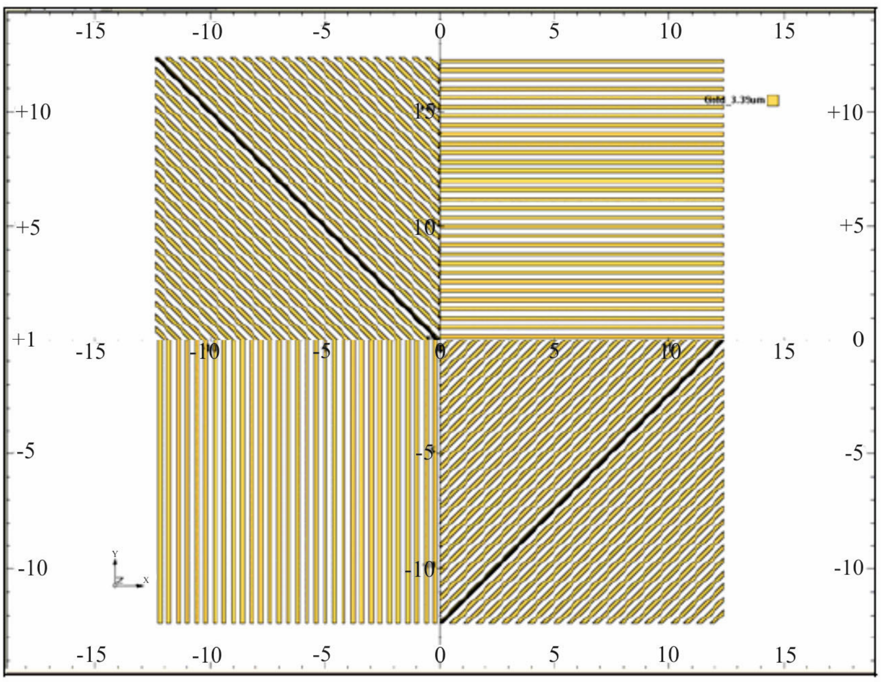

Fig. 5. Model of MBM superpixel model

Commercial IR polarizers are commercially available from some optical companies, such as Edmund & Tydex. Such polarizers are designed for linear polarization of radiation in the transmission mode in the spectral range from 1.5 μm to millimetre wavelengths. They are a type of diffraction grating and are cut into a crystalline or polymer substrate. The polarizer grating is a set of triangular profile strokes. An aluminium coating is applied to one of the faces of each stroke. Depending on the material of the substrate, polarizers are made using a diffraction grating technology.

The Edmund Optics company supplies the market with polarizers using a special holographic technique, owing to which the distance between the wires is micrometers [20]. Compared to conventional methods, the holographic method creates a finer groove spacing that optimizes performance for short wavelengths. Holographic wire polarizers are created from barium fluoride (BaF_2), zinc selenide (*ZnSe*), thallium bromo-iodide (KRS-5) and germanium (*Ge*).

Table 2 shows the characteristics of wire polarizers, and Fig. 6 depicts the appearance of a polarizer [20].

Table 2

Technical characteristics of wire polarizers

Substrate material	*ZnSe*	*Ge*	KRS-5
Spectral range, µm	(1.5 – 14)	(8 – 14)	(2 – 30)
Standard aperture, mm	D25 × 25	D25 × 25	D34
Frame size for standard aperture, mm	D42 × 8	D42 × 8	-
Effective transmittance, T_1	65- 70 % with one-sided anti-reflection coating 50 % without coating	>50 % with one-sided anti-reflection coating	60 %
Transmission of unwanted polarization, T_2	<0.1 % for 10 µm	<0.1 % for 10 µm	-
Degree of polarization $(T_1 - T_2)/(T_1 - T_2)$	>99 % for 10 µm	>99 % for 10 µm	
Manufacturer	TYDEX	TYDEX	Edmund Optics

For physical and mathematical simulation of wire polarizers, the period of which is much shorter than the wavelength, the theory of coupled waves is used [16, 19].

a)

b)

Fig. 6. KRS-5 polarizer (a) and phase plate (b) from Edmund Optics company [18]

Quarter-wave plate

In [16] demonstrated the possibility of manufacturing and using wire polarizers and wire achromatic phase plates that provide the required extinction ratio and phase delay. Test results of micro polarization superpixel arrays indicate that each element (polarizer and phase plate) is manufactured on its own substrate, as it is too sensitive to crosstalk.

This crosstalk is a consequence of diffraction from the periodic structures of micro polarizers and/or microwave plates. Diffracted light propagates inside the substrate to the next element or into free space. To reduce the effect of this phenomenon on the temperature and spatial separation, it is proposed to integrate micro polarizers into the MRR matrix structure during its manufacture. The birefringent wave plate is manufactured on its own substrate and is compatible with the active zone of the integrated “micro polarizer-pixel” structure. The wave plate must have a two-sided anti-reflection coating. This approach significantly complicates the process of manufacturing the optical-electronic system of PT.

A quarter-wave plate (retarder) can be made in the form of a rhombic prism or a wave plate. Such optical elements are often called compensators, for instance, the Babinet-Soleil compensator. Retarders can be designed for a certain wavelength or for a wide range of the spectrum (achromatic compensators).

Phase retarders based on uniaxial crystals

Changing the phase difference in compensators can be achieved by using anisotropic uniaxial crystals, in which the optical axis is parallel to the crystal faces:

$$\Delta\varphi = \varepsilon = \frac{2\pi}{\lambda} d(n_e - n_o). \tag{8}$$

The optical path difference is due to two parameters: plate thickness d and birefringence $(n_e - n_o)$. For positive crystals $n_e > n_o$. An extraordinary beam with a refractive index n_e is polarized parallel to the optical axis, and an ordinary beam with a refractive index n_o is polarized perpendicular to the optical axis.

The slow axis is the direction in the medium with the highest refractive index n_e, that is, for a uniaxial positive medium it will be its optical axis. *The fast axis* is the direction in the medium with the smallest refractive index n_o.

The most common commercial retarders are quarter-wave and half-wave plates, which provide a phase difference between E_s and E_p components equal to $\pi/2$ and π. A quarter-wave retarder produces circular polarization when the azimuth of linearly polarized incident light makes an angle of 45º with the fast axis. A half-wave retarder forms linearly polarized light, the plane of polarization of which is rotated by an angle of 2θ, when the azimuth of partially polarized incident light is at an angle of θ relative to the fast axis.

IR achromatic retarder

Fig. 7 shows the diagram of operation of a prismatic retarder, in which there is no deviation of the beam [13]. In the optical element, there are two total internal reflections (TIR) at points A_1, B_1 and A_2, B_2 and reflection at the air-metal interface at points C_1, C_2.

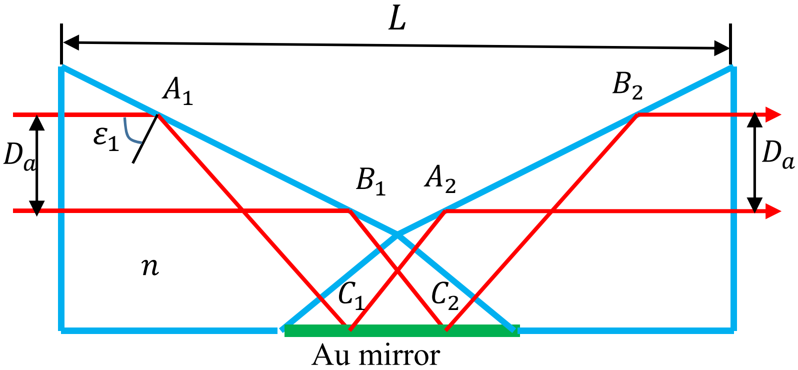

Fig. 7. Infrared achromatic prismatic retarder

The operating principle of the prism is based on the fact that between the plane-polarized components E_s and E_p of the input radiation there are significant phase shifts at TIR points. These phase changes (phase difference) are calculated by the formulae [13]

$$\delta_{pr,s} = 2\mathrm{arctg}\frac{\sqrt{n^2\sin^2\varepsilon_1 - 1}}{n\cos\varepsilon_1}, \tag{9}$$

$$\delta_{pr,p} = 2\mathrm{arctg}\frac{n\sqrt{n^2\sin^2\varepsilon_1 - 1}}{\cos\varepsilon_1}, \tag{10}$$

where ε_1 is the angle of incidence, and n is the refractive index of the prism material (Fig.7).

The linear delay associated with TIR is a net phase shift between the two components E_s and E_p:

$$\Delta_{pr} = \delta_{pr,p} - \delta_{pr,s}. \tag{11}$$

Moreover, phase shifts between E_s and E_p components are observed during reflection from metal:

$$\Delta_{met} = \delta_{met,p} - \delta_{met,s}. \tag{12}$$

Then the total delay for two TIRs and reflection from the metal is equal to

$$\Delta\varphi = 2\Delta_{pr} + \Delta_{met}. \tag{13}$$

The refractive indices of optical materials that transmit radiation well in the IR range of the spectrum are higher than the refractive indices for the visible range. As a rule, for the IR range they are greater than 2.0, and for the visible range they are within (1.4 – 1.7). The higher refractive indices for the IR range result in larger phase delays between the E_s and E_p components for a given angle of incidence than for the visible range. A prismatic retarder for IR radiation, which has more than two TIRs, will have large dimensions, which causes certain difficulties in its application.

Prisms are made from homogeneous materials in which there is no birefringence. Zinc selenide, zinc sulphide, germanium and gallium arsenide satisfy such requirements in the IR range of the spectrum. For the manufacture of mirror surfaces use gold, silver, copper and aluminium. Preference is given to gold, which has a high reflection coefficient in the IR range and significant resistance to corrosion.

The angles of incidence at the entrance and exit of the two prisms were chosen to reduce the Fresnel reflection losses. Table 3 show the parameters of a retarder made of zinc selenium and a gold mirror, which provides a change in the optical length by $\lambda/4$ in the range (8 – 14) μm. The calculation was made or a wavelength of 10 μm [14].

Table 3

Numerical data of an IR achromatic retarder

Wavelength λ, μm	Refractive index ZnSe, n	Refractive index Au, n	Extinction index Au, κ	Total phase delay δ, degree
8	2.418	4.93	57.6	89.91
10	2.407	7.62	71.5	90.02
12	2.394	10.8	85.2	90.04
14	2.378	14.5	98.6	89.98

The use of a subwavelength wire grating leads to the formation of birefringence, which provides the desired phase difference, as well as dispersion, which helps to design an achromatic phase plate [16]. Effective medium theory simulates the subwavelength grating as a thin film with an effective index determined by the grating materials and the polarization of the incident radiation.

For the production of commercial IR retarders, the Edmund Optics company uses wire gratings operating in the zero order of diffraction [20]. Compared to multi-order phase plates, zero-order plates provide increased transmission and lower sensitivity to temperature changes.

These plates are produced with a λ/4 or λ/2 phase delay over a wide spectral range and are ideal for a variety of IR instruments.

The characteristics of a commercial phase plate are given in Table 4, and its appearance is depicted in Fig. 6b.

Table 4

Characteristics of the Edmund Optics phase plate

Delay	λ/4
Spectral range, μm	(3 – 9)
Frame diameter, mm	25.4
Aperture, mm	10
Thickness, mm	8
Phase plate material	Cadmium thiogalate
Transmittance	0.5

Recommendations for choosing IR polarizer and phase plate

The above studies show the following:

1. For practical use in PT, wire polarizers (WP) are primarily suitable, which have a number of advantages compared to polarizers based on Brewster`s reflection law, namely:

- have relatively high transmittance;
- form radiation with a high degree of polarization;
- have small dimensions and weight. The main disadvantages of WP are: considerable chromatic distortion (dispersion); technological complexity of their production, which determines their high cost.

2. Phase plate (retarder) can be made with the use of:

- birefringence, which is problematic for the spectral region (8 – 14) μm;
- the law of total internal reflection and reflection of radiation at the air-metal interface. However, such a phase plate has large overall dimensions, which complicates its use in small-size thermal imagers;
- diffraction of radiation on a wire diffraction grating. Such a diffraction grating of a certain structure provides a phase delay of 90º in a wide spectral range.

3. A promising direction for the creation of PT is the use of MBM, each pixel of which has a wire micro polarizer with a certain orientation of the polarization plane. Four adjacent pixels form a superpixel, which makes it possible to simultaneously determine four parameters of the Stokes vector without using an optical-mechanical scanning system. The use of MBM with micro polarizers has significant advantages:

* absence of an optical-mechanical system for scanning (rotating) a polarizer or a phase plate;
- the ability to simultaneously measure all Stokes parameters in one image frame;
- a simplified electronic system for processing signals from MRR pixels to determine the parameters of the Stokes vector;
- small dimensions of the optical system and low power consumption of the PT.

The main disadvantages of PTs that use MBMs with micro polarizers are:

- technological difficulties of manufacturing such MBMs with micro polarizers and the high cost of such matrices;
- additional image distortions caused by the diffraction of radiation after passing through the diffraction grating and its propagation inside the substrate to the next element.

Conclusions

A deep understanding of the physical processes of infrared radiation transformation in a polarimetric thermal imager allows one to study the optical system of the thermal imager and justify the choice of a polarizer and a phase plate to effectively obtain the polarization characteristics of radiation from the observation object and the background.

It is expedient to use commercial wire polarizers as an infrared polarizer. To conduct laboratory studies of the polarization properties of radiation, Brewster`s law of reflection from a germanium plate can be used.

In polarimetric thermal imagers operating in a wide spectral range, it is necessary to use commercial retarders based on a wire diffraction grating as an infrared achromatic phase plate. An infrared prismatic retarder can be used for experimental research.

A promising direction in the creation of a modern polarimetric thermal imager is the use of a micro bolometric matrix, each pixel of which has a wire micro polarizer with a certain orientation of the polarization plane. Four adjacent pixels form a superpixel, which makes it possible to simultaneously determine the four parameters of the Stokes vector without using an optical-mechanical scanning system.

Further research should be directed to the development of a mathematical model of PT, which would make it possible to calculate the temperature and spatial separation, to substantiate the methods of their increase, which is important for environmental monitoring, monitoring of natural resources, thermal observation systems of wide application [21, 22].

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ПІДВИЩЕННЯ ЧУТЛИВОСТІ КОМП'ЮТЕРНО-ІНТЕГРОВАНИХ ТЕПЛОВІЗОРІВ В ДОСЛІДЖЕННЯХ ТЕРМОЕЛЕКТРИЧНИХ ЯВИЩ ТА ДИСТАНЦІЙНИХ СПОСТЕРЕЖЕННЯХ

Робота присвячена обґрунтуванню вибору поляризаційних оптичних елементів для тепловізійних дистанційних спостережень та вимірювань. Виконано порівняльний аналіз основних методів отримання поляризаційних зображень: з допомогою обертання поляризатора, обертання фазової пластинки і з використанням комбінованих матричних приймачів інфрачервоного випромінювання з мікро поляризаторами. Для аналізу використано спрощені математичні моделі перетворення сигналів в основних оптичних елементах поляриметричних тепловізорів – лінійних поляризаторах та фазових (чверть-хвильових) пластинках. Показана перевага дротяних поляризаторів порівняно з поляризаторами на основі відбивання. Також обґрунтовано, що серед різних фізичних ефектів, що викликають фазові затримки - подвійне променезаломлення, повне внутрішнє відбивання і відбивання випромінювання на межі повітря-метал, дифракція на дротяній дифракційній ґратці – найбільш прийнятним є використання останнього ефекту. Бібл. 21, рис. 7.

Ключові слова: поляриметричні тепловізори, вектори Стокса, поляризатор, чверть-хвильова пластинка

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