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RADIATIVE PROPERTIES OF LIGHT-TRANSPARENT METALLIZED COATINGS

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Experimental data are presented for the transparency τ in the visible spectral region and the emittance ε at room temperature for composites of organic glass and metal, a calculational model is proposed, and the effect of the constitution of the composite on the radiative properties of the specimens considered is analyzed.

Metallized coatings on organic films and glasses based on metals that reflect infrared electromagnetic radiation well (aluminum, copper, platinum, gold, and silver) find wide use in various areas of economic activity. Some of these composites possess good transparency in the visible spectral region and practically do not distort the color spectrum in visual perception of objects viewed through them. On the other hand, they have low emittance in the infrared region of the spectrum of electromagnetic radiation and fairly good electrical conductivity. These properties of theirs provide the possibility of creating visually transparent radiative heat insulation that has passive (a low integral emittance) and active (the possibility of heating a metal film by an electric current) properties of protecting various objects against radiation losses. Radiative heat insulation is indispensable when visual observation of the object is needed or heat losses by radiation cannot be compensated for by other methods (infant incubators in intensive therapy, aerospace suits, etc.). Investigations of aluminum and silver coatings optical and radiative deposited by metal vaporization on organic glass in a vacuum ($p = 7\cdot10^{-3}$ N/m^2) have furnished an explanation of the anomalous radiative properties of a composite based on Ag and SiO. From the authors' viewpoint, such behavior is linked to formation of a pseudoporous silver layer of reticular structure functioning similarly to a screen that transmits visible radiation λ = (0.4–0.7) μm and reflects infrared radiation λ = (5–60) μm.

Calculational Model. As follows from the foregoing, the basic parameters of optically transparent radiative heat insulation are the coefficient of transmission of visible radiation τ and the integral emittance ε. The transmission coefficient for the isothermal composite "substrate + layer of vaporized-on material" can be written in the form [1]

$$\tau = \tau_s \, \tau_m \, , \tag{1}$$

where τ_s is the coefficient of radiation transmission by the substrate and $\tau_m \approx \exp(-\chi_1\delta)$ is the coefficient of radiation transmission by the metal film.

The integral emittance of the composite is defined similarly:

$$\varepsilon \approx \varepsilon_1 + (\varepsilon_s - \varepsilon_1) \exp(-\chi_2\delta) \, , \tag{2}$$

where ε_s is the integral emittance of the substrate.

From Eqs. (1) and (2) it is easy to obtain the interrelation between the coefficient of transmission of visible radiation and the integral emittance:

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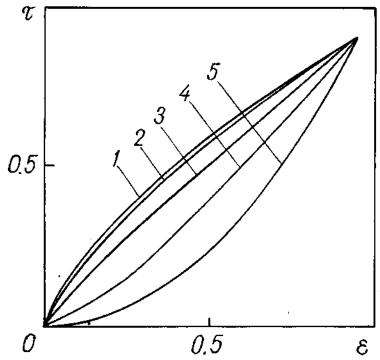


Fig. 1. Transmission coefficient as a function of the emittance for various materials: 1) gold (χ_1/χ_2 = 0.66); 2) silver (0.7); 3) copper (0.84); 4) aluminum (1.2); 5) platinum (2.0).

$$\tau = \tau_s \left(\frac{\varepsilon - \varepsilon_1}{\varepsilon_s - \varepsilon_1} \right)^{\chi_1/\chi_2} . \tag{3}$$

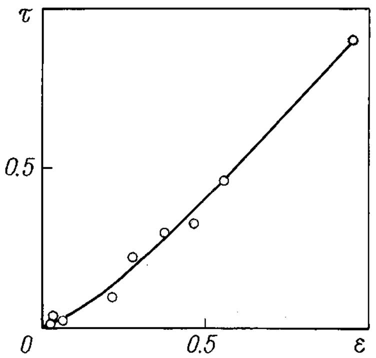
As follows from expression (3), for the same values of ε the transparency is larger the smaller the expression χ_1/χ_2. Figure 1 presents τ as a function of ε calculated from Eq. (3) for various metallized coatings that reflect the infrared radiation well. The values of χ_1 and χ_2 are borrowed from [2].

Measurement of the Transmission Coefficient. The transmission coefficient, equal to the ratio of the radiation transmitted by the material to the incident radiation flux, was measured on standard equipment. A Peleng 500 A projector was used as the light source, and an IMO-4S Laser Radiation Power Meter was used as the meter of the luminous flux. The intensities of the luminous flux were determined by the relative method. Measurements were performed with the considered specimen placed in the experimental complex and in its absence. To preclude the influence of scattered radiation on the measurement results, the light source and the power meter were located a distance of 1 m from the specimen.

Measurement of the Emittance. The emittance of the specimens considered was measured by a radiative method that consists in comparison of measurements of the radiation flux emitted by the considered specimens and ideal blackbodies at the same temperature. As the radiation detector, a specially fabricated radiative microcalorimeter was used that consisted of a massive copper thermostat and a thin blackened copper plate (δ = 0.1 mm, d = 10 mm), which received the incident radiation. Between the thermostat and the receiving plate, a copper-constantan hyperthermocouple was placed that measured the temperature variation of the receiving plate relative to the thermostat. The influence of convection on the receiving plate was precluded with the aid of a thermostated irregular lightguide. As the model of the ideal blackbody, a cylindrical isothermal model of a blackbody with an effective emittance ε = 0.997 was used. Measurements were performed in air. The specimen considered was placed in a heated cell (the specimen overheating relative to the ambient temperature was (1–2)^{o}C). Then, the radiation flux from the model of the blackbody heated to the same temperature as that of the specimen was measured. Measurements were performed for the coefficient of light transmission and the emittance of organic glass produced by various domestic and foreign manufacturers. The glass thickness ranged from 4 to 10 mm. For these thicknesses, the transparency is specified mainly by the state of the material surface and is $\tau \approx 0.9$. The integral emittance of these specimens is also independent of the thickness and is ε = 0.96.

Measurement of the Thickness of the Vaporized-on Metal Film. The effective thickness of the metallized coating δ_{eff} was determined by measuring the electrical resistance between opposite sides of a square of this coating. The resistance is independent of the square size and is determined by just the thickness of the vaporized-on film:

$$R = \rho/\delta_{eff} . \tag{4}$$



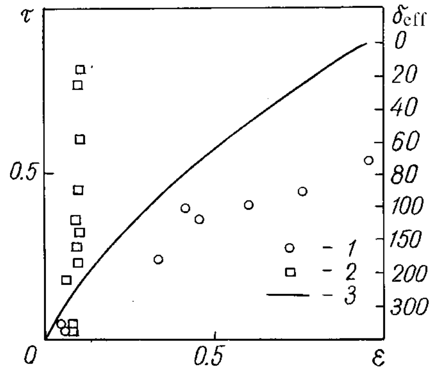


Fig. 2. Transmittance as a function of the emittance (material "organic glass + Al"). Points denote experimental data; curve, results calculated from Eq. (3).

Fig. 3. Transmittance as a function of the emittance: 1) material "organic glass + Ag"; 2) material "organic glass + Ag + SiO"; 3) results calculated from Eq. (3).

Comparison of Calculation Results and Experimental Data. Substantiation of the Model of a Pseudoporous Layer. Figures 2 and 3 present measurement results for the integral emittance and the coefficient of transmission of visible radiation for aluminum and silver films of various thicknesses. For silver the measurements were performed for two types of coatings: pure metal and metal covered with a thin protective SiO film (δ_{SiO} = (0.1–0.2) μm). The specimens considered, made of polymethyl methacrylate, were in the shape of a square of side l = 30 mm and thickness 8 mm. Al, Ag, and Ag + SiO metal coatings of various thicknesses were applied to these specimens. The purity of the vaporized-on coatings was 99.9%.

The same figures present calculation results determined from Eq. (3) for the transmission coefficient as a function of the integral emittance. As is seen from the figures, for aluminum the calculation results are in good agreement with the experimental data.

For the silver coatings, the situation is opposite. For thick films ($\delta \geq 200$ Å), the agreement between the calculation results and the experimental data is satisfactory for both pure silver and the coatings covered with a protective SiO film.

For the films covered with a protective coating, with decrease in the thickness the integral emittance does not vary and remains $\varepsilon \approx 0.1$, and the transmission coefficient of the composite increases to $\tau = 0.8$. Pure-silver coatings with a thickness $\delta < 150$ Å become nonconducting and have a tinge of blue when viewed in transmitted light. With subsequent decrease in the coating thickness, the transmittance varies insignificantly (from 0.4 to 0.5 with the emittance varying from 0.4 to 0.96).

Study of the structure of a vaporized-on Ag + SiO coating in an electron microscope made it possible to establish that these coatings have pronounced volume-inhomogeneous structure. For thin coatings (the resistance of the square is R = (6–8) Ω), this structure resembles a reticle. Large thick metallic formations of dimensions (200–1500) Å are separated by thin metallic formations of dimensions (500–1500) Å. This inhomogeneity of the silver coatings is evidently linked to the dynamics of formation of clusters in the vacuum deposition and their adsorption on organic glass. Unlike Al atoms, much heavier and less mobile Ag atoms form fairly large clusters while moving from the vaporization site to the vaporized-on specimen. The content of atoms in the clusters is usually several thousand [3]. Since the adhesion of silver to polymethyl methacrylate is poor, the adsorption of clusters occurs on a relatively small number of the most active surface centers. As a result, regions of thick metallic spots are formed. Thin metallic formations appear as a result of adsorption of individual silver atoms. This pseudoporous structure accounts very well for the anomalous properties of silver coatings. It is known [1, 2] that radiation transmitted by small apertures attenuates by an exponential law. Apertures that are smaller than $\lambda_{inc}/6$ (λ_{inc} is the wavelength of the incident radiation) are practically impenetrable to electromagnetic radiation. On the other hand, particles separated by distances $>0.3\lambda_{inc}$ with a ratio of this distance to the characteristic particle dimension greater than >0.4 behave as independent scatterers [1], i.e., radiation is transmitted by such voids practically without losses.

For the pure-silver coatings (thin formations of ~1000 Å and large spots of ~500 Å), only 40% of visible radiation is transmitted, which is in satisfactory agreement with the experimental data (see Fig. 3). For Ag + SiO coatings with this structure, the transmission coefficient approaches 0.9 because of a decrease in the wavelength in the protective SiO coating ($\lambda = \lambda_{inc}/n$, $n = 1.5$ is the refractive index of SiO). Partial losses are mainly linked to absorption of radiation in the thin metallic formations. Infrared radiation $\lambda = (5–60)$ μm is insensitive to the structural features of such a coating and is reflected by the large metallic inclusions (see Fig. 3). As for the behavior of the emittance of Ag coatings, this is evidently linked to the interaction of the silver film with atmospheric hydrogen sulfide. The loss of electrical conductivity of thin Ag films also results from corrosion.

From the foregoing it follows that the proposed model of a pseudoporous coating accounts well for the anomalous properties of coatings based on Ag and SiO and permits the development of optically transparent radiative heat insulation with prescribed properties.

NOTATION

δ, film thickness, Å; d, specimen diameter, mm; l, specimen length, mm; p, pressure, N/m^2; λ, radiation wavelength, μm; τ, coefficient of transmission of visible radiation, %; ε, integral emittance; ε_1, integral emittance of an infinitely thick layer of metal coating; χ_1, cross section of absorption of radiation by the metal averaged over the visible spectral region, m^{-1}; χ_2, integral cross section of absorption of radiation by the metal, m^{-1}; ρ, specific electrical resistance of the vaporized-on metal, $\Omega\cdot$m; R, resistance of a square of the vaporized-on film, Ω. Subscripts: m, metal; s, substrate; eff, effective.

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