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OPTIMIZATION OF TRANSMISSION FACTOR OF HEAT-REFLECTIVE COATING

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The results of computer optimization of visual transmission factor T_v of the heat-reflective coating SnO_2-Ag-SnO_2 и TiO_2-Ag-TiO_2 with protective layers are presented. It is stated that for the condition $T_v \geq 80$ % to be fulfilled the thickness of protective silver layers for SnO_2-Ag-SnO_2 should not exceed 1,5 nm, but for TiO_2-Ag-TiO_2 it is 2 nm. Heat reflective coatings with one protective layer are shown to possess better optical characteristics in comparison with two protective layers.

As a consequence of oil crisis and steady growth of fuel prises an urgent problem has become not only development of energy on the basis of alternative, for example renewable sources of energy, but also introduction of new energy-saving technologies into construction of residential, office and industrial buildings. Application of energy-saving glazing in construction decreases energy consumption for building heating in winter, and for their cooling in summer. The basic element of energy-saving glazing constructions is either heat-absorbing or neutrally-coloured or heat-reflecting glasses [1–4].

Heat-reflecting glass is sheet glass, on which a heat-reflecting coating (HRC) representing a selective dielectric-metal-dielectric coating is applied. Application of three-layer structure of HRC is explained by the fact that for increasing metal adhesion with glass an intermediate layer is used, but for decreasing metal reflection coefficient and its environmental protection a antireflective layer is applied. As a metal layer thin films from Cr, Ni, Ag, Cu, Au, Al are employed, but the main metal of HRC is silver that reflects radiation of infrared spectrum strongly and has a small degree of polarization even at large angles of radiation falling [5, 6].

On the commercial scale application of HRC on flat structural glass is made by magnetron spraying machine. To protect silver layer from the action of oxygen plasma at magnetron application protective (barrier) layers are used [1–4]. As metals, semiconductors, oxides and etc. form continuous films by different thickness, investigating influence of structure, material and thickness of barrier layers on optical characteristics of HRC is of great practical interest.

The purpose of the given work is to study the influence of structure, material and layer thickness on optical characteristics of heat-reflective coating, to determine optimal thickness of protective layers by the computer simulation method. As an object of investigation the SnO_2-Ag-SnO_2 (SAS) and TiO_2-Ag-TiO_2 (TAT) HRC have been chosen.

As a criteria of HRC optimization visual transmission factor T_v, which is defined by the formula, is chosen

$$T_v = \frac{\int_{\lambda_1}^{\lambda_2} E(\lambda)V(\lambda)T(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} E(\lambda)V(\lambda)d\lambda}, \qquad (*)$$

where $V(\lambda)$ is the relative spectrum sensitivity of human eye [7], $T(\lambda)$ is the HRC-glass system transmission factor, λ_1 and λ_2 are the boundaries of visual spectrum region, $E(\lambda)$ is the standard spectrum of direct flux of solar radiation AM1.5 [8]. The spectrum is normalized to the maximum value.

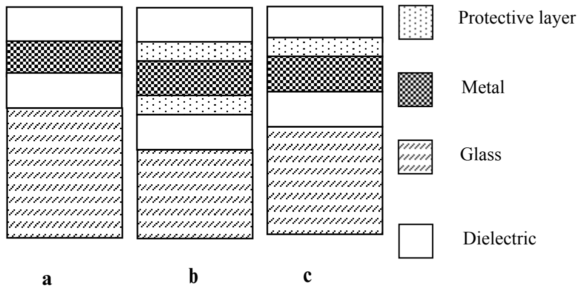

Fig. 1. *HRC structure without protective layer (a), with two protective layers (b), with one protective layer (c). The numbering of layers is from the top down*

By optimization in the given work is meant search for structures, materials and layer thicknesses of HRC, for which T_v have maximum values. Materials, layer thicknesses and structures of HRC realizing the maximum values of T_v, are called optimal below.

Computer methods of optical coating design are based on mathematical methods of multiparametric optimization [9–11]. The results of optimization are known to depend on the choice of initial values of objective variables, therefore, in the present work search for the most value (*) is carried out by the method of layer thickness enumeration. The step of thickness change is chosen not less than the accuracy with which one can apply layers, but the interval of layer thickness change is chosen in such a way that it would include all values taking place in practice

$$d_i \in [0,75 d_{\min}, 1,25 d_{\max}],$$
$$d_{\min} = \min(\gamma_1, \gamma_2),$$
$$d_{\max} = \max(\gamma_1, \gamma_2),$$

where d_i is the thickness of *i-th*layer coating, γ_1=0,25λ_1/n_1, γ_2=0.25λ_2/n_2, n_1, n_2 are the refractive indexes of *i-th*layer for λ_1=0,40 mkm λ_2=0,75 mkm. The thickness of silver layer is 12 nm, corresponding to continuous film, remains constant at simulation. Description of mathematical model of multi-layer thin-film system and recurrence formulas for calculation of refractive, transmittance, absorption indexes is presented in [9]. The glass refractive index is taken to be equal to 1,5. The integral is calculated numerically, optical constants of layer materials are borrowed from [10–14].

Optimization of layer thickness of SAS and TAT is performed without protective layers (fig. 1, *a*). Calculations show (fig. 2) that for optimal thicknesses the transmittance indexes in infrared region of the spectrum are practically the same, but in short-wave region of the spectrum of TAT they have better optical characteristics in comparison with SAS. Visual transmittance coefficient of both coatings is equal to 97,0 %.

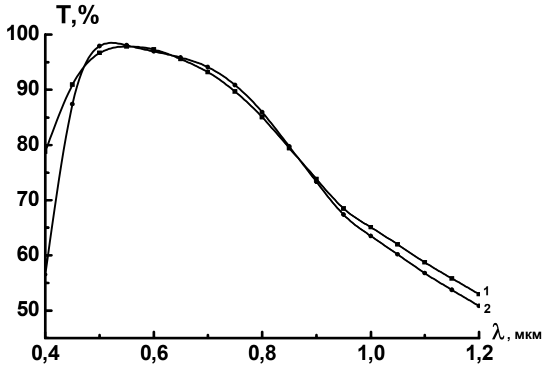

Fig. 2. *Spectrum transmittance indexes: 1) SnO_2(44 нм)-Ag-SnO_2(55 nm) and 2) TiO_2(39 nm)-Ag-TiO_2(47 nm)*

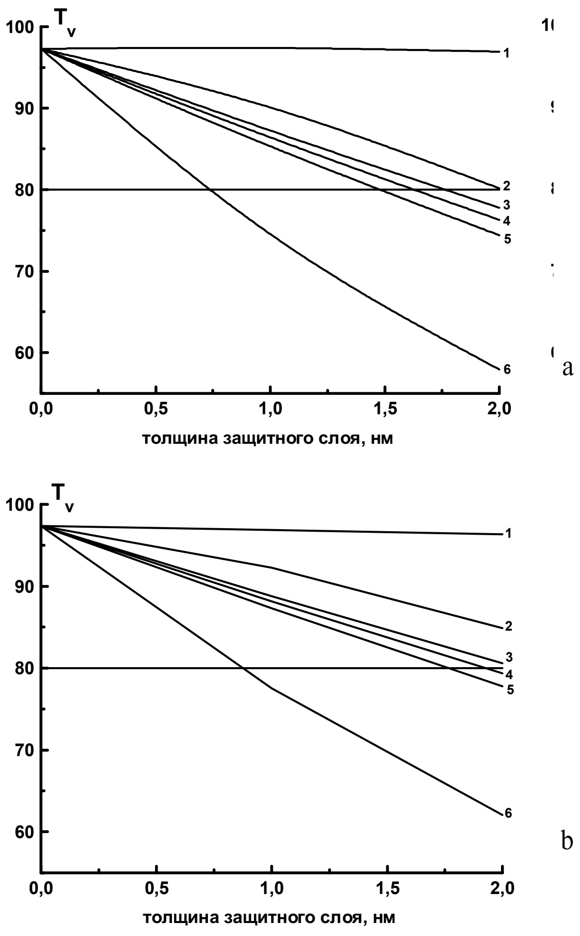

Fig. 3. *Influence of protective layer thickness on visual transmittance index TiO_2-Ag-TiO_2 (a) and SnO_2-Ag-SnO_2 (b). For different materials: 1) Si, 2) Al, 3) Ti, 4) $Ni_{85}Cr_{15}$, 5) Ni, 6) Cr*

In fig. 3 the calculation results of dependence T_v on thickness of protective layer of different materials are presented. Requirements for the material of protective layer are obvious: minimal decrease in T_v, stability to corrosive oxygen medium, capacity for formation of continuous films of small thickness on the layer surfaces. Simulation showed that for HRC with barrier layers (fig. 1, *b*) optimal structure is a symmetrical one, i. e. a structure with equal thickness of protective layers. Limiting thickness and optimal material of protective layer can be determined using the condition $T_v \geq T_{v,\min}$, where $T_{v,\min}$ is the specified minimal value of T_v. For example, if $T_{v,\min}$=80 % (in fig. 3 is the line parallel to abscissa axis), then:

- Maximum thickness of protective layers for SAS is 1,5 nm, for TAT it is 2 nm;
- The use of chromium as a protective layer is of no point;
- The use of Ti as a protective layer instead of $Ni_{85}Cr_{15}$ decrease the duration of spraying operation cycle (one need not season the targets from Ni-Cr alloy in plasma of magnetron charge);
- Barrier layers of 1,5 nm thick and 2 nm from Al, Ti, $Ni_{85}Cr_{15}$, Ni make visual transmittance index of SAS 10 and 20 % less, but TAT make 8,0 and 17,0 % less.

To improve optical characteristics of HRC in [4] one protective layer is suggested to use (fig. 1, *c*). In order to compare optical characteristics of the same materials optimization of visual transmittance index of HRC with one protective layer has been performed. The results of optimization are presented in the table.

Table. *The results of T_v calculation for HRC with one (the value is at the top) and two (the value is at the bottom) protective layers*

Barrier layer	SnO_2-Ag-SnO_2		TiO_2-Ag-TiO_2	
	1 nm	2 nm	1 nm	2 nm
Al	94,1	89,9	94,9	92,1
	90,0	80,1	92,3	84,9
Ti	92,0	86,6	92,7	88,2
	87,2	77,8	88,9	80,6
$Ni_{85}Cr_{15}$	91,5	85,8	92,3	87,5
	86,4	76,3	88,1	79,4
Ni	91,0	84,8	91,6	86,7
	85,4	74,4	87,3	77,8

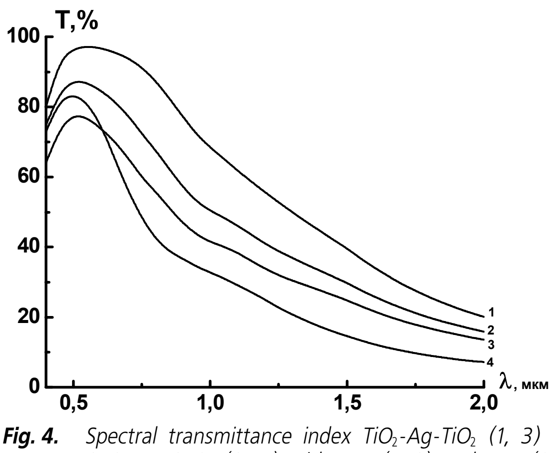

Fig. 4. *Spectral transmittance index TiO_2-Ag-TiO_2 (1, 3) and SnO_2-Ag-SnO_2 (2, 4) with one (1, 2) and two (3, 4) $Ni_{85}Cr_{15}$ protective layers*

Comparison of T_v values and that in fig. 4 indicates the advantage of HRC with one protective layer in comparison with that with two layers. It is evident that application of one protective layer is possible if silver does not diffuse into dielectric and protective layers.

It should be noted that use of SnO_2 in HRC production is conditioned by the fact that its spraying index (cooling rate correspondingly) is several times higher than that of TiO_2 [14]. In our opinion, modification in construction of magnetron spraying devices on the purpose of increasing spraying index of target materials will contribute to introduction of HRC on the basis of TiO_2 into the production [15].

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INCREASING CRACKING RESISTANCE OF HIGH-PRESSURE POLYETHYLENE MODIFIED BY ULTRAFINE POWDERS

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The affect of small additions (≤1 wt. %) of ultrafine fillers AlN и Al_2O_3 on cracking resistance of high-pressure polyethylene has been investigated. The most increase of cracking resistance is obtained for polyethylene samples produced at low cooling rate filled with AlN (0,075 wt %).

Introduction

One of the reasons for rapid destruction of polyethylene products and constructions of high pressure (PEHP) is their cracking under the action of external mechanic stress. At the same time polyethylene is widely used in everyday life, in industry, as well as in high-voltage electrophysical devices operating under the condition of high voltage field, stresses, high temperature, different climatic factors. To increase cracking resistance is possible introducing powder mineral substances, for example, aerosol, chalk, talc into the polymer, but the effect is achieved at additives significant in content [1]. A wide application of the given method is inhibited by the absence of efficient modifiers which would increase cracking resistance sufficiently even in low content and would not impair other polymer characteristics. From the viewpoint of economical and technological utility of new polymer modifiers the problem is to produce composite materials by means of the equipment and methods applied in manufacturing goods at present [2].