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INFLUENCE OF THE ATOMIC MASS OF A PLASMA-FORMING TARGET ON THE PARAMETERS OF LASER-EMISSION DISCHARGE

V. V. Shkurko

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A study has been made of the influence of the atomic mass of the material of a plasma-forming target on the characteristics of a laser-emission discharge developing under the action of Nd-laser radiation on the target. It has been shown that the atomic mass substantially affects the efficiency of conversion of the energy of laser radiation to the energy of a quasistationary electric current; the behavior of the dependences of the load power on the atomic mass of the target substance is different for high vacuum and for resonance pressure and it is not related to the regime of development of the discharge.

In interaction of high-power pulsed laser radiation with a solid target that is in vacuum, a plasma torch is formed. Because of the presence of large gradients of pressure and temperature in the plasma, an electric double layer of space charge and consequently the electromotive force $\varepsilon = kT/e$ occur at the torch boundary [1]. As a result, an electric current traverses the system plasma torch–target–load–wall of the vacuum chamber and laser-emission discharge develops in it [2]. In [3], it has been shown that there can be two regimes of development of the discharge (high-current and low-current) depending on the value of the external load R. In accordance with this, the efficiency of conversion of the energy of laser radiation to the energy of a undirectional quasistationary electric current will be determined primarily by the regime of development of the discharge. Furthermore, the conversion efficiency substantially depends on the pressure in the vacuum chamber [2] and, as the results obtained demonstrate, on the atomic mass of the substance of a plasma-forming target subjected to the action of laser radiation.

In this work, we present results of experimental investigations into the dependence of the efficiency of conversion of the energy of laser radiation to the energy of an electric current traversing the external load (to the external-load power) on the atomic mass of a plasma-forming target at two pressures in the vacuum chamber (P_1 = 1 Pa and $P_2 = 10^{-3}$ Pa) and for the two regimes of development of laser-emission discharge indicated above.

In the experiments, we employed a Q-switched neodymium glass laser (wavelength λ = 1.06 μm) (Fig. 1). The half-width duration of a pulse was $25\cdot10^{-9}$ and the energy was 2.5 J. The laser radiation was focused by a plano-convex lens with a focal distance of 120 mm to a target located in a metal vacuum chamber. The diameter of the focal spot on the sample was 0.5 mm. Under these conditions, the density of the laser-radiation flux reached values of $q = 5\cdot10^{10}$ W/cm^2. The targets were manufactured from Al, Cu, Zr, Ta, and Pb in the form of cylinders 1 cm in diameter and 0.5-cm thick, which made it possible to cover the range of atomic masses of 27 to 207. The targets were placed in the vacuum chamber the pressure in which could be varied from 10^{-3} Pa to atmospheric pressure. Special noninductive resistors were used as the load. The resistance of the resistors was changed discretely from 0.2 to 1500 Ω. The experimental results were averaged over five implementations. In this case, with the existing variance, the relative error of measurement of the amplitudes of currents and voltages on the target was no higher than 8% for a confidence coefficient of 0.95 [4]. The load power was calculated from the expression $W = E^2/4r$. The quantities E and r in turn were determined from the load characteristics of the laser-emission discharge that correspond to the high-current and low-current regimes of its development and to the pressures of the residual gas in the chamber P_1 and P_2. The relative error of determination of W amounted to 17% for the same confidence coefficient.

As the experiments have shown, the load power (all other things being equal) depends on the residual pressure in the vacuum chamber, the regime of development of the laser-emission discharge, and the atomic mass of the

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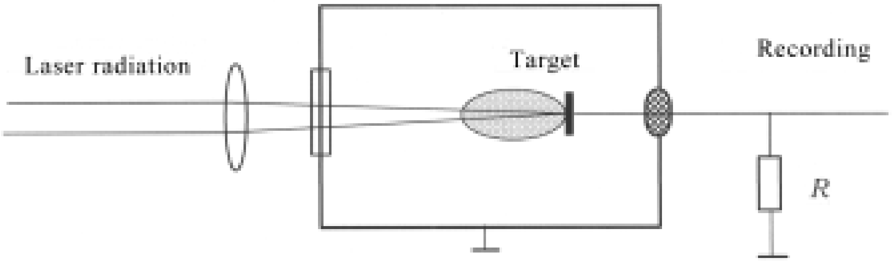

Fig. 1. Experimental scheme.

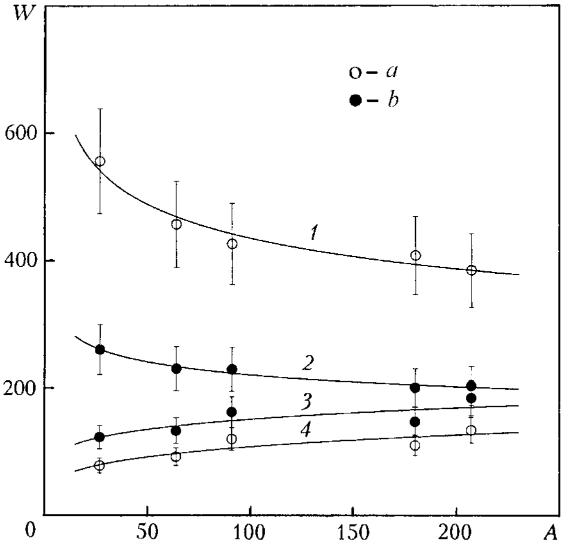

Fig. 2. Load power W vs. atomic mass of the substance of a plasma-forming target A [a) high-current regime and b) low-current regime of development of the discharge]. W, W.

substance of the plasma-forming target. The corresponding dependences obtained for the high-current and low-current regimes of development of the discharge at the pressures indicated above are presented in Fig. 2. Curves 1 and 2 correspond to the "resonance" pressure $P_1 = 1$ Pa, i.e., to the pressure at which a sharp (2 to 3 orders of magnitude) increase in the value of the laser-emission current is observed [2], while curves 3 and 4 correspond to the high vacuum $P_2 = 10^{-3}$ Pa. Let us consider their characteristic features. Different types of behavior of the dependence of the load power W on the atomic mass A of the target substance for the case of development of a laser-emission discharge in high vacuum at the "resonance" pressure are particularly worth noting. In vacuum, the load power increases monotonically, whereas at the "resonance" pressure, conversely: W decreases monotonically with increase in the atomic mass. The behavior of the dependences for the high-current and low-current regimes is analogous, and it is determined by just the value of the pressure. The dependence $W = f(A)$ is the most pronounced for the high-current regime at a residual pressure of air of $P_1 = 1$ Pa in the vacuum chamber. Under the same conditions, the load power is the highest for all the variants investigated. In all the remaining cases, the efficiency of laser-emission conversion of the energy of coherent radiation to the energy of a unidirectional quasistationary electric current is much lower. It is characteristic that the differences in the released power, all other things being equal, are the strongest for targets with a small atomic mass. Thus, for the aluminum target the power released at the "resonance" pressure in the high-current regime is an order of magnitude higher that the corresponding value for high vacuum. As the atomic mass of the material of the plasma-forming target increases, these differences become not so significant. Moreover, as is clear from Fig. 2, for large A curves 2, 3, and 4 come closer and asymptotically tend to a single value. Consequently, for targets with a large atomic mass (under these experimental conditions, beginning with lead) it is unnecessary to select the optimum pressure in the chamber in operation of the laser-emission converter in the low-current regime, since the load power will be the same, in practice, for both the high vacuum and the "resonance" pressure.

Thus, the atomic mass of the substance of the plasma-forming target substantially affects the characteristics of the laser-emission discharge. For high vacuum the regularities obtained are attributable to the dependence of the electron temperature of the plasma torch T_e on the atomic mass of its ion component. According to [5], we have

$$T_e = 5.2 \cdot 10^{-6} A^{1/5} (\lambda^2 q)^{\alpha} ,$$

where α can take on a value of 3/5 or 2/3 depending on the degree of ionization of the plasma. The quantity T_e in turn determines the emf of the electric double layer at the torch boundary and accordingly the electromotive force of the discharge E. On the basis of [5], the emf of the discharge and consequently the load power must increase with atomic mass, which is confirmed by this experiment. It is difficult to explain dependences 1 and 2 as yet. Nonetheless, if we seek to obtain a maximum coefficient of conversion of the laser-radiation energy to the electric-current energy, all other things being equal, we must employ a metal with a small atomic mass as the material of the plasma-forming target, the pressure in the vacuum chamber must be close to 1 Pa, and R should be selected such as to implement the high-current regime of development of the laser-emission discharge.

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NOTATION

E, electromotive force, V; k, Boltzmann constant, J/deg; T_e, electron plasma temperature, eV; e, electron charge; R, load resistance, Ω; r, internal resistance of the discharge, Ω; P, pressure, Pa; λ, wavelength, μm; q, density of the laser-radiation flux, W/cm^2; W, load power, W; A, atomic mass. Subscript: e, electron.

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