NUMERICAL SIMULATION OF PLUME DYNAMICS IN PULSED LASER ABLATION FOR DEPOSITION OF DIAMOND-LIKE CARBON FILMS

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Pulsed laser deposition (PLD) is not a new way of forming high-quality thin coatings materials with extraordinary characteristics [1]. PLD is fairly straightforward. A high-intensity, pulsed laser beam is focussed on a target in a chamber that is either evacuated or filled with a specific gas. The laser beam causes the target material to vaporize (or ablate) into the chamber. A substrate to be coated is placed in the path of the laser-produced plume, and the vapor clings to its surface, forming a thin layer of the ablated target material. It is possible to build films of specific thickness by using appropriate characteristics of laser pulses (laser wavelength, laser irradiance, pulse length, gas environment, etc.).

Dynamics of a carbon ablation plasma plume when preparing diamond-like carbon films by pulsed laser deposition was investigated using computational simulation. The developed self-consistent model for laser–solid interaction [2] includes: heating and evaporation of material, dispersion of erosive plasma in environmental space, absorption of laser radiation by a torch, target screening, real thermal-physical and optical characteristics of substance in a wide range of temperatures and densities realized under the laser action. Consideration is made using the two-dimensional axially symmetric approach (Fig.1). For computer simulation the data on the equations of state and thermodynamic functions, thermal conductivity and optical characteristics are necessary. The equation of state for carbon plasma is calculated and tabulated in the ranges of temperatures $T = 10^3 - 10^6$ K and densities $\rho = 10^{-9} - 10^{-2}$ g/cm^3. The composition of plasma representing an intermixture of molecules, atoms and ions of different-degree ionization is defined according to “the chemical model” with usage of the relevant equilibrium constants. The optical characteristics (absorption coefficients for laser radiation) are determined taking into account the main mechanisms of laser radiation absorption in the plasma (bremsstrahlung, photoionization and selective absorption) [3].

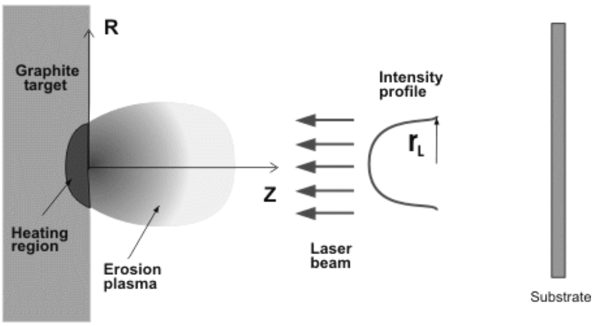

Fig. 1. The geometrical scheme of pulsed laser deposition

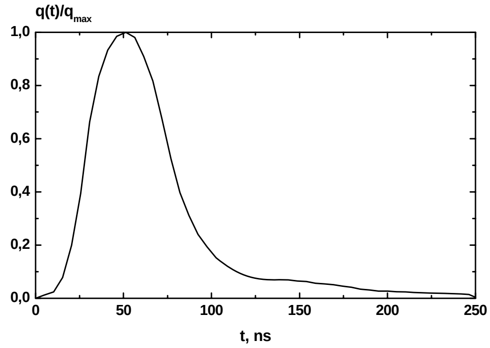

Fig.2. Laser intensity-time profile assumed in the model

The modelling was carried out for the conditions of experiments [4] (wavelength of 1064 nm, 50 ns pulse duration half-width with a “tail” up to 250 ns, the ambient pressure of a gas equal to 10^{-6} atm). Among the main parameters, laser pulse energy and also power density have been changed in the study. A detailed study has been performed of a space-time development of the laser ablation plume on a graphite sample at the following conditions: 2 - 8 J laser pulse energy uniformly distributed with a 9 mm characteristic radius. It corresponds to maximum irradiance of 6.5 - 65 MW/cm^2 . The time profile of the laser pulse (normalized to irradiance in maximum) is given in Fig. 2. A substrate to be coated is placed opposite to the graphite target at a distance of 10 cm. The thermophysical properties and optical parameters of graphite (with a density of 2.2 g/cm^3) necessary for numerical simulation were set in view of the temperature dependence according to the literature data [5,6].

Dynamics of temperature of the graphite target and thickness of the evaporation layer for different laser energy is given in Fig. 3. Estimated critical irradiance for the erosion is observed at ~20 MW/cm^2). For all investigated laser irradiance (20<q<70 MW/cm^2) the target evaporation comes to the end to the moment of time ~100 ns. Let us notice that for this irradiance the laser plume remains transparent and the shielding of the target is not observed.

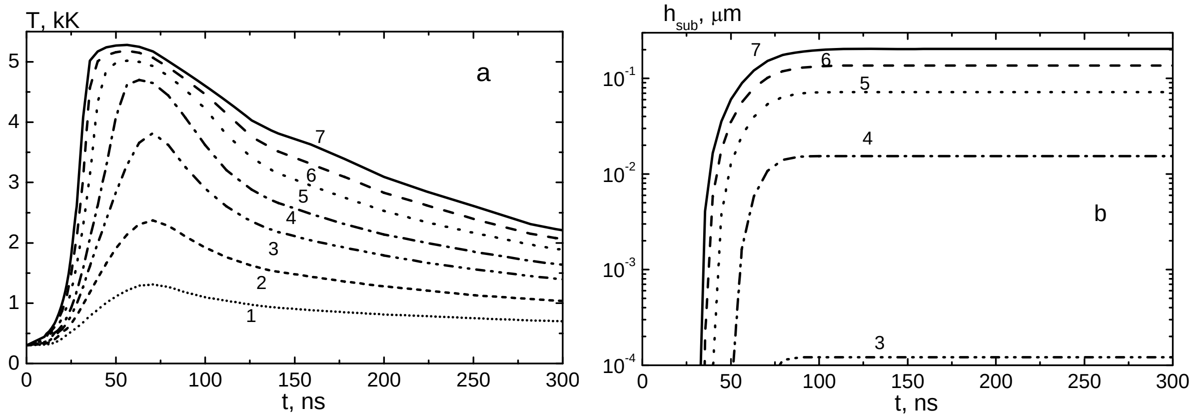

Fig. 3. Calculated temperature at the target surface (a) and evaporation depth (d) vs. time for pulse laser energy: 1 – 1 (6.5), 2 – 2 (13), 3 – 3 (20), 4 – 4 (26), 5 – 6 (40), 6 – 8 (52), 7 – 10 J (65.5 MW/cm^2). Maximum irradiance is given in brackets

The time dependence of the plasma density (a) and temperature (b) close by substrate at different laser pulse energy is presented in Fig. 4.

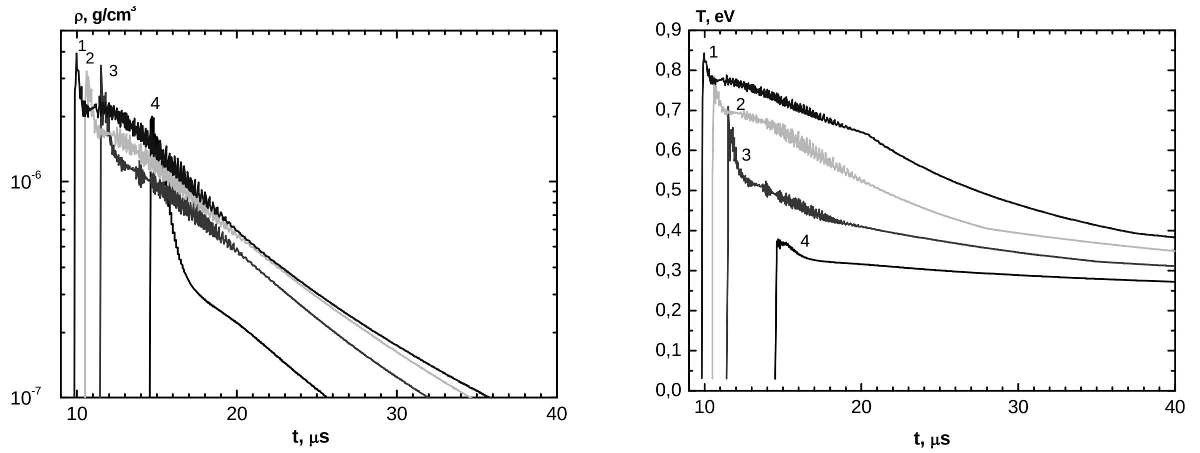

Fig. 4. Calculated carbon plasma density (a) and temperature near the substrate (b) vs. time for energy of the laser pulse: 1 – 10; 2 – 8; 3 –6; 4 – 4 J

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