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POLARIZATION MODEL OF THERMAL CONTRAST OBSERVATION OBJECTS

This paper proposes a polarization model of a thermal imager for the purpose of its application in the study of thermoelectric phenomena and devices, which allows increasing the efficiency of such devices. To study and design such thermal imagers, a physico-mathematical model of polarization of radiation from observation objects is considered, which takes into account the polarization properties of the intrinsic thermal radiation and the reflected external radiation. The developed model was used to determine the polarization properties of the radiation from a flat iron plate. The analysis of the obtained results shows that for thermal radiation at observation angles ψ <40 ° the components of the radiation coefficient are almost identical $\varepsilon_{\|}\approx\varepsilon_{\perp}\approx 0.16$, but $\varepsilon_{\|} < \varepsilon_{\perp}$. As the observation angle ψ <40 ° increases, the perpendicular polarization component $\varepsilon_{\perp}$ decreases monotonically to zero, and the parallel component $\varepsilon_{\|}$ increases and reaches its maximum value at an angle ψ = 84 °, and then decreases to zero. The degree of polarization of radiation increases with increasing angle ψ and at an angle ψ = 84 ° is equal to 0.96. The obtained research results are worthwhile to be used in the development of a model of thermoelectrics which can be employed in the design of a polarization thermal imager. Bibl. 8, Tabl. 1, Fig. 7.

Key words: polarization thermal imager, temperature distribution, partially polarized radiation, degree of polarization.

Introduction

Thermal imagers are widely used in various fields of science, technology and military art, as well as in the study of thermoelectric phenomena and devices [1–3]. Thermal imagers observe the contrast of brightness (intensity) of the object of observation, located in the background, and make it possible to measure the temperature distribution on the surface of the thermoelectric sensor in static or dynamic modes. To increase the temperature and spatial separation, promising thermal imagers use the polarization characteristics of the radiation from the observation object and the background.

Infrared (IR) radiation generated by the observation objects contains information about the objects and their location. The perception of this information by means of a thermal imager and its corresponding processing enable one to define and control many parameters which are difficult or impossible to measure directly.

The object of research in this paper is the polarization characteristics of thermal radiation from the objects and the possibility of their use to build a polarization thermal imager.

Modeling of thermal radiation polarization

At present, modeling methods are widespread in almost all fields of science and technology. This is due to the fact that modeling simplifies and speeds up the search for the right solutions, is cost-effective and easy to use. In the field of determining the affiliation of an object to a narrow class (for example, a car or a tank), we can distinguish two directions in modeling methods:

1. Mathematical – used to process finished images using a complex mathematical apparatus (e.g, spatial spectral analysis) in order to improve image quality and further processing to solve a specific problem.

2. Physical and mathematical – used to process images directly in the process of obtaining them, the result of which is an algorithm for solving the problem (detection, recognition, classification, identification).

In the general case, polarization of the intrinsic radiation of materials arises due to the phenomena of reflection and refraction at the "medium - air" interface, which are described by the theory of reflection for metals and dielectrics [4]. In this case, the degree of polarization of the intrinsic surface radiation increases with increasing the angle between the direction of radiation and the normal to the radiation surface.

Objects with temperatures above the absolute zero Kelvin emit light energy by changing the energy state of electronic, oscillating and rotational transitions of atoms and molecules. The thermal radiation of objects is based on Planck's formula, which determines the spectral luminosity of the surface of nonblack body [5, 6]

$$M_{bb}(\lambda, T) = \frac{c_1}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T}\right) - 1\right]}, \quad \frac{\text{Вт}}{\text{см}^2 \cdot \text{мкм}} \tag{1}$$

where c_1 = 37415 W·cm^{-2}·μm^4, c_2 = 14388 μm·K are constant coefficients; λ is wavelength, μm.

The spectral luminosity of the surface of nonblack body is determined as

$$M(\lambda, T) = \varepsilon(\lambda, T) M_{bb}(\lambda, T), \tag{2}$$

where $\varepsilon(\lambda, T)$ is the spectral coefficient of radiation the value of which is less than unity.

If the surface of the object radiates according to Lambert's law, the spectral energy brightness is determined by the formula

$$L(\lambda, T) = \frac{1}{\pi} \varepsilon(\lambda, T) M_{bb}(\lambda, T) \cos\psi, \tag{3}$$

where $\psi = \theta_v = \theta_t$ is the observation angle of the object surface element (Fig. 1).

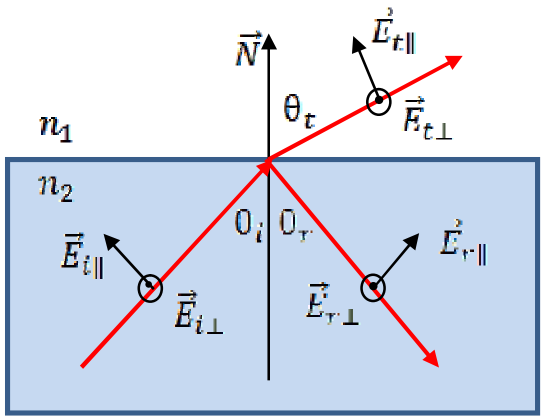


Fig. 1. Schematic for explaining the polarization of the intrinsic thermal radiation of the object: n_1 and n_2 are refractive indices of air and metal, respectively; $\vec{N}$ is normal to the element surface; θ_i, θ_r, and θ_t are the angles of incidence, reflection and refraction (observation angle θ_v), respectively.

According to formula (3), the brightness of the intrinsic radiation of the observation object is formed by two processes:

1. Direct radiation by the bulk of the object, which is described by the Planck function, and depends on the object temperature.

2. The contribution of the object surface, which is determined by the radiation coefficient of the surface and the state of its roughness. The radiation coefficient $\varepsilon(\lambda, T)$ depends on the complex refractive index $n_c = n+j\kappa$ of the medium.

Under the condition of thermodynamic stability for opaque media the absorption coefficient $\alpha(\lambda, T)$ is equal to the radiation coefficient $\varepsilon(\lambda, T)$ [7,8], and the spectral energy coefficients of reflection $R(\lambda, T)$ and radiation $\varepsilon(\lambda, T)$ are interrelated by the ratio

$$\varepsilon(\lambda, T) = 1 - R(\lambda, T)\,. \tag{4}$$

The degree of polarization of the intrinsic radiation is determined by the difference between the radiation coefficients of the object surface $\varepsilon_\|$ and $\varepsilon_\perp$ for the components of this radiation, polarized in the plane of refraction and perpendicular plane, respectively. The magnitude of the degree of polarization of the object intrinsic radiation is determined by the formula

$$P(\psi)=\frac{L_\|(\lambda,T;x,y)-L_\perp(\lambda,T;x,y)}{L_\|(\lambda,T;x,y)+L_\perp(\lambda,T;x,y)}=\frac{\varepsilon_\|-\varepsilon_\perp}{\varepsilon_\|+\varepsilon_\perp}\,. \tag{5}$$

The values of $\varepsilon_\|$ and $\varepsilon_\perp$ for opaque media are determined by the Fresnel formulae [6,9], which characterize the dependence of the polarization components of the radiation coefficient on the real and imaginary part of the complex refractive index $n_c = n+j\kappa$:

$$\varepsilon_\| = \frac{4n\cos\psi}{(n\cos\psi+1)^2+\kappa^2\cos^2\psi}; \tag{6}$$

$$\varepsilon_{\perp} = \frac{4n\cos\psi}{(n\cos\psi)^2 + \kappa^2}. \tag{7}$$

The total radiation coefficient is the average value of the parallel and perpendicular components:

$$\varepsilon(\psi) = \frac{\varepsilon_{\|} + \varepsilon_{\perp}}{2}. \tag{8}$$

The degree of polarization of the intrinsic radiation from the object surface is obtained by substituting (6) and (7) to the formula (5):

$$P(\psi) = DOP(\psi) = \frac{(n^2 + \kappa^2 - 1)\sin\psi}{(n^2 + \kappa^2 + 1)(1 + \cos^2\psi) + 4n\cos\psi}. \tag{9}$$

The degree of polarization of the intrinsic radiation of materials is determined by the state of the surface, as well as the real and imaginary components of the complex refractive index. For example, for glass ($1 < n < 2$, $\kappa << 1$) the radiation is less polarized than for metals $\left(\sqrt{n^2 + \kappa^2} > 3.3\right)$

Along with the intrinsic radiation, external IR radiation falls on the object surface, which is reflected and refracted. Let us consider the features of the reflected radiation, which is perceived by the thermal imager. Since partial polarization of light occurs during reflection and refraction, it is rather difficult to solve the problem posed directly for natural light. To simplify the solution of this problem, consider a model of natural light, in which its vector $\vec{E}_n$ is represented as the sum of two waves which are linearly polarized in two mutually perpendicular planes, have the same intensity and propagate in the direction of natural light (Fig. 2). Mathematically, this can be represented in the form of relations

$$\vec{E}_n = \vec{E}_{\|} + \vec{E}_{\perp};\ I_n = I_{\|} + I_{\perp};\ I_{\|} = I_{\perp} = 0.5 I_n, \tag{10}$$

where $\vec{E}_{\|} = \vec{E}_p$ is vector of a linearly polarized wave, the plane of polarization of which is parallel to the plane of incidence of the beam; $\vec{E}_{\perp} = \vec{E}_s$ is vector of a linearly polarized wave, the plane of polarization of which is perpendicular to the plane of incidence of the beam; I_n, $I_{\|}$, $I_{\perp}$ – are intensities of light waves $\vec{E}_n$, $\vec{E}_{\|}$, $\vec{E}_{\perp}$, respectively.

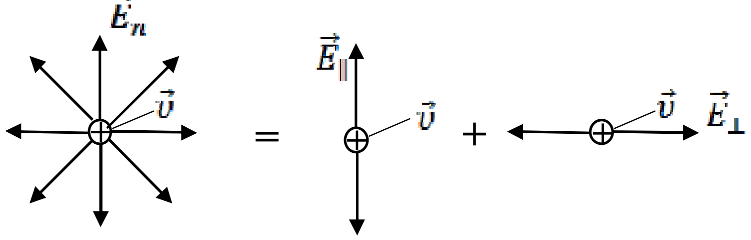


Fig. 2. Model of natural light

Let the natural radiation fall on the "air - metal" interface at an angle θ_i , which is reflected and refracted into the metal (Fig. 3). Let us determine the parameters of the reflected radiation using the model of natural light in the form of two linearly polarized in mutually perpendicular planes components $E_{\|} \perp E_{\perp}$.

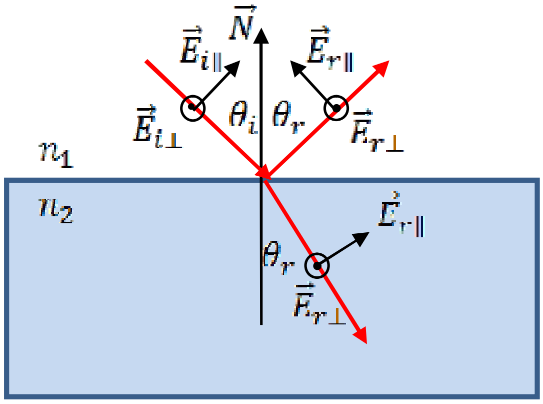


Fig. 3. Schematic for explaining the polarization of reflected radiation

The energy reflection coefficients for the parallel $R_{\|}$ and perpendicular $R_{\perp}$ components are determined by the Fresnel formulae [4]

$$R_{\|} = \left|\frac{E_{R0\|}}{E_{n0\|}}\right|^2 = \left|\frac{n_2\cos\theta_i - n_1\cos\theta_t}{n_2\cos\theta_i + n_1\cos\theta_t}\right|^2 , \tag{11}$$

$$R_{\perp} = \left|\frac{E_{R0\perp}}{E_{n0\perp}}\right|^2 = \left|\frac{n_1\cos\theta_i - n_2\cos\theta_t}{n_1\cos\theta_i + n_2\cos\theta_t}\right|^2 . \tag{12}$$

The angle of incidence θ_i and the angle of refraction θ_i are interrelated by the Snell's law.

$$n_1\sin\theta_i = n_2\sin\theta_t . \tag{13}$$

With a normal incidence of radiation on the surface of metal when θ_i=0°, formulae (11) and (12) are given by

$$R_{\|} = R_{\perp} = \frac{(n_2-1)^2+\kappa^2}{(n_2-1)^2+\kappa^2} . \tag{14}$$

Partial energy reflection coefficients can be calculated on the basis of relation (4) as

$$R_{\|} = 1-\varepsilon_{\|} \text{ and } R_{\perp} = 1-\varepsilon_{\perp} . \tag{15}$$

The degree of polarization of the reflected radiation is determined as

$$P(\theta_r) = \frac{R_{\parallel}(\theta_r) - R_{\perp}(\theta_r)}{R_{\parallel}(\theta_r) + R_{\perp}(\theta_r)}. \quad (16)$$

The magnitude of the radiation reflected from the object depends on the intensity of the external radiation, and, as a rule, in most cases it will be less than the intrinsic radiation. In this case, its effect on the polarization model can be neglected. In some cases, if there are high-temperature obstacles near the object, it is necessary to take into account the reflected radiation.

Polarization ellipse

Consider the propagation of a plane electromagnetic wave along the Z axis (Fig. 4). In the general case, the monochromatic wave is described by the equation

$$\vec{E}(\vec{r}, t) = \vec{E}_0(\vec{r})\cos(\vec{k}\vec{r} + \delta), \quad (17)$$

where $\vec{E}_0(\vec{r})$ is constant amplitude at point $P(x, y, z)$; ω and δ are the frequency and the initial phase of the wave, respectively; $\vec{k}$ is a wave vector that is directed along the propagation of the wave; $\vec{r}$ is radius vector that determines the coordinates of point $P(x, y, z)$. In so doing, the scalar product of two vectors $\vec{k}$ and $\vec{r}$ is determined by the equation

$$\vec{k}\vec{r} = \frac{2\pi}{\lambda}\left(x\cos\alpha + y\cos\beta + \mathrm{z}\cos\gamma\right), \quad (18)$$

where λ is the wavelength; $\cos\alpha, \cos\beta, \cos\gamma$ are guiding cosines that determine the direction of wave propagation. In a light wave, the electrical field intensity vector $\vec{E}$ is always perpendicular to the direction of wave propagation, i.e. $\vec{E} \perp \vec{k}$.

Consider the components of the vector $\vec{E}$ in the plane xy (Fig. 4):

$$E_x(x, y, t) = E_{0x}(x, y)\cos(\omega t - \vec{k}\vec{r} + \delta_x), \quad (19)$$

$$E_y(x, y, t) = E_{0y}(x, y)\cos(\omega t - \vec{k}\vec{r} + \delta_y),, \quad (20)$$

$$E_z(x, y, t) = 0. \quad (21)$$

Let us establish the relationship between the components E_x and E_y by excluding the time variable t from equations (19) and (20):

$$\left(\frac{E_x}{E_{0x}}\right)^2 + \left(\frac{E_y}{E_{0y}}\right)^2 - 2\frac{E_x}{E_{0x}}\frac{E_y}{E_{0y}}\cos\delta = \sin^2\delta, \quad (22)$$

where $\delta = \delta_x - \delta_y$.

Equation (22) is called the equation of the polarization ellipse with the angle of polarization (orientation) θ, which is determined by equation (Fig. 5)

$$\mathrm{tg}2\theta = \frac{2E_{0x}E_{0y}}{E_{0x}^2 - E_{0y}^2}\cos\delta. \tag{23}$$

The shape of the ellipse is determined by the ellipticity angle χ as the ratio of the smaller axis of the ellipse *a* to the larger axis *b*:

$$\mathrm{tg}\chi = \pm\frac{b}{a}. \tag{24}$$

Through the electric field components E_{0x} and E_{0x} the ellipticity angle can be expressed as

$$\sin 2\chi = \frac{2E_{0x}E_{0y}\sin\delta}{E_{0x}^2 + E_{0y}^2}. \tag{25}$$

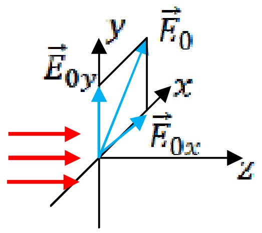


Fig. 4. Vector model of natural light

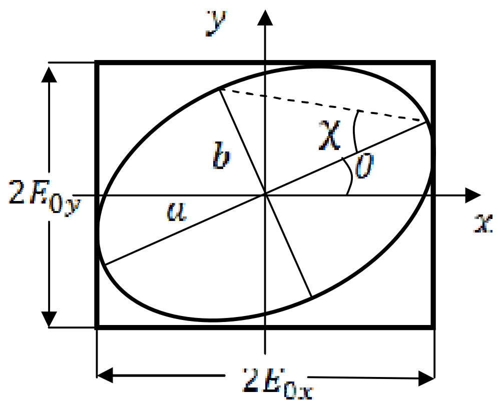


Fig. 5. Polarization ellipse

In the general case, the ellipse (22) is located inside a rectangle of size $2E_{0x} \times 2E_{0y}$ 2 and touches its contour at four points (Fig. 5). If the third term in equation (22) is zero, then the axes of the ellipse are parallel to the *x* and *y* axes.

The shape of the ellipse can be represented as linear and circular polarization. Linear polarization occurs when the phase difference δ is 0º or 180º.

If θ = π, then Eq.(22) is transformed into equation of the line

$$E_y = \pm\frac{E_{0y}}{E_{0x}}E_x. \tag{26}$$

Eq.(26) characterizes a linearly polarized light for which the angle of polarization θ is determined by the formula $\mathrm{tg}\theta = \frac{E_{0y}}{E_{0x}}$. The ellipticity angle χ for the linearly polarized light is equal to zero.

The resulting vector $\vec{E} = \vec{E}_x + \vec{E}_y$ rotates clockwise, when $\sin\delta > 0$ (R-polarization). If $\sin\delta < 0$, then the vector $\vec{E}$ rotates counterclockwise (*L*-polarization). The state of polarization is determined by the ratio of the axes of the ellipse, the angle of orientation 0 and *R*- *L*-polarizations.

If $E_{0x} = E_{0y} = E_{0c}$, and $\delta = 2\pi$, then Eq.(22) is given by

$$E_x^2 + E_y^2 = E_{0c}^2 . \tag{27}$$

Equation (27) characterizes circularly polarized light.

Stokes vector

The polarization state of the reflected or emitted IR light (energy brightness, luminosity, illuminance), which determines the background-target environment (BTE), is calculated using the Stokes parameters. The BTE polarization model is characterized by the image intensity, the degree of polarization and the polarization angle which are determined by the Stokes parameters. Parameters S_0, S_1, S_2, S_3 can be written as one column vector or matrix.

The Stokes vector is a column vector composed of four Stokes parameters that describe the state of polarization of light. The Stokes parameters were introduced in 1852 by Gabriel Stokes as a mathematically convenient alternative for describing the state of partially polarized light in terms of the total intensityS_0, the degree of polarization P, and the parameters azimuth θ and ellipticity χ.

Table 1 shows the Stokes parameters calculated for several states of polarization. In this case, the light intensity was normalized to S_0=1. The results clearly show the meaning of the Stokes parameters: for S_1 the extreme values ±1 are achieved with horizontal and vertical linear polarization; for S_2 – with linear polarization and the orientation of polarization plane at an angle of ±45º; for S_3 – with circular polarization. The parameter S_0=1 determines the intensity of light, and other parameters – the state of polarization of the electromagnetic wave. For the case of unpolarized light, $a = b$, $S_0 = 1$, and $S_1 = 0$. Since δ has arbitrary values, on the average sinδ = cosδ = 0. Also in this case $S_2 = S_1 = 0$.

The Stokes parameters can be determined through the electric field components E_{0x} and E_{0x} and the phase difference δ between two orthogonal electric field strengths $\vec{E}_x \perp \vec{E}_y$:

$$S_0 = I_{0x} + I_{0y}; \tag{28}$$

$$S_1 = I_{0x} - I_{0y}; \tag{29}$$

$$S_2 = 2\sqrt{I_{0x} I_{0y}} \cos\delta; \tag{30}$$

$$S_3 = 2\sqrt{I_{0x} I_{0y}} \sin\delta. \tag{31}$$

The first three Stokes parameters can be determined from the intensity of radiation polarized in a plane oriented at angles of 0º, 90º and 45º relative to the horizon

$$S_0 = I_{0^\circ} + I_{90^\circ}; \tag{28'}$$

$$S_1 = I_{0^\circ} - I_{90^\circ}; \tag{29'}$$

$$S_2 = 2I_{45^\circ} - I_{0^\circ} - I_{90^\circ}. \tag{30'}$$

Table

Stokes vectors for some polarization states

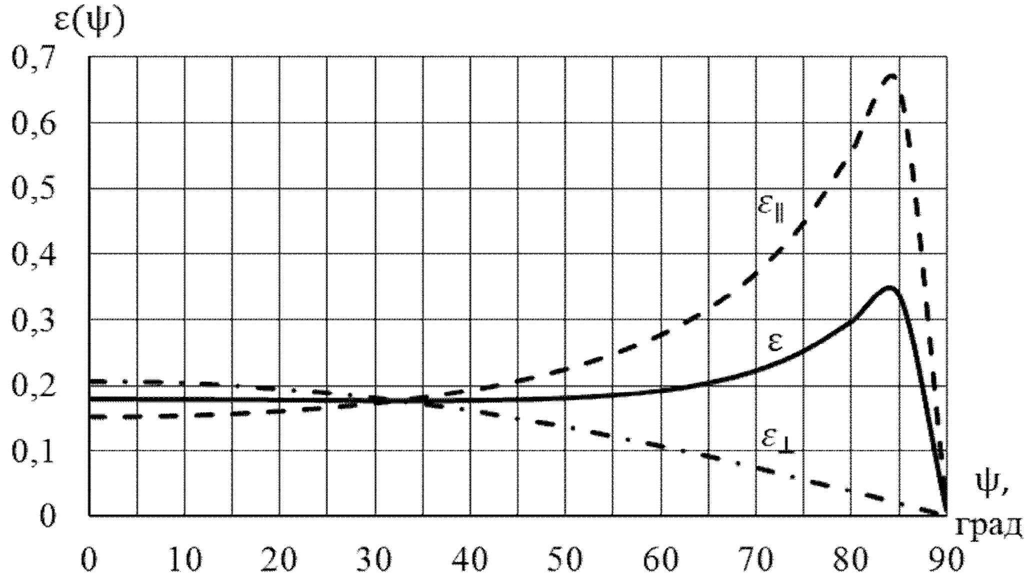
	Linear polarization				Circular polarization	
	horizontal	vertical	+45°	–45°	right	left
θ	0	+90°	+45°	–45°	–	–
$\cos 2\theta$	1	-1	0	0	–	–
$\sin 2\theta$	0	0	1	-1	–	–
χ	0	0	0	0	+45°	–45°
$\cos 2\chi$	1	1	1	1	0	0
$\sin 2\chi$	0	0	0	0	1	–1
S_0 S_1 S_0 S_3	$\begin{bmatrix}1\\1\\0\\0\end{bmatrix}$	$\begin{bmatrix}1\\-1\\0\\0\end{bmatrix}$	$\begin{bmatrix}1\\0\\1\\0\end{bmatrix}$	$\begin{bmatrix}1\\0\\-1\\0\end{bmatrix}$	$\begin{bmatrix}1\\0\\0\\1\end{bmatrix}$	$\begin{bmatrix}1\\0\\0\\-1\end{bmatrix}$

For a *polarimetric thermal imager*, *the Stokes parameters are calculated for each pixel*. The image intensity *I*, the degree of polarization *P* and the polarization angle θ are determined from the Stokes parameters by the formulae:

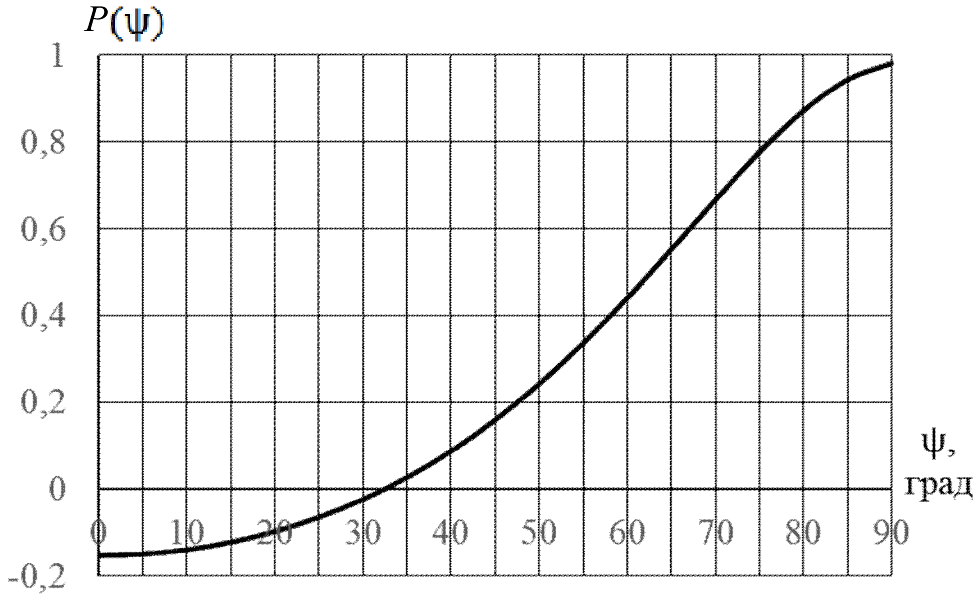
$$I = S_0;\, P = DOP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0};\, \theta = \frac{1}{2}\operatorname{arctg}\left(\frac{S_2}{S_1}\right). \tag{30}$$

Examples of calculation of polarization characteristics of radiation from thermal objects

Fig. 6 shows the dependences of the partial radiation coefficients $\varepsilon_{//}$ and $\varepsilon_{\perp}$ and the degree of polarization of the natural radiation on the observation angle ψ for an iron plate having a complex refractive index $n_c = 5.81 - j30.4$ or a wavelength of 10 μm [6]. For thermal radiation at observation angles ψ <40 °, the components of the radiation coefficient are almost the same $\varepsilon_{\parallel} \approx \varepsilon_{\perp} \approx 0.16$, but $\varepsilon_{\parallel} < \varepsilon_{\perp}$. At an angle ψ = 33° $\varepsilon_{\parallel} = \varepsilon_{\perp} = 0.175$. As the angle ψ < 40° increases, the perpendicular polarization component $\varepsilon_{\perp}$ decreases monotonically to zero, and the parallel component $\varepsilon_{//}$ increases and reaches a maximum value at an angle of 84°, and then decreases to zero. The degree of polarization of radiation increases with increasing angle ψ, but at an angle ψ = 33 ° it is zero, and at an angle ψ = 84 ° - 0.96.



a)



b)

Fig. 6. The dependence of the components of the radiation coefficients ε∥ and ε⊥ (a) and the degree of polarization P (b) of the intrinsic radiation from the iron surface with a complex refractive index $n_c = 5.81 - j30.4$ *the angle of observation* ψ

Fig. 7 shows the dependences of partial energy reflection coefficients $R_{\|}$ and $R_{\perp}$ and the degree of polarization P of reflected radiation at the “air – iron” interface on the incidence angle θ_i. The reflection coefficient with a normal incidence according to formula (14) is about 0.848.

For any angle, the perpendicularly polarized component is larger than the parallel component. The parallel component has a minimum of 0.32, at an angle of incidence of about 84º. For this angle, the degree of polarization of the reflected radiation is equal to 0.49.

For the “air-dielectric” interface the coefficient of reflection for the parallel component is equal to zero with a Brewster angle, and the perpendicular component is equal to unity.

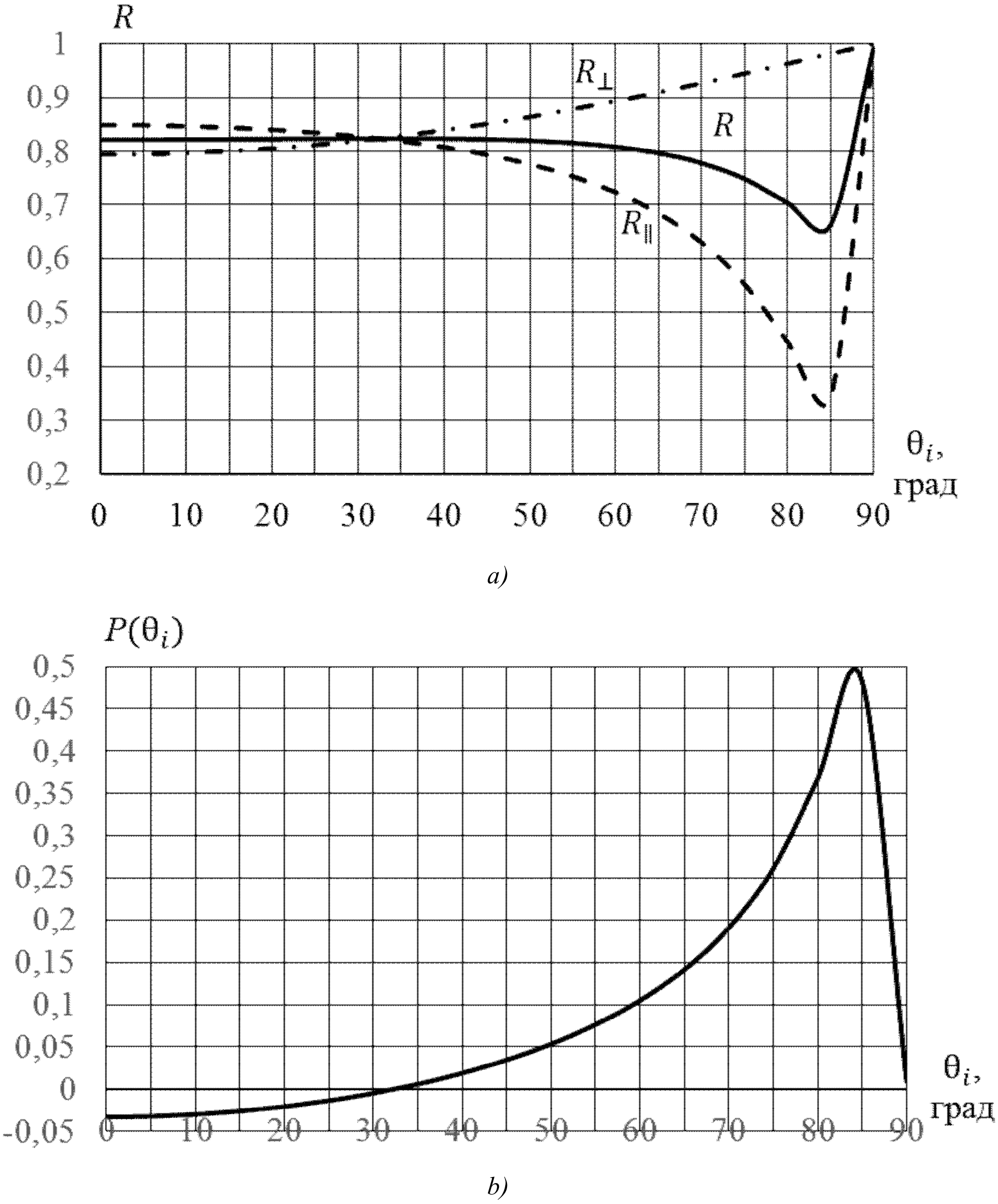


Fig. 7. Dependence of the components of reflection coefficient $R_\parallel$ and $R_\perp$ at the "air-iron" interface and the degree of polarization P of the reflected radiation on the incidence angle θ_i

Conclusions

The use of thermal imagers for the study of thermoelectric phenomena and devices can increase the efficiency of such devices. Using the polarization properties of the infrared radiation to visualize thermal contrast objects enables one to create a new class of high-precision optoelectronic devices, i.e. polarization thermal imagers. To study and design such thermal imagers, a physico-mathematical model of polarization of radiation from observation objects is considered, which takes into account the polarization properties of the intrinsic thermal radiation and the reflected external radiation. As a result of research of this model it is established that

1. The intrinsic radiation is partially polarized due to the difference in the radiation coefficients of the object surface for two linearly polarized waves in mutually perpendicular planes. The study of the components of the radiation coefficients showed that the component for the wave that is polarized in the plane of incidence is greater than the component that is polarized in the perpendicular plane.

2. The reflected external radiation is also partially polarized due to the difference in the reflection coefficients of the object surface for two linearly polarized waves in mutually perpendicular planes. Moreover, the component that is polarized in the plane of incidence is always less than the component that is polarized in the perpendicular plane.

3. To simulate the polarization state of the radiation from the observation object, it is advisable to choose the image intensity, the degree of polarization and the polarization angle determined by the Stokes parameters.

4. The developed model was used to study the polarization properties of the radiation from a flat iron plate, which had a complex refractive index. Analysis of the results shows that

4.1. For thermal radiation at observation angles ψ <40°, the components of the radiation coefficient are almost the same $\varepsilon_{\|} \approx \varepsilon_{\perp} \approx 0.16$, but $\varepsilon_{\|} < \varepsilon_{\perp}$. As the observation angle ψ <40 ° increases, the perpendicular polarization component $\varepsilon_{\perp}$ decreases monotonically to zero, and the parallel component $\varepsilon_{\|}$ increases and reaches its maximum value at an angle of 84º, and then decreases to zero. The degree of polarization of radiation increases with increasing angle ψ and at an angle ψ = 84 ° is equal to 0.96.

4.2. The reflection coefficient at normal incidence is equal to 0.85. For any angle, the perpendicularly polarized component is larger than the parallel component. The parallel component has a minimum of 0.32 at an angle of incidence of 84º. For this angle, the degree of polarization of the reflected radiation is equal to 0.49.

5. It is advisable to use the obtained research results when developing a model of thermoelectrics which is necessary when designing a polarization thermal imager.

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ПОЛЯРИЗАЦІЙНА МОДЕЛЬ ТЕПЛОКОНТРАСТНИХ ОБ'ЄКТІВ СПОСТЕРЕЖЕННЯ

У статті запропоновано поляризаційну модель тепловізора з метою його застосування при дослідженні термоелектричних явищ і пристроїв, що дозволяє підвищити ефективність роботи таких пристроїв. Для дослідження і проектування таких тепловізорів розглянута фізико-математична модель поляризації випромінювання від об'єктів спостереження, яка враховує поляризаційні властивості власного теплового випромінювання і відбитого зовнішнього випромінювання. Розроблена модель була застосована для визначення поляризаційних властивостей випромінювання плоскої залізної пластини. Аналіз отриманих результатів свідчить про те, що для теплового випромінювання при кутах спостереження $\psi < 40°$ *складові коефіцієнта випромінювання є майже однаковими* $\varepsilon_{\parallel} \approx \varepsilon_{\perp} \approx 0.16$, *але* $\varepsilon_{\parallel} < \varepsilon_{\perp}$. *Із збільшенням кута спостереження* $\psi < 40°$ *перпендикулярна поляризаційна компонента* $\varepsilon_{\perp}$ *монотонно зменшується до нуля, а паралельна компонента* $\varepsilon_{\parallel}$ *збільшується і досягає максимального значення при куті* $\psi = 84°$, *а потім зменшується до нуля. Ступінь поляризації випромінювання зростає із збільшенням кута* ψ *і при куті* $\psi = 84°$ *дорівнює 0.96.*
Отримані результати досліджень доцільно використовувати при розробці моделі термоелектриків, яка може використовуватись при проектуванні поляризаційного тепловізора. Бібл. 8, рис. 7, табл. 1.
Ключові слова: поляризаційний тепловізор, температурне розділення, частково поляризоване випромінювання, ступінь поляризації.

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У статті запропоновано поляризаційну модель тепловізора з метою його застосування при дослідженні термоелектричних явищ і пристроїв, що дозволяє підвищити ефективність роботи таких пристроїв. Для дослідження і проектування таких тепловізорів розглянута фізико-математична модель поляризації випромінювання від об'єктів спостереження, яка враховує поляризаційні властивості власного теплового випромінювання і відбитого зовнішнього випромінювання. Розроблена модель була застосована для визначення поляризаційних властивостей випромінювання плоскої залізної пластини. Аналіз отриманих результатів свідчить про те, що для теплового випромінювання при кутах спостереження $\psi < 40°$ складові коефіцієнта випромінювання є майже однаковими $\varepsilon\_\| \approx \varepsilon\_\perp \approx 0.16$, але $\varepsilon\_\| < \varepsilon\_\perp$. Із збільшенням кута спостереження $\psi<40°$ перпендикулярна поляризаційна компонента $\varepsilon\_\perp$ монотонно зменшується до нуля, а паралельна компонента $\varepsilon\_\|$ збільшується і досягає максимального значення при куті $\psi=84°$, а потім зменшується до нуля. Ступінь поляризації випромінювання зростає із збільшенням кута ψ і при куті $\psi = 84°$ дорівнює 0.96. Отримані результати досліджень доцільно використовувати при розробці моделі термоелектриків, яка може використовуватись при проектуванні поляризаційного тепловізора. Бібл. 8, рис. 7, табл. 1.

Ключові слова: поляризаційний тепловізор, температурне розділення, частково поляризоване випромінювання, ступінь поляризації.

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