λ, wavelength; a, thermal diffusivity; $\overline{V}_{\infty}$, quasisteady value of the ablation rate; y, distance from the heater surface; Θ^*, dimensionless isotherm temperature $(T^* - T_0)/(T_W - T_0)$; T_a, temperature at the start of surface ablation; q_k, calorimetric heat flux.

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COMPUTATIONAL METHOD OF THERMAL DESIGN OF SOLID STATE LASER QUANTRONS WITH NATURAL COOLING.

2. PARAMETRIC OPTIMIZATION

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Recipes and results of parametric optimization of a single-tube solid-state laser quantron with natural cooling are presented.

We consider parametric optimization method in an example of the determination of geometric dimensions of elements and parameters of their mutual disposition in the base construction of a quantron (Fig. 1) in whch GSGG or YAG crystals are used as active medium. Among the variatable parameters are the inner dimensions of the reflectors D_1 and D_2, the thickness of the leucosaphire tube δ_T, the magnitude of the gap between the active element and the tube δ_g, and the spacing between the axes of the active element and the pumping tube ℓ.

The nature of the influence of the variatable geometric parameters on the magnitude of the relative output energy η is clarified during design by performance of cycles of computations and the combination of their values is determined that will assure the maximal value of η at the end of the laser operation time interval.

Selection of the optimal values of the geometric parameters is executed in several stages. First, the parameters whose influence on the quantity η within the intervals of their variation is unsubstantial are disclosed. It is allowable to determine their values from considerations of simplicity of technical realization. Later quantities are found for

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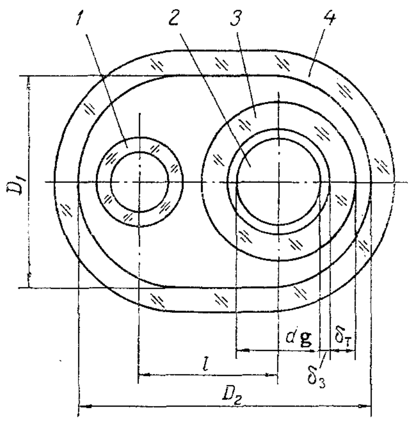

Fig. 1

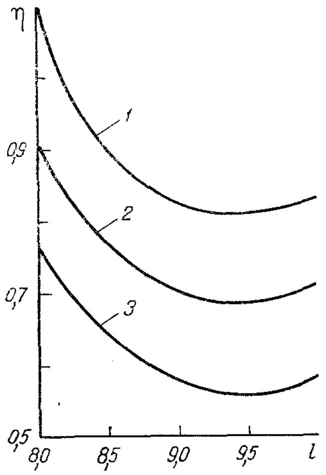

Fig. 2

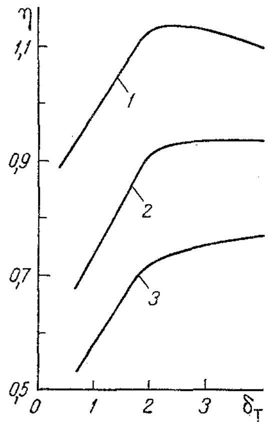

Fig. 3

Fig. 1. Quantron construction: 1) pumping tube; 2) active element; 3) leucosapphire tube; 4) reflector.

Fig. 2. Dependence of the quantity η on the spacing ℓ, mm between the axes at different times τ: 1) $\tau = 0$; 2) 1; 3) 5 sec.

Fig. 3. Dependence of the quantity η on δ_T, mm at different times τ: 1) $\tau = 0$; 2) 1; 3) 5 sec.

which the dependence of η in their intervals of variation is monotonic in nature for any values of the remaining parameters. After clarification of such quantities, only those modifications of the construction can be analyzed later in which they are either minimal or maximal (depending on the nature of the influence on η). In the concluding stage, values of the parameters for which the dependence is extremal in nature are selected.

DESIGN OF A QUANTRON WITH ACTIVE ELEMENT BASED ON GSGG

The laser operates in the active Q-modulation mode with 20 Hz pulse repetition rate in 5 sec. The pumping energy is 15 J. An INP-3/45 type pumping tube is used in the device. The quantron has a hollow quartz reflector with diffuse reflecting coating (Fig. 1). An active element of ϕ 5 × 50 mm dimensions is placed in the leucosapphire tube. The experimental model has the following parameters: D_1 = 10 mm, D_2 = 18 mm, reflector wall thickness 1.75 mm, δ_T = 1.25 mm, δ_g = 0.075 mm, ℓ = 8 mm, resonator output metal reflection coefficient R = 0.29, passive resonator loss coefficient α = 0.15, and number of thresholds in the unperturbed state n_t = 2.

A set of values of the geometric parameters D_1, D_2, δ_T, δ_g, and ℓ that assure the maximal value of the ratio η in a finite time τ = 5 sec was determined during quantron design.

Both a computational and experimental analysis (on the model) showed that complex non-axisymmetric thermal aberrations occur in the active element. An aberration close to a thermal wedge is observed in the plane passing through the pumping lamp and active element axes, and a thermal lens in the plane perpendicular to it. The thermal wedge exerts influence on the output energy for the resonator used in the laser. The magnitude of the thermal wedge deformation was determined from the formula [1]

$$\beta = \frac{L}{D} W\Delta T. \tag{1}$$

In this case it is expedient to represent the function $\alpha_B(T(\bar{x}, \tau))$ in the form of a dependence of the additional passive loss coefficient on the magnitude of the thermal wedge deformation $\alpha_B(\beta)$. In a first approximation the function $\alpha_B(\beta)$ can be approximated by a linear dependence

$$\alpha_B = \xi\beta, \quad \xi = \frac{d\alpha_B}{d\beta}, \tag{2}$$

in which the coefficient ξ is determined by experimental means for this kind of resonator.

It was established as a result of investigations on the model that the drop in output energy is 30% after 5 sec of operation. A computation performed without taking account of the increase in passive losses because of thermal perturbations of the active element yields a smaller magnitude of the drop equal to 10%. A description of the change in output energy, adequate to experiment, with the influence of the thermal wedge deformation on it taken into account is achieved for a coefficient ξ from (2) equal to 0.0305 cm^{-1} per angular min. This value is used in estimating the quantron construction modifications being analyzed.

Computations of the first stage of GSGG quantron optimization showed that the influence of the change in gap thickness δ_g between the active element and the leucosapphire tube on the laser output energy is insignificant. Diminution of δ_g from 0.25 mm to 0.1 mm results in less than a 1% increase in the ratio η.

It was determined in the second stage that the dependence of η in the distance between the axes ℓ is monotonic in nature. The minimal value of this distance ℓ_{min} is determined as the sum of the radii of the pumping tube, the leucosapphire tube and the minimal gap thickness between their surfaces, equal to 0.5 mm according to technological considerations. An increase in the distance ℓ between the axes above the minimal value results in diminution of η for any values of the remaining parameters (Fig. 2). This is explained by the efficiency of the illumination system during compression of its arrangement.

The data obtained permit making a deduction about the expedience of selecting the minimal value of the distance between the axes. Moreover, it can be shown that diminution of the gap thickness between the reflector and the pumping tube and active element surfaces in the plane passing through their axes contributes to a rise in the efficiency and an improvement in the thermal mode. There results from these two facts that the quantities δ_T and D_2 are uniquely interrelated. For instance, for a given δ_T the value of D_2 is found from the minimal values of the distance between the axes and the above-mentioned gaps.

The quantities for which the dependence η is extremal in nature are selected in the third stage. Among them are the tube thickness δ_T as well as the reflector inner diameter D_1. Dependences of η on δ_T are represented in Fig. 3 for three times τ for minimally possible values of D_1, D_2, and ℓ. As δ_T changes from 0 to 2-2.1 mm the quantity η grows practically linearly at any times. As δ_T increases further, the ratio η either diminishes at the initial times in connection with the diminution of the pumping system efficiency (since an increase in tube thickness results in growth of the minimal value of the distance ℓ between the axes and in the diameter D_2) or remains practically constant at finite times. This latter circumstance is due to the following reasons. As the thickness of the leucosapphire tube increases, the temperature distribution over its section becomes more uniform, resulting in equilibration of the active element temperature field and diminution of its thermal wedge deformation. Moreover, an increase in the tube thickness results in growth of its total specific heat and reduction of the mean-volume temperature of the active element because of accumulation of an additional quantity of heat in the tube in the nonstationary mode.

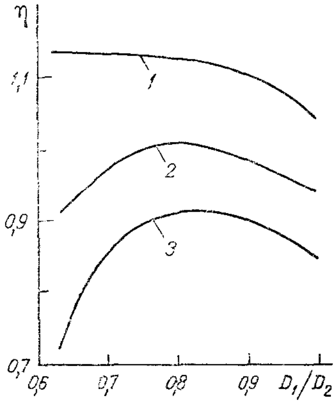

Fig. 4. Dependence of the quantity η on the ratio D_1/D_2 at different times τ: 1) τ = 0; 2) 1; 3) 5 sec.

Therefore, an increase in δ_T above the values 2-2.1 mm results in a reduction in η at the initial times and an increase in the quantron dimensions. In this connection it is expedient to select the thickness δ_T equal to ~2 mm.

By using the value of δ_T the minimal distance ℓ = 8 mm between the axes can be found and the magnitude D_2 = 16.5 mm can be obtained for the inner diameter. There now remains to determine the value of the inner diameter D_1. Dependences of η on the ratio D_1/D_2 at different times are represented in Fig. 4. Results of computations show that as the ratio D_1/D_2 increases the pumping system efficiency drops resulting in a reduction of the output energy at the initial time (curve 1 in Fig. 4). At other times a diminution in the thermal wedge deformation contributes to an increase in the output energy. Hence, the dependence of the quantity η on the ratio D_1/D_2 has a maximum that is achieved for values of D_1/D_2 in the 0.8-0.9 range (Fig. 4, curves 2, 3). This range of extremal values is also conserved for other values of D_2, ℓ, and δ_T. Setting D_1/D_2 = 0.8, we find the smaller inner diameter equal to 13.5 mm.

Therefore, the optimal quantron construction has the following geometric parameters: larger inner reflector diameter D_2 = 16.5 mm, smaller inner reflector diameter D_1 = 13.5 mm (D_1/D_2 = 0.8), distance ℓ = 8 mm between the axes, tube thickness δ_T = 2.05 mm. A construction with such parameters assures less thermooptical distortion and a lower temperature level in an active element as compared with the experimental model. In the case of a GSGG active element the utilization of such a construction permits obtaining a 15-20% higher output energy as compared with the experimental model.

RESULTS OF DESIGNING A QUANTRON WITH ACTIVE ELEMENT ON THE BASIS OF YAG

The method described above was utilized also to optimize the geometric parameters of an analogous base construction of a quantron with YAG active element. The feature of this quantron is that the thermal wedge deformation that occurs in the active element for a given mode of laser operation is much smaller than in the GSGG active element and has insignificant influence on the output energy. In this connection, the optimal value of the reflector smaller inner diameter is its minimal value D_1 = 10.5 mm (the remaining parameters of the optimal construction are the same as in the case of utilizing the GSGG active element). The output energy in an optimal construction with a YAG active element exceeds by 40-50% the value obtained in the experimental model.

The results obtained permit making a deduction about the expediency of utilizing the described design method for developing solid-state laser quantrons functioning in a stressed thermal mode.

NOTATION

η, ratio between laser output energy when using the quantron construction modification being analyzed and the output energy of the experimental model; L, D, active element length and diameter; ΔT, mean temperature drop over the active element between the nearest and most remote active element points from the pumping tube that lie in a plane perpendicular to the tube and active element axes; W, thermooptical constant of the active medium; α_B, function describing the increase in the passive loss coefficient because of thermal aberrations of the active element.

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HEATING OF A HALF-SPACE BY A HEAT SOURCE IN THE SHAPE OF A RECTANGULAR FRAME

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UDC 536.2.083

A solution is presented for the inverse nonstationary spatial coefficient problem of heat conduction for a half-space heated through a domain in the shape of a rectangular frame on its surface by an arbitrary heat source with respect to time.

Solutions of nonstationary heat conduction problems obtained [1, 2] for an isotropic half-space under discontinuous boundary conditions of the second kind (a heater in the shape of a circle, ring, square) are used to investigate a set of thermophysical characteristics (TPC) of isotropic materials. To find the TPC set from one experiment there is no necessity to place the sensor within the isotropic body under investigation, i.e., the complex measurements of appropriate thermophysical quantities are realized by nondestructive testing methods [1]. A simple expression is obtained in [3] for the temperature field in the center of an annular heater and the set of TPC of isotropic bodies is investigated on its basis by nondestructive testing methods.

Let us consider an isotropic half-space heated in the domain of the surface $z = 0$ by a heat flux of density $q(\tau)$ in the shape of a rectangular frame $2x_2 \times 2y_2 - 2x_1 \times 2y_1$ (Fig. 1). The rest of the surface is assumed heat insulated. We assume the initial temperature and the temperature at infinity equal to t_i = const, while the first derivatives of the temperature function with respect to the coordinates x, y equal zero. We shall consider those temperature ranges to be considered when the material TPC are temperature independent. In this case, we have the following boundary value problem to determine the excess temperature $\theta = t - t_i$:

$$\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2} + \frac{\partial^2\theta}{\partial z^2} = \frac{\dot{\theta}}{a}, \quad \lambda \frac{\partial\theta}{\partial z}\Big|_{z=0} = -q(\tau)\, M(x, \quad y), \tag{1}$$

$$\theta|_{z\to\infty} = 0, \tag{2}$$

$$\theta|_{\tau=0} = 0, \quad \theta|_{|x|,\,|y|\to\infty} = 0, \quad \frac{\partial\theta}{\partial x}\Big|_{|x|\to\infty} = \frac{\partial\theta}{\partial y}\Big|_{|y|\to\infty} = 0, \tag{3}$$

where $M(x, y) = N_2(x)N_2(y) - N_1(x)N_1(y)$, $\theta = \partial\theta/\partial\tau$, $N_i(x) = S(x + x_i) - S(x - x_i)$, $i = 1, 2$.

Applying the Fourier integral transform in x, y and the Laplace in τ to Eq. (1) and boundary conditions (2) under the boundary conditions (3), we obtain, respectively

$$\frac{d^2\bar{\theta}}{dz^2} - \gamma^2\bar{\theta} = 0, \tag{4}$$

$$\frac{d\bar{\theta}}{dz}\Big|_{z=0} = -\frac{\tilde{q}(s)}{\lambda}\hat{M}(\xi, \ \eta), \ \ \bar{\theta}|_{z\to\infty} = 0, \tag{5}$$

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