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# DYNAMICS OF PARAMETERS OF AN EROSION TORCH FORMED UNDER THE ACTION OF SUBMICROSECOND LASER RADIATION ON A ZINC TARGET

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*By the laser probing method the time dependence of the transmission factor of an erosion laser torch of zinc under the action on a metal target of intensive submicrosecond pulses has been determined. On the basis of the results of laser probing, a conclusion on the formation mechanism of the liquid-drop phase of the target material under the given irradiation conditions has been drawn.*

***Keywords:*** *erosion laser torch, liquid-drop phase, submicrosecond radiation pulse, condensation.*

**Introduction.** Recent years have seen enhanced interest in methods for obtaining nanodimensional objects, controlling their characteristics, and using such objects in science and technology. The interest in nanotechnologies is due to the specific properties of nanostructures. For example, in many metals the mechanical, electrical, magnetic, optical and chemical properties change markedly. One of the problems of nanotechnologies is the obtaining of aqueous suspensions of metal nanoparticles, which can find wide application in medicine, cosmetology, chemistry, etc.

**Formulation of the Problem.** In [1], it was proposed to obtain an aqueous suspension of nanoparticles by trapping fine-disperse particles of the liquid-drop phase of the nickel target material by an aqueous medium. Particles are formed in a erosion laser torch due to the volume vaporization. This method is based on the fact that under the action of laser radiation of moderate power density (10–$10^8$ W/cm$^2$) on metals, erosion products consisting of vapors, plasma, and the liquid-drop phase of the target material [2–7] are formed. In [1], a neodymium laser with a radiation pulse width of ~1500 μsec of total energy up to 1 kJ was used. The disadvantage of this laser is that the time intervals between individual pulses are long (15–20 min), which is necessary for cooling the working substance. Lasers operating in the frequency mode give a better performance. However, as a rule, such lasers have short durations (20–100 nsec) of individual radiation pulses. While for fairly long (10 μsec–10 msec) laser radiation pulses of moderate density the processes of interaction with metals have been well studied [2–9], there is lack of information on the formation mechanism of the liquid-drop phase of the target material for short high-intensity pulses. There is a review article [10] in which questions of the formation of nanoclusters due to the condensation of vapors under the action of laser radiation on various materials in vacuum are broached. However, primary consideration is given by the authors to theoretical aspects of the problem. The references therein to experimental works, because of the specificity of the methods for controlling nanoparticle sizes, are devoted to the formation of nanoclusters from semiconductor and polymer targets exposed to short pulses.

The present work is devoted to the investigation of the dynamics of erosion torch parameters and the formation of the liquid-drop phase under submicrosecond (~200 nsec) intensive laser irradiation of zinc.

**Experimental.** To solve the problems connected with the investigation of the dynamics of parameters of erosion laser torches, we created an experimental facility whose basic diagram is given in Fig. 1.

The generator of radiation acting on a zinc target 10 is based on the standard head GOS 1001. For the modulating element, we used, instead of a totally reflecting mirror, a rotating totally reflecting prism which also forms a sync pulse for the entire facility. Such a generator has made it possible to obtain radiation monopulses with the following parameters: wavelength 1064 nm, pulse width 200 nsec, energy up to 7 J, and output beam diameter 30 mm. Focusing this radiation pulse on the target surface into a spot of diameter 1 mm, we attained a power den-

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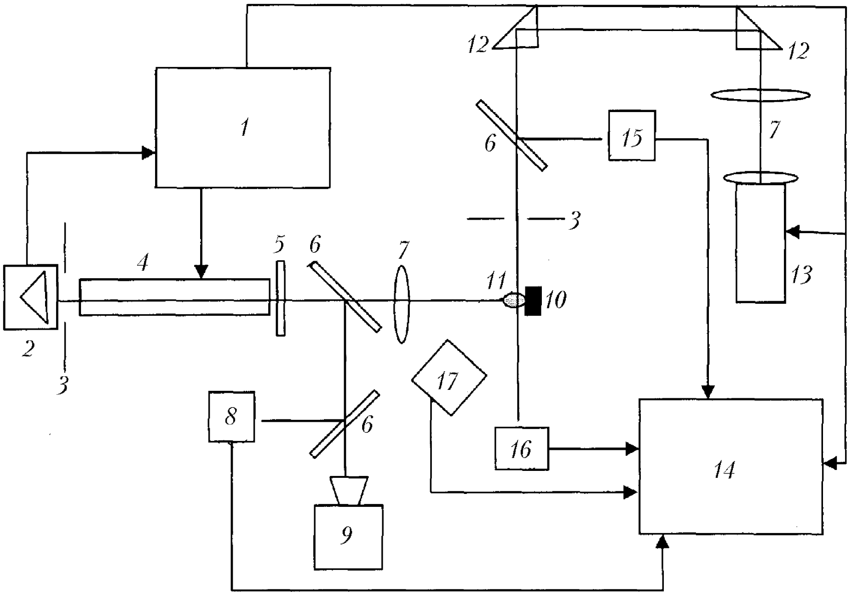

Fig. 1. Scheme of the experimental facility: 1) synchronizing system; 2) rotating total internal reflection prism with the possibility of sync pulse generation; 3) diaphragms; 4) working substance of a neodymium laser with pumping lamps; 5) semireflecting mirror (at 1064 nm); 6) deflecting plane-parallel quartz plates; 7) lenses; 8) photodetector of the temporal shape of the acting radiation pulse; 9) calorimeter; 10) target; 11) erosion laser torch; 12) rotating prisms; 13) semiconductor laser generating probing radiation at a wavelength of 800 nm; 14) computer with an ADC unit; 15, 16) photodetector of the temporal shape of the incident and transmitted probing radiation, respectively; 17) photodetector of the temporal shape of the torch luminescence.

sity of $10^9$ W/cm$^2$. Irradiation of the target leads to the formation over the metal surface of an erosion plasma torch 11 which is exposed to the radiation from an auxiliary semiconductor laser 13 having the following parameters: radiation wavelength 800 nm, pulse width 1.5 μsec, power density in the probing zone $10^2$ W/cm$^2$. The time resolution in using the given laser is determined by the speed of response of the analog-digital converter (ADC) and is 25 nsec. In the experiment, the time dependence of the probing radiation intensity of the auxiliary laser incident on the erosion torch is registered by a photodetector 15, and the radiation transmitted through the erosion torch is registered by a photodetector 16. This permits determining the change with time in the transmission coefficient of the erosion plasma torch at the wavelength $\lambda$ = 800 nm. Moreover, in the course of the experiment the change with time in the spectrum-integral luminescence of the torch (photodetector 17), as well as in the temporal shape of the irradiation pulse (photodetector 8) and its energy characteristics (calorimeter 9), are registered.

The experimental results for the zinc target are presented in Fig. 2. The power density of the action neodymium laser radiation thereby was $5 \cdot 10^8$ W/cm$^2$. The probing radiation passed at a distance of 1 mm from the target surface. Figure 2 shows on a single time scale: 1) the pulse shape of the acting neodymium laser radiation, 2) the erosion torch plasma luminescence, 3) the pulse shape of the probing semiconductor laser, and 4) the portion of the probing radiation transmitted through the erosion torch. As is seen from Fig. 2, the neodymium laser radiation acting on the target and the radiation of the probing laser appear practically simultaneously. Plasma luminescence is somewhat delayed from the acting radiation. At moments of high parameters of the plasma control it was difficult to record in our case the coefficients of transmission by the erosion torch of the probing radiation because of the strong interfering luminescence of the plasma. Reliable recording of the coefficient of transmission by the erosion torch of the probing semiconductor laser radiation at the wavelength $\lambda$ = 800 nm became possible only when the luminescence of the zinc target destruction products was halved.

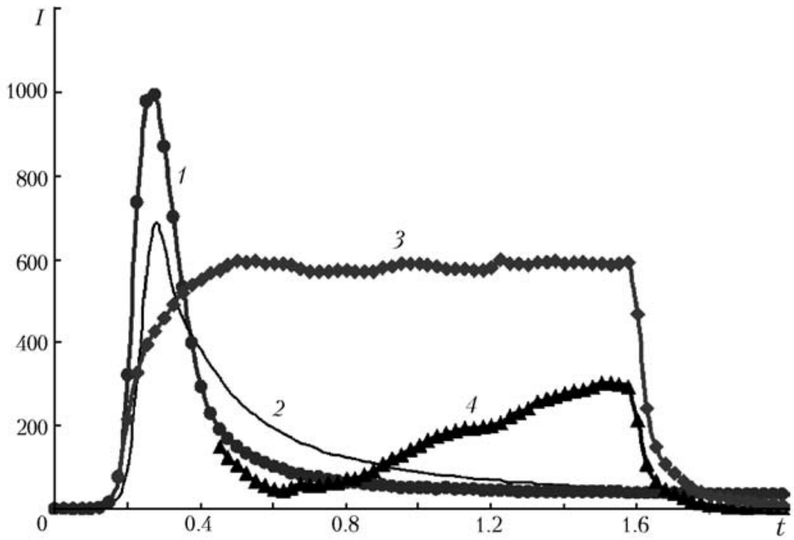

Fig. 2. Optical characteristics of the erosion zinc torch probed by a semiconductor laser. *I*, arbitrary units; *t*, μsec.

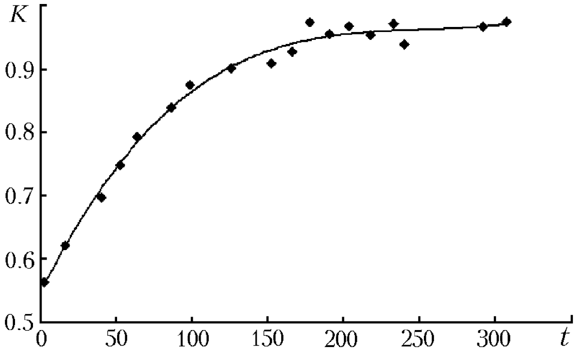

Fig. 3. Temporal shape of the transmission factor of the erosion zinc torch probed by a ruby laser. *t*, μsec.

Since the main mechanism of radiation losses in the plasma is the absorption by charged particles, with decreasing parameters of the erosion torch plasma (concentration of charged particles, temperature, luminescence intensity, etc.) the transmission coefficient should increase. However, as is seen from Fig. 2, the transmission coefficient decreases down to 0.6 μsec from the beginning of recording.

Another mechanism of probing radiation losses in the erosion laser torch is the scattering and absorption by particles of the fine-disperse phase of the target material. In [11], the results of the investigation of the initial destruction of metals exposed to laser pulses of wavelength 40–300 nsec are presented. It has been shown that in the limits of the duration of the leading front of the laser pulse on the target surface there appear microhills and macrocraters of size 1–10 μm. Moreover, near the surface microparticles of size ~1 μm moving at a velocity of 30–100 m/sec appear. All this determines the plasma initiation threshold. The plasma formed is a smoothing factor. Unfortunately, in [11] questions of the behavior of particles in the process of plasma outflow are not considered. In our opinion, such particles may evaporate in the laser beam field and thus increase the plasma density. Whether these particles evaporate or not, because of their low velocity they may find themselves in the probing zone only much later (at a probing height of 1 mm the flying-up time will be no less than 10 μsec).

However, if we assume that the main losses of the probing radiation take place on fine-disperse particles of the target material, then the decrease in the transmission coefficient (see Fig. 2) during a time from 350 to 450 nsec from the beginning of laser irradiation is due to the increase in the number of particles. The increase in the number of particles upon plasma cooling may only be caused by the condensation of target material vapors and the formation

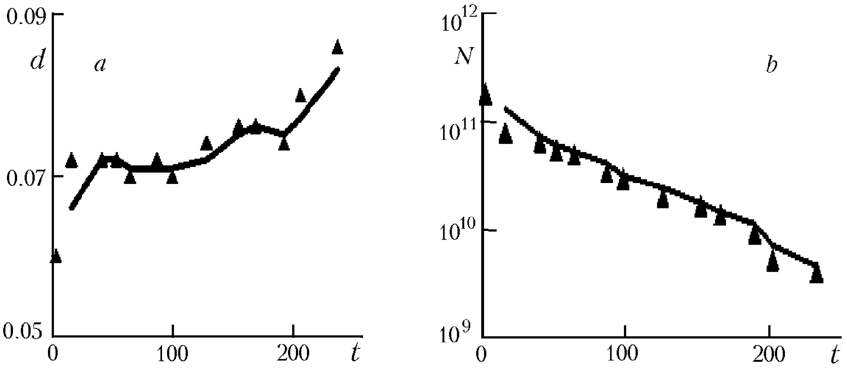

Fig. 4. Time dependences of the effective diameter (a) and concentration of particles of the condensed-phase of zinc (b) at its laser erosion under the action of a submicrosecond pulse. *d*, μm; *N*, $\text{cm}^{-3}$; *t*, μsec.

of the fine-disperse liquid drop phase of the target material. After 450 nsec from the beginning of irradiation the transmission of the erosion torch increases, which is explained by the decrease in the number of particles and the increase in their sizes.

To determine the numerical concentration of condensed-phase particles and their sizes, we created an experimental facility. This facility differs from the one shown in Fig. 1 in that instead of a semiconductor laser, a free-running ruby laser lasing at a wavelength of ~0.7 μm during 1000 μsec is used. This permits probing the erosion laser torch during a much longer time interval than with the use of a semiconductor laser. The time resolution therewith is determined by the spike structure of the ruby laser oscillation and is equal to ~5–10 μsec. Another important difference of the given experimental facility is that the laser target is placed in an integrating sphere. This permits simultaneous control of the incident (probing) radiation intensity of the ruby laser transmitted through the erosion torch and of the probing radiation scattered by it to all sides. The absorbed part of the ruby laser probing radiation is calculated from the energy balance.

From the ratio of the absorbed and scattered components of the probing radiation one can control in real time the sizes of particles, as well as their numerical concentration. These methods are described in more detail in [12].

Figure 3 shows the time dependence of the coefficient of transmission by the erosion laser zinc torch of the ruby laser probing radiation. Probing is carried out at a height of 1 mm from the target surface. The acting radiation parameters are the same as in Fig. 2. As is seen from Fig. 3, the erosion torch transmissivity increases in the course of time up to 180 μsec (from the moment of action), after which the probing radiation losses are insignificant. This points to the fact that in the course of time the number of particles of the liquid-drop phase decreases and their sizes increase.

**Results and Discussion.** With the use of the laser probing methods [12], the time dependences of sizes (effective parameters) of particles (Fig. 4a) and their numerical concentration (Fig. 4b) have been obtained. These dependences are in good agreement with the shape of the curves shown in Figs. 2 and 3. As is seen from Fig. 4, the particle sizes are much smaller than those given in [11] and in the course of time they increase, which points to condensation as a probable mechanism of their formation. In so doing, the numerical concentration of particles markedly decreases, which also confirms the presence of condensation processes.

Thus, from the experiments performed it follows that from a certain instant of time after the onset of irradiation of the zinc target by submicrosecond laser radiation an erosion laser torch with intensive luminescence of destruction products is formed. As the acting radiation decays, the luminescence intensity of the torch decreases with some time delay from the acting pulse and small liquid-drop particles of the target material condense from the torch vapors. In the course of time their sizes increase and the concentration decreases, which makes it possible to speak of condensation as the most probable mechanism of their formation. Erosion laser torch transmittivity measurements by both the semiconductor and ruby lasers also point qualitatively to the proceeding of condensation processes in the torch.

**Conclusions.** The results of the investigations performed show that the use of submicrosecond laser pulses is promising for obtaining nanoparticles of metals. The application of modern frequency lasers for generating short pulses makes it possible to develop technologies of forming media containing nanoparticles of metals.

## NOTATION

$d$, effective size of particles, μm; $I$, relative radiation intensity; $K$, transmittivity; $N$, numerical concentration of particles, cm$^{-3}$; $t$, time, μsec; λ, radiation wavelength, nm.

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