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EFFECT OF HEAT LOSSES FROM THE SURFACE OF A TWO-LAYER SPECIMEN ON MEASUREMENT OF THERMOPHYSICAL CHARACTERISTICS BY THE PULSED METHOD

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The errors introduced by heat losses from a plate surface are estimated by comparing the solution of the heat propagation problem in a two-layer system with action of a pulsed heat source on one side in the presence of radiant heat exchange at the outer surfaces of the plate with the solution of the same problem for adiabatic boundary conditions.

The appearance in construction and technology of new synthetic materials with unknown thermophysical properties demands use of highly productive procedures for study of the latter. Among such techniques are pulsed methods, which permit determination of thermal diffusivity and thermal conductivity coefficients as well as specific heat of a film coating deposited on a base with known thermophysical characteristics.

The pulse method for determining thermophysical characteristics of coatings described in [1] assumes thermal insulation of the specimen surface on both sides, which is impossible to accomplish completely, even for measurements in a vacuum.

The present study will establish temperature limits for use of the pulse method for determining thermophysical characteristics of coatings deposited on a base. The theoretical basis of this method is solution of the heat propagation problem in a two-layer plate upon action of a pulsed radiation source on the coating surface (Fig. 1). Using generally accepted assumptions the problem can be described by the following system of equations:

$$\frac{\partial T_1}{\partial \tau} = a_1 \frac{\partial^2 T_1}{\partial x^2}, \quad 0 \leqslant x \leqslant l_1, \tag{1}$$

$$\frac{\partial T_2}{\partial \tau} = a_2 \frac{\partial^2 T_2}{\partial x^2}, \quad -l_2 \leqslant x \leqslant 0, \tag{2}$$

$$\lambda_1 \left(\frac{\partial T_1}{\partial x}\right)_{x=l_1} = Q\delta(\tau) - g_{l_1}, \tag{3}$$

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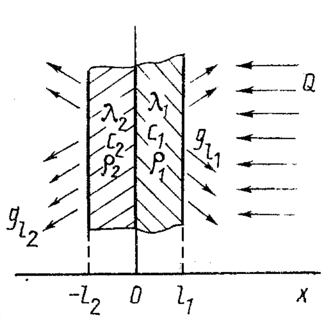

Fig. 1

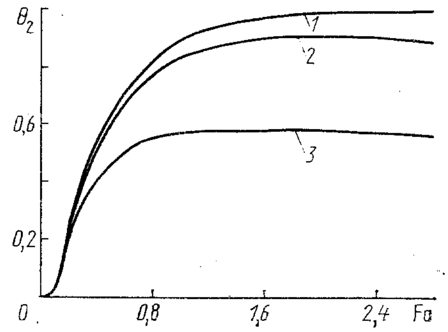

Fig. 2

Fig. 1. Diagram of two-layer specimen.

Fig. 2. Chronological thermograms for back side of two-layer plate: 1) $T_0 = 0$; 2) 1073; 3) 2073 K.

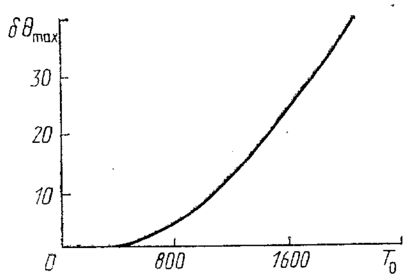

Fig. 3

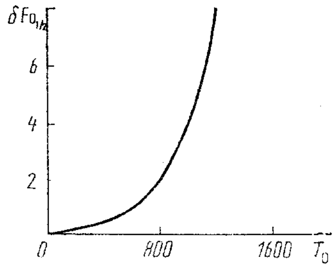

Fig. 4

Fig. 3. Error in determination of θ_{max} in presence of heat exchange between two-layer plate and surrounding medium. $\delta\theta_{max}$, %; T_0 K.

Fig. 4. Parameter $Fo_{1/2}$ vs temperature of thermally insulated specimen. $\delta Fo_{1/2}$, %.

$$\lambda_2 \left(\frac{\partial T_2}{\partial x}\right)_{x=-l_2} = g_{l_2}, \tag{4}$$

$$T_1|_{x=0} = T_2|_{x=0}, \tag{5}$$

$$\lambda_1 \left(\frac{\partial T_1}{\partial x}\right)_{x=0} = \lambda_2 \left(\frac{\partial T_2}{\partial x}\right)_{x=0}. \tag{6}$$

The problem thus formulated can be solved by the Laplace transform method. Boundary conditions (3)-(6) are transformed following the recommendations of [2, 3]. An analytical solution was thus obtained for the nonsteady-state temperature field of the base surface in the form

$$\theta_2(-l_2, \tau) = \frac{T_2(-l_2, \tau)(c_1\rho_1 l_1 + c_2\rho_2 l_2)}{Q} = \frac{4(K_1+1)}{K_1} \sum_{n=1}^{\infty} \frac{-K_{la}\mu_n^3 \exp(-\mu_n^2 \mathrm{Fo})}{\psi(\mu_n)}, \tag{7}$$

where

$$\psi(\mu_n) = \mu_n (1+K)(1+K_{la})(z_1 l_1 z_2 l_2 - \mu_n^2 K_{la}) \cos[\mu_n(1+K_{la})] -$$

$$-\mu_n(1-K)(1-K_{la})(z_1l_1z_2l_2+\mu_n^2K_{la})\cos[\mu_n(1-K_{la})]-$$
$$-(1+K)\{\mu_n^2[(1+K_{la})(z_1l_1K_{la}+z_2l_2)+K_{la}]+z_1z_2l_1l_2\}\times$$
$$\times\sin[\mu_n(1+K_{la})]-(1-K)\{\mu_n^2[(1-K_{la})(z_1l_1K_{la}-z_2l_2)+K_{la}]-$$
$$-z_1z_2l_1l_2\}\sin[\mu_n(1-K_{la})], \quad (8)$$

μ_n are the roots of the characteristic equation

$$\cos[\mu_n(1+K_{la})][(1+K)\mu_n(z_1l_1K_{la}+z_2l_2)]+$$
$$+\cos[\mu_n(1-K_{la})][(1-K)\mu_n(z_1l_1K_{la}+z_2l_2)]+$$
$$+\sin[\mu_n(1+K_{la})][(1+K)(z_1z_2l_1l_2-\mu_n^2K_{la})]-$$
$$-\sin[\mu_n(1-K_{la})][(1-K)(z_1z_2l_1l_2+\mu_n^2K_{la})]=0, \quad (9)$$
$$K=\sqrt{a_1/a_2}(\lambda_2/\lambda_1).$$

When measurements are performed in a vacuum, adiabatic conditions are not satisfied due to heat losses from the specimen by radiation. For corresponding linearization of boundary conditions (3) and (4) the coefficients z_i can be written as

$$z_i=\frac{4\varepsilon_iT_0^3\sigma_0}{\lambda_i}. \quad (10)$$

The error produced by radiation can be estimated by the solution obtained, Eqs. (7)-(10), with the solution for adiabatic boundary conditions of [4].

For this purpose numerical calculations were performed for a specimen with the following characteristics: λ_1 = 0.1 W/(m·K), ε_1 = 0.66, λ_2 = 126 W/(m·K), ε_2 = 0.023, K_{1a} = 0.3076, K_1 = 0.084, $l_1 = 5\cdot10^{-5}$ m; $l_2 = 5\cdot10^{-4}$ m.

Figures 2-4 show the calculation results. The form of the chronological thermograms $\theta_2(-l_2, \tau)$ as functions of temperature are shown in Fig. 2. By using the temperature change of the thermograms as a parameter for thermophysical characteristic calculations one should consider specimen heat exchange with the surrounding medium. Figure 3 shows the dependence of the error in maximum temperature elevation of the base with pulsed heating from the side of the coating upon specimen heating temperature. As is evident from the figure, the divergence between values for thermally insulated and radiating specimens increases with incase in heating temperature, and can reach 41% at T_0 = 2073 K. For a specimen with the thermophysical characteristics indicated above use of temperature change as the informative parameter for calculating characteristics is possible at temperatures below 473 K with an error of not more than 1%.

If the time change of the thermogram is used as the information parameter one usually employs the moment in time $Fo_{\frac{1}{2}}$ at which the surface temperature reaches half the maximum value. The effect of heat liberation on this parameter is shown in Fig. 4, whence it is evident that the time parameters are more stable to action of heat losses on the specimen surfaces and can be used for calculation of coating characteristics is possible even at temperatures up to 673 K with an error of not more than 1.3%.

CONCLUSIONS

1. In determining thermophysical characteristics of coating by the pulsed method it is necessary to consider heat losses from the specimen surface.

2. Use of the time change in the thermogram as the information parameter permits reduction in the error of determining coating thermophysical characteristics due to nonconsideration of specimen heat exchange with the surrounding medium.

NOTATION

Here $\lambda(\tau)$ is the Dirac delta function; Q, heat pulse energy; l, thickness; a and λ, thermal diffusivity and conductivity coefficients; ρ and c, density and specific heat; $K_1 = c_1\rho_1l_1/c_2\rho_2l_2$; $K_{la} = (a_1/a_2)^{1/2}(l_2/l_1)$; $z_i = [\partial g_{\varepsilon i}/\partial T_0](1/\lambda_i)$, i = 1.2; ε, Stefan—Boltzmann constant; T_0, temperature of surrounding medium; Fo = $a\tau/l^2$, Fourier number; subscripts: 1) coating; 2) base.

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OPTIMIZATION OF THE CONSTRUCTION OF THE REACTION CHAMBER ON TEMPERATURE DISTRIBUTION IN A SEMICONDUCTOR PLATE ON HEATING BY INCOHERENT RADIATION

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Irradiation and temperature fields are calculated in a semiconductor plate heated by pulsed incoherent radiation. An optimal arrangement of the sample and irradiation elements is selected.

Increasing application of pulsed thermal processing of semiconductor structures by incoherent radiation in the technology of solid-state electronics calls for constant improvement in the processing equipment. The reliability of operation, the percentage of the output of suitable semiconductor devices, is determined in many respects by the uniformity in the temperature distribution along the plate during thermal operations, in particular, when heated by pulsed incoherent radiation.

The choice of the construction of the reaction chamber, which determines the distribution of temperature fields along the processed plate, is considered in [1, 2]. However, at present there are no models of reaction chambers that incorporate a direct dependence of the temperature distribution on the arrangement of the reactor elements. Available models for calculating temperature fields under condition of a homogeneous irradiation [3, 5] neglect dynamic and nonlinear effects, which cannot affect the temperature distribution.

The purpose of the present paper is to find an optimal arrangement of the plate and radiation elements in order to provide the minimal temperature gradient in the plate.

To solve the formulated problem a mathematical model of the temperature distribution along the radius of the semiconductor plate is developed, which allows for the dynamics of heating and also for nonlinear optical and thermophysical characteristics of the semiconductor sample. In addition, the model allows for the following features: plate dimensions; distances from the plate to the plane of the location of the lamps and to the chamber's walls; one-sided or two-sided heating; sizes, powers, and types of heating lamps; their number and arrangement; and the reflection coefficient of the chamber's walls.

We consider assumptions that can be made when solving the formulated problem. As is shown in [5], when the duration of the processing pulse is of the order of a few seconds, the temperature difference of the face and reverse sides of the plate is equal to tenths of a percent. Therefore, with a sufficient degree of accuracy we can average the temperature along the thickness of the sample and assume that it is constant.

We consider the reaction chamber represented in Fig. 1, in which the semiconductor plate is heated from one side or two sides. In the chamber, the sample is placed vertically in order to decrease the sagging of the large-diameter plate during high-temperature processing.

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