RADIATION CHARACTERISTICS OF COMPOSITE INORGANIC MATERIALS WITH AN OPTICALLY SMOOTH SURFACE

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A method is suggested for determining the monochromatic reflectance of a multicomponent inorganic material with an optically smooth surface on the basis of its mineralogical and chemical composition.

During its transport, electromagnetic radiation undergoes changes as a result of absorption, scattering, and emission in the medium as well as reflection, refraction, and surface scattering at the boundaries. We distinguish between the radiation characteristics of the attenuating medium and of the boundary surfaces in radiative heat exchange theory. The radiation characteristics of the interface between two media are determined by their refraction indices, the absorption factors, and the magnitude and form of roughness of the boundary surface. If the medium is diathermic and has a refraction index close to unity, while the boundary surface is optically smooth, the radiation characteristics of the surface are determined by

$$a^{(p)}_{\lambda,\Theta} = \varepsilon^{(p)}_{\lambda,\Theta} = 4n_\lambda \cos\Theta / [(n_\lambda^2 + \varkappa_\lambda^2)\cos^2\Theta + 2n_\lambda \cos\Theta + 1],$$
$$a^{(s)}_{\lambda,\Theta} = \varepsilon^{(s)}_{\lambda,\Theta} = 4n_\lambda \cos\Theta / (n_\lambda^2 + \varkappa_\lambda^2 + 2n_\lambda \cos\Theta + \cos^2\Theta), \qquad (1)$$

where $a_{\lambda,\Theta}$ and $\varepsilon_{\lambda,\Theta}$ are the directional monochromatic absorptivity and emittance of the surface respectively, for electromagnetic radiation with the wavelength λ, which is incident (and is correspondingly, emitted) at the angle Θ with respect to the normal, while the strength vector of the electric field of this radiation oscillates in the plane of incidence p and in the direction perpendicular to it s, respectively:

$$a_{\lambda,\Theta} = \varepsilon_{\lambda,\Theta} = 0.5\,(a^{(p)}_{\lambda,\Theta} + a^{(s)}_{\lambda,\Theta}). \qquad (2)$$

Here, $a_{\lambda,\Theta}$ and $\varepsilon_{\lambda,\Theta}$ is the directional monochromatic absorptivity of the surface for nonpolarized radiation, which is equal to its directional spectral emittance,

$$a_{\lambda,n} = \varepsilon_{\lambda,n} = 4n_\lambda (n_\lambda^2 + \varkappa_\lambda^2 + 2n_\lambda + 1)^{-1}. \qquad (3)$$

The quantities $a_{\lambda,n}$ and $\varepsilon_{\lambda,n}$ are the normal monochromatic absorptivity and the normal monochromatic emittance of the surface, respectively,

$$\varepsilon_\lambda = \int\limits_{\Theta=0}^{\pi/2} \varepsilon_{\lambda,\Theta}(\lambda,\ \Theta) \sin 2\Theta d\Theta, \qquad (4)$$

where ε_λ is the hemispheric monochromatic emittance of the surface, the specific expression for which is very cumbersome [1].

It follows from Eqs. (1)-(4) that the radiation characteristics of an optically smooth surface for the assigned temperature and wavelength are unambiguously determined by the values of the refraction index and the absorptivity of the material. They can be found if their respective relationships are known:

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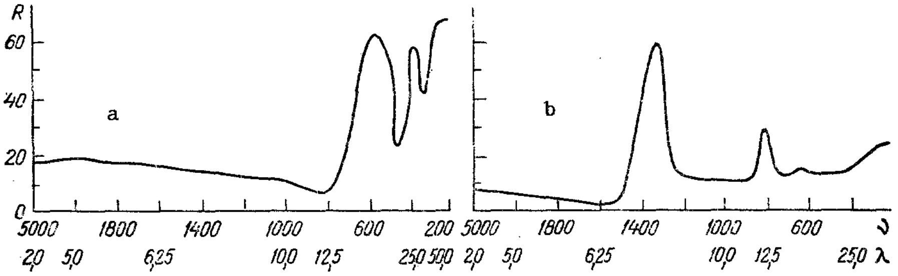

Fig. 1. Monochromatic reflectance of materials. a) TiO_2; b) KNO_3; R, %; ν, cm^{-1}; λ, μm.

$$n_\lambda = n_\lambda(\lambda, T), \ \varkappa_\lambda = \varkappa_\lambda(\lambda, T). \tag{5}$$

The theoretical basis of an accurate method for determining the refraction index and the absorptivity of a material are considered in [2]. It is based on the relationship between n_λ and κ_λ resulting from the dispersion theory. If the expression for the monochromatic reflectance of an optically smooth surface R_λ is known in a wide range of wavelengths (theoretically, for $\lambda = 0 - \infty$), the phase angle for reflected radiation with the wavelength λ_0 can be calculated by using the equation

$$\delta(\lambda_0) = \frac{\lambda_0}{\pi} \int\limits_{\lambda \to 0}^{\infty} \frac{\mathrm{Ln}\, R_\lambda(\lambda)}{\lambda^2 - \lambda_0^2}\, d\lambda, \tag{6}$$

while the values of n_λ and κ_λ for the same wavelength λ_0 are found by using the expressions [2]

$$\begin{gathered} n_\lambda(\lambda_0) = \frac{1 - R_\lambda(\lambda_0)}{1 + R_\lambda(\lambda_0) - 2\sqrt{R_\lambda(\lambda_0)}\cos\delta(\lambda_0)}, \\ \varkappa_\lambda(\lambda_0) = \frac{2\sqrt{R_\lambda(\lambda_0)}\sin\delta(\lambda_0)}{1 + R_\lambda(\lambda_0) - 2\sqrt{R_\lambda(\lambda_0)}\cos\delta(\lambda_0)}. \end{gathered} \tag{7}$$

Thus, in order to determine the radiation characteristics of the optically smooth surface of a material, it is necessary to have data on its monochromatic reflectance.

A method of measuring the monochromatic reflectance of powder materials was proposed in [3], and a data bank was built up. Sharp and narrow bands were recorded in the reflectance spectra (Fig. 1).

Data on the reflectance of powder materials with a simple composition make it possible to make assumptions regarding prediction of the reflectance of optically smooth surface of composite powder materials.

We performed investigations in order to check this assumption. Well-known chemically pure powder materials were mixed together in the assigned proportions to produce a composite powder mixture and were then pressed. The monochromatic reflectance of such a pressed specimen was then measured. In performing the experiments, we used powders which did not react chemically with each other. The fine grain composition ensured uniform distribution during the intermixing of particles of different powders, whereby a specular surface was obtained on the specimen during the pressing process.

It was found during the experiments that the monochromatic reflectance of a material increased with an increase in the amount of one of the powder materials in the mixture. A pure powder material alone displayed the maximum value of reflectance. In this, the selective reflectance bands did not vary with respect to wavelengths, regardless of the number of types of powder materials in the mixture.

The reflectance is a property of the surface. The investigation results have shown that the monochromatic reflectance of a composite inorganic material is determined by fractions of the surface occupied by the components.

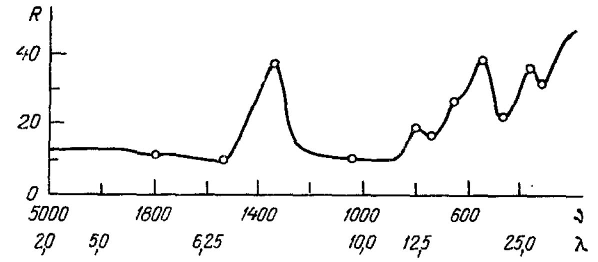

Fig. 2. Monochromatic reflectance of a composite powder material consisting of 50% TiO_2 and 50% KNO_3; the curve pertains to the experimental results, while the points represent the calculation data.

Assuming that the surface fractions are proportional to the volume fractions in a 2/3 powder ratio [4] and that the molecular volumes of the components (equal to the molecular mass μ_i divided by the density ρ_i) are different from each other, we define the fraction of the surface occupied by the i-th component as

$$f_i = \left[\frac{M_i \frac{\mu_i}{\rho_i}}{\sum_{i=1}^{n} M_i \frac{\mu_i}{\rho_i}} \right]^{2/3}. \tag{8}$$

where M_i is the mole fraction of each component.

The monochromatic reflectance of a multicomponent material is determined according to the rule of averaging as the weighted-mean sum of the surface fractions occupied by the components with an allowance for the monochromatic reflectance of the components.

For purposes of practical calculations of the optically smooth surface of a composite inorganic material consisting of simple components, its monochromatic reflectance can be determined by means of the expression (f_i, %).

$$R_\lambda = 0.01 \sum_{i=1}^{n} f_i R_{\lambda,i}, \tag{9}$$

where $R_{\lambda,i}$ is the monochromatic reflectance of the i-th simple material.

As an example, Fig. 2 shows the experimentally measured reflectance of a composite powder material consisting of 50% TiO_2 and 50% KNO_3. It it evident that the experimental and the calculation results are in agreement.

Thus, it is possible to predict the reflectance of the optically smooth surface of a composite inorganic material with respect to its mineralogical and chemical composition.

Modern methods of x-ray structural and chemical analysis make it possible to determine quantitatively the mineralogical and chemical composition of any composite material. Consequently, if we have quantitative data on the mineralogical and chemical composition of composite inorganic materials and a data bank on the reflectance of the simple materials constituting the composite material in question, we can predict without much trouble its monochromatic reflectance and then its radiation characteristics by means of Eqs. (6) and (7).

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