The interaction of a laser pulse with a high-temperature-superconducting target is studied on the basis of the heat conduction equation. It is found that the surface layer of the target overheats at certain radiation intensities. This overheating in turn disturbs the metastable state of the material and results in its explosive ejection from the surface.

One of the most widely used methods of obtaining high-temperature-superconducting (HTSC) films is laser deposition. A fairly large number of experimental studies have been made of this process [1], but it has been studied little from a theoretical viewpoint. The authors of [2] attempted to explain the mechanism of deposition by numerically solving the heat-conduction equation. However, the initial premise that the temperature of the surface was equal to the melting point was a very rough approximation [3]. As a result, the maximum temperature of the target was underestimated, while the temperature gradient was clearly overestimated.

In the present study, we examine the interaction of a laser pulse with a HTSC material and we numerically analyze the temperature field in the target during radiation.

We will analyze the temperature profile by means of the heat conduction equation

\[ \frac{\partial T}{\partial t} = \chi \frac{\partial^2 T}{\partial z^2} + \frac{1}{\rho c} Q_{\text{ext}}, \]

(1)

\[ Q_{\text{ext}} = \alpha \cdot \rho \cdot r \exp \left( -\alpha \cdot z \right) f(t). \]

(2)

Here \( \chi \) is thermal diffusivity; \( \rho \) is the density of the substance; \( c \) is heat capacity; \( I_0 \) is the intensity of the laser radiation; \( \alpha \) is the absorption coefficient; \( r \) is the reflection coefficient; \( f(t) \) is the envelope of the pulse (the pulse is considered rectangular in the study). Equation (1) must be supplemented by the boundary condition

\[ K \frac{\partial T}{\partial z} \bigg|_{z=0} = q_s(T). \]

(3)

Here, \( K \) is thermal conductivity; \( q_s(T) \) is a function describing vaporization from the surface. System (1)-(3) is nonlinear. Its approximate solution was constructed as follows:

\[ T = T_l + T_{nl}, \]

(4)

where \( T_l \) is the solution of the following linear problem:

\[ \frac{\partial T_l}{\partial t} = \chi \frac{\partial^2 T_l}{\partial z^2} + \frac{1}{\rho c} Q_{\text{ext}}, \]

\[ \frac{\partial T_l}{\partial z} \bigg|_{z=0} = 0, \]

(5)

while \( T_{nl} \) is the solution of the nonlinear problem:

\[ \frac{\partial T_{nl}}{\partial t} = \chi \frac{\partial^2 T_{nl}}{\partial z^2}, \]

\[ K \frac{\partial T_{nl}}{\partial z} \bigg|_{z=0} = q_s(T). \]

(6)
Problem (5) has an exact solution, and the solution of problem (6) can be found in a first approximation by writing

\[ q_s(T) \approx q_s(T_0). \]  

Having used the Laplace transformation on (5)-(7), we obtain the following (for \( t \leq \tau \), where \( \tau \) is the duration of the pulse)

\[ T_s(z, t) = T_0 + \left( \frac{\alpha z}{2 \chi} \right) [\exp(-\alpha z + \chi \alpha t) \text{erfc} \left( \frac{2 \chi \alpha t - z}{2 \chi} \right) + \exp(-\alpha z) \text{erfc} \left( \frac{2 \chi \alpha t + z}{2 \chi} \right) + 2 \exp(-u z)]], \tag{8} \]

where \( \text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty \exp(-t^2) dt \), \( \text{ierfc}(x) = \int_{-\infty}^x \text{erfc}(t) dt \).

In the first approximation

\[ T_{ni}(z, t) = \]

\[ = -\frac{1}{2} \int q_s(T_s(0, t')) \exp \left(-z^2/4\chi(t-t') \right) / K(t-t') \cdot dt'. \]  

Now we need to specify the function \( q_s(T) \). Unfortunately, there are no experimental data on the dependence of the rate of vaporization on surface temperature. We thus constructed the following function \( q_s(T) \):

\[ q_s(T) = \sum P_i (2 \pi \mu_i T_i)^{-1} : \left( 1, 5RT + \mu_i L \right) \exp \left( \lambda_i (1 - T_s/T) \right), \]

\[ \lambda_i = \mu_i L / RT_i, \quad i = \text{Y, Ba, Cu, O}. \]  

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