INFLUENCE OF THERMOPHYSICAL PROPERTIES OF THE SOLID DEPENDENCE FROM TEMPERATURE ON THE THERMAL CHARACTERISTICS AND EROSION UNDER THE ACTION OF HIGH-POWER PULSED ION BEAMS

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This paper presents data on the evolution of erosion, melting, evaporation of matter under the influence of powerful pulsed beams of carbon ions. The calculations of dependence of physical characteristics on the temperature are performed. Considered current density 300-1000 A/cm^2 at an initial energy of the beam particles equal to 300 kEv, and 70-140 A/cm^2 for the initial energy of beam particles equal to 1 MeV. Correct cases of neglecting dependencies on temperature are established.

INTRODUCTION

Action of powerful pulsed beams of charged particles with matter leads to significant changes in its properties, which cannot be produced in other ways. They are commonly used in the technologies, based on surface modification.

Modifying effect of powerful pulsed beams caused by high heating of thin surface layers up to the phase transition temperatures. So it is important to have an understanding of thermal processes evolution. Mathematical modeling plays an important role here. There was created a number of models describing the behavior of matter under the influence of powerful pulsed beams of charged particles [1]. Usually calculations of the temperature fields, the amount of vaporized and melted substance is produced using thermal characteristics that do not depend on temperature [2-4]. The approach is correct, if it is required to study the behavior of the characteristics on a qualitative level, without requiring great precision to the obtained values.

Recently there was a demand to solve problems when we need to know the evolution of processes with a high degree of accuracy; for example, to model structure and phase composition of matter or to identify optimal technological parameters of processing material. In this case, solutions without dependency on thermal conductivity and the heat capacity cannot satisfy the requirements. Therefore the purpose of work, the results of which are presented in this article is to provide a numerical model of heat and erosion processes in solids under the action of pulsed beams, which takes into account the dependence of the thermal characteristics of the temperature. With its help we investigated discrepancy between the results of calculations performed with and without dependent physical characteristics of the temperature for different beam parameters and target materials.

MATERIALS AND METHODS

Was used the model of energy dissipation, developed in [1]. Dimensional model of heat and erosion processes in a solid body has the following form:

$$\frac{\partial E(x,t)}{\partial t} - \upsilon(T)\frac{\partial E(x,t)}{\partial x} = \frac{\partial}{\partial x}\lambda(T)\frac{\partial T(x,t)}{\partial x} + \frac{W(x,t)}{C(T)\rho(T)}, \quad (1)$$

here E is thermal component of internal energy, υ - rate of evaporation front, W(x,t) is the space-time function of energy release when the beam particles come to a stop in the irradiated substance. In its turn, the function of energy release looks like:

$$W(x,t) = \frac{1}{e} j(t)G(x), \qquad (2)$$

where e is electron charge, j(t) - temporal distribution of current density pulse, G(x) - spatial distribution of linear energy losses during the passage of a single ion with an initial energy E_0 through the matter.

The boundary and initial conditions are imposed to equation (1):

$$\begin{cases} \lambda(T)\left.\frac{\partial T}{\partial x}\right|_{x=0} = \upsilon(T)\rho(T)\Delta H, \\ \lambda(T)\left.\frac{\partial T}{\partial x}\right|_{x=x_{end}} = 0, \\ T(x,0) = T_0 = 300K, \end{cases} \qquad (3)$$

where *ΔH* is the difference between the enthalpy of the vapor and condensed phases.

There was used developments of C(T) andλ(T) from [7] (Fig.1,2 – line 1) – on example of copper.

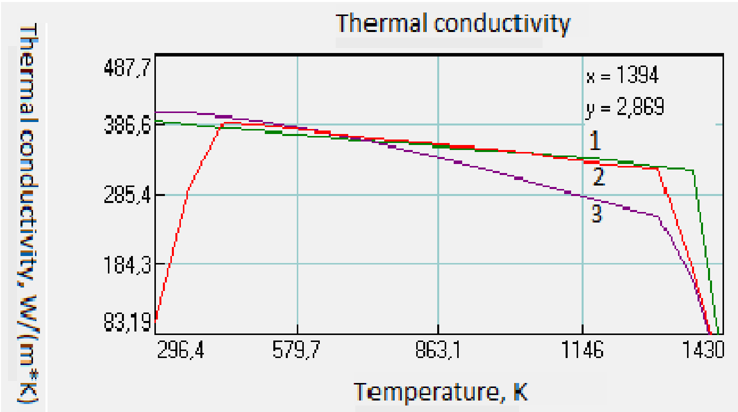

Fig.1. Dependence of thermal conductivity of copper on temperature (1 – [7], 2 – [6], 3 – [5]).

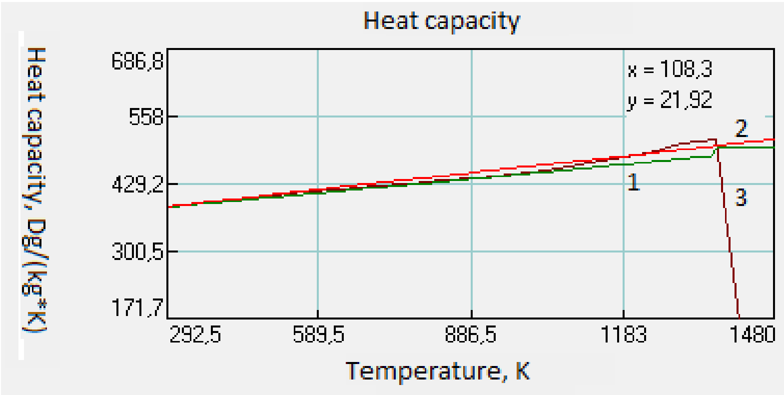

Fig.2. Dependence of heat capacity of copper on temperature (1 – [7], 2 – [6], 3 – [5]).

Account the dependence of the density of matter on the temperature did not occur because it is virtually constant for the investigated range of beam parameters.

ANALYSIS OF THE DATA

We considered carbon ion beams, 100 ns with an initial energy of 300 keV and 1 MeV. We modified existing program modeling the dynamics of basic processes occurring under the influence of powerful pulsed beams of charged particles with matter by dependencies of thermal conductivity and heat capacity.

The calculations are performed for silver, iron, aluminum and copper at change of current density j in the beam from 300 A/cm^2 to 1000 A/cm^2 at the initial particle energy E_0 = 300 keV and for j from 70 A/cm^2 to 490 A/cm^2 at E_0 = 1 MeV.

Calculations were performed for thickness of the evaporated layer, the lifetime of the liquid phase, the erosion coefficient and the thickness of the molten layer.

The article presents the data on the thickness of the evaporated layer and the lifetime of the liquid phase for aluminum and iron in the initial beam energy E_0 = 300 keV (Fig. 3, 4). It also presents data on the difference in the results of calculations obtained taking into account the dependence of thermal conductivity and specific heat on temperature, and without it. The difference was calculated as:

$$\frac{|M_{with} - M_{without}|}{M_{with}} \cdot 100\%.$$

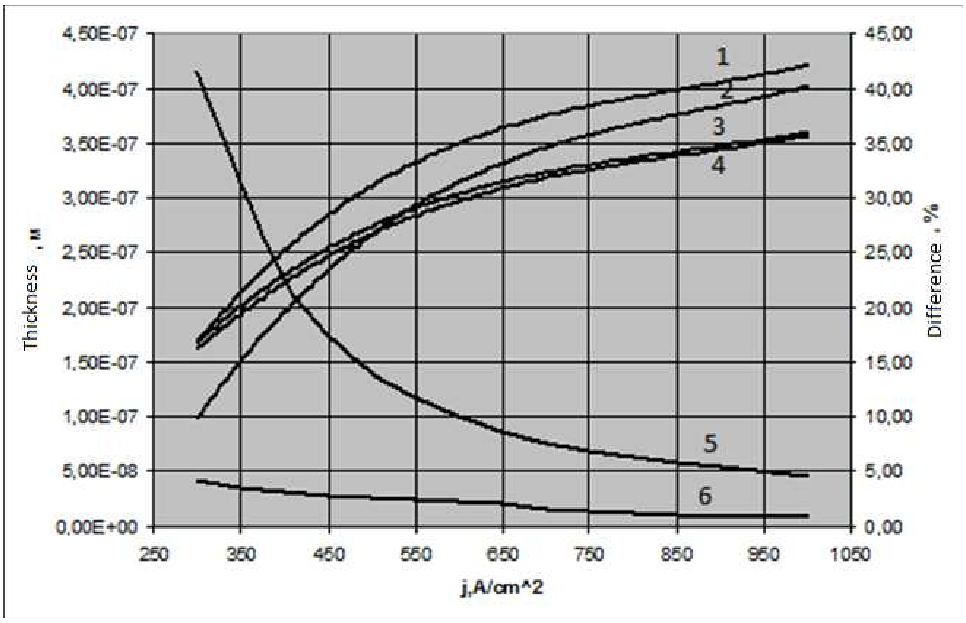

Fig.3. Dependence of the thickness of the evaporated substance layer on the current density (1 – Ag considering dependence, 2 – Ag without dependence, 3 – Fe considering dependence, 4 – Fe without dependence, 5 – difference between 1 and 2, 6 – difference between 3 and 4).

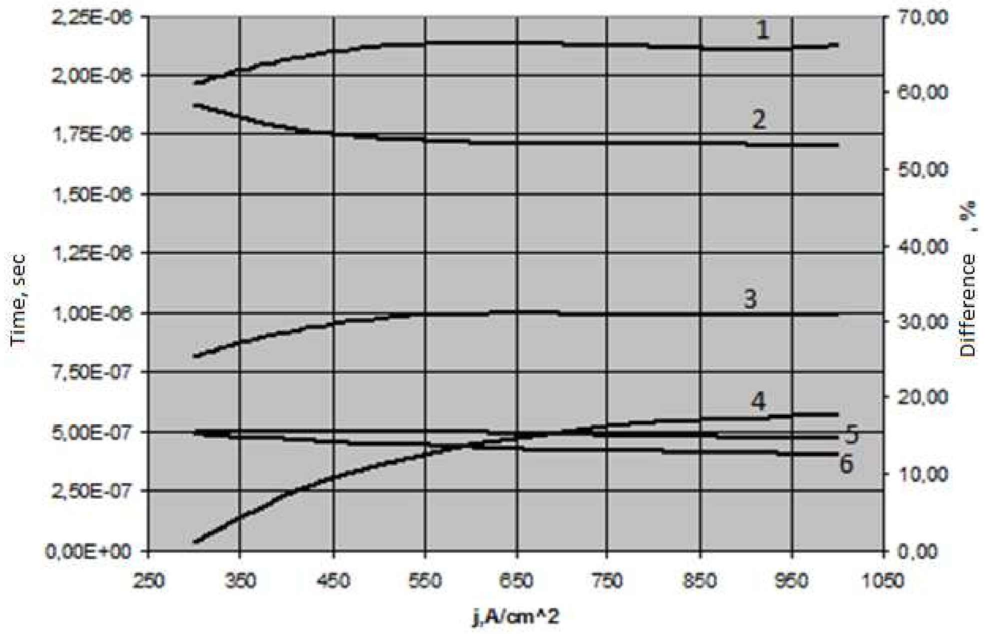

Fig.4. Dependence of liquid phase lifetime of a substance on the current density (1 – Ag considering dependence, 2 – difference between 1 and 3, 3 – Ag without dependence, 4 – difference between 5 and 6, 5 – Fe without dependence, 6 – Fe considering dependence).

The biggest difference observed at low current densities. In the case of silver, it reaches 40% of the thickness of the vaporized layer and 60%; for the lifetime of the liquid phase for the iron - 5% and 18% respectively.

By increasing the current density difference is stabilized. At the same time the thickness of the evaporated layer is decreases with increasing j, the values for the lifetime of the liquid phase in the case of silver - reduction, and for iron - increase.

Higher differences in calculating the thickness of the evaporated layer and the lifetime of the liquid phase are performed with and without thermal properties of irradiated materials, in the case of silver compared with iron explained as follows. The coefficient of thermal conductivity of silver is significantly higher than iron. Hence the contribution of thermally conductive flow in the energy balance in the surface region of the target is greater. Accuracy of the calculation of a heat sink affects the final result.

The higher the current density, the faster the evaporation is. Besides, as the temperature increases the thermal conductivity falls. Therefore, at high current densities difference in the thickness of the evaporated layer is less.

For aluminum, the difference in the values of the thickness of the evaporated layer was smaller, but for the lifetime of liquid phase it is in the range of 30-35% throughout the observation interval.

CONCLUSION

When metals are exposed to powerful submicrosecond pulse ion beams of duration of 100 ns in the low current the density difference (the existence of a liquid phase, the thickness of the molten layer) is significantly higher than in the range of high-j.

For metals with high thermal conductivity (silver, copper, etc.) in the modeling of thermal and erosion processes under the influence of submicrosecond carbon ion beams it is required to consider changing of thermal conductivity and the heat capacity. For substances such as iron, neglecting of dependence of thermophysical characteristics on the temperature is justified.

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