SIGNALS OF LIGHT SCATTERING FROM A MODEL WATER DROPLET AEROSOL EXPOSED TO THE PULSES OF INTENSE RADIATION OF A CO_2–LASER

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The paper presents the results of experimental studies of signals of laser illumination scattered from a water droplet medium of different dispersed composition at a wavelength of 0.49 μm *under conditions of explosive evaporation of particles upon exposure to the* CO_2*–laser pulse.*

The dependence of the amplitude of scattered signals on the energy density in the heating beam and aerosol microstructure has been established.

The paper presents the results of experimental study of signals of visible radiation scattered from a water–droplet medium, irradiated by the pulses of the intense CO_2–laser radiation, in the direction close to backward. The experiments were aimed at evaluating the effect of the aerosol dispersed composition and the pulse energy on the parameters of the scattered signal. The investigations are important for developing the new methods of diagnostics of the dispersed media with the use of the high–power lasers as well as for studying the peculiarities of thermodynamic processes in matter in an overheated state.

During the experiment an aerosol medium of different microstructure was modeled, and the signal of scattered radiation under conditions of different energies of heating radiation initiating the explosive vaporization of the aerosol particles was measured. A water droplet monodisperse aerosol with the rms radius of particles $\alpha_0 = 2.7$ μm produced by the ultrasonic generator and a water droplet polydispersed aerosol approximated by the gamma distribution with the parameters $\alpha_m = 4$ μm and $\mu = 1$ and $\alpha_m = 10$ μm and $\mu = 1.21$ produced by a sprayer, were used as a model aerosols. The size distribution was monitored using the method of air intakes and processing photomicrographs. The aerosol disperse composition was chosen so that the scattered signal was formed 1) solely by the uniformly absorbing particles with α_a, $\alpha_0 < 1$, where α_a is the volume absorption coefficient, or 2) by the aerosol with different contribution of nonuniformly absorbing large particles with α_a, $\alpha_0 > 1$ (see Ref. 7). The aerosol was sprayed into an interaction region in the form of a jet whose diameter was $\leq 2\cdot10^{-2}$ m and the direction of propagation was perpendicular to that of the laser beam. The transverse dimensions of the aerosol medium did not exceed the diameter of the caustic of the focused heating beam (the focal length was $f = 6\cdot10^{-1}$ m) and transmission of the medium was 90% at the wavelength of heating radiation that allowed one to assume that the energy density along the entire path and over the cross section of the interaction region was uniform.

A CO_2 laser radiating a pulse of the duration $t_p \sim 3$ μs with energy density varying within the limits 1–20 J/cm^2 was used as a heating radiation source which initiated the explosion of the aerosol particles. The scattered signal was received at an angle of 172° with respect to the direction of propagation of the laser beam at the wavelength of probing radiation $\lambda = 0.49$ μm which was directed toward the interaction region coaxially with the heating beam. The diameter of the probing beam was $\sim 2\cdot10^{-3}$ m, the diameter of the heating beam in the focal plane was $\sim 4\cdot10^{-3}$ m. The probing beam cut out the region of smooth (quasi homogeneous) energy distribution over the cross section of the heating beam. An LGN–503 1 W cw argon laser was used as a source of the probing radiation.

The time dependence of the amplitude of the signal at $\lambda = 0.49$ μm caused by scattering of a probing beam on the aerosol particles subject to the explosive effervescence upon exposure to the CO_2 –laser beam with different energy densities is shown in Fig. 1 (the parameters of the initial aerosol particle size distribution were $\alpha_m = 4$ μm and $\mu = 1$).

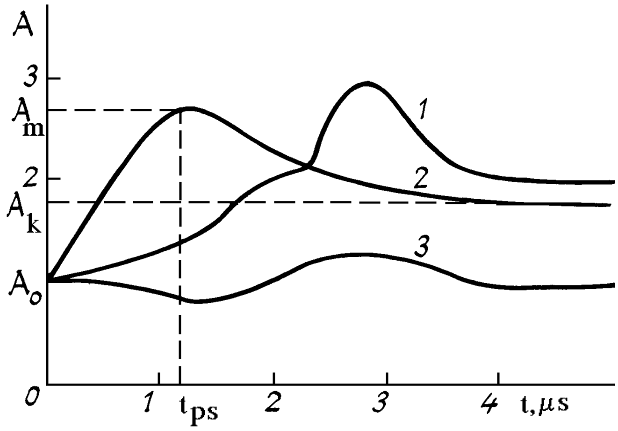

FIG. 1. Time dependence of the amplitude of the signal at $\lambda = 0.49$ μm *caused by scattering ofa probing beam with different energy densities: 1)* 4 J/cm^2, *2)* 17 J/cm^2, and *3)* 2 J/cm^2.

We can identify several characteristic amplitudes of the scattered signal: the initial amplitude of scattering A_0 (linear case), the maximum amplitude of the scattered signal A_m, directly related to the explosion of the aerosol particles, and the final amplitude of scattering A_f, establishing after the pulse passage and describing the

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scattering properties of the secondary aerosol medium. It is also possible to determine the characteristic time t_{ps} for the amplitude of the radiation scattered by the medium to reach its peak value.

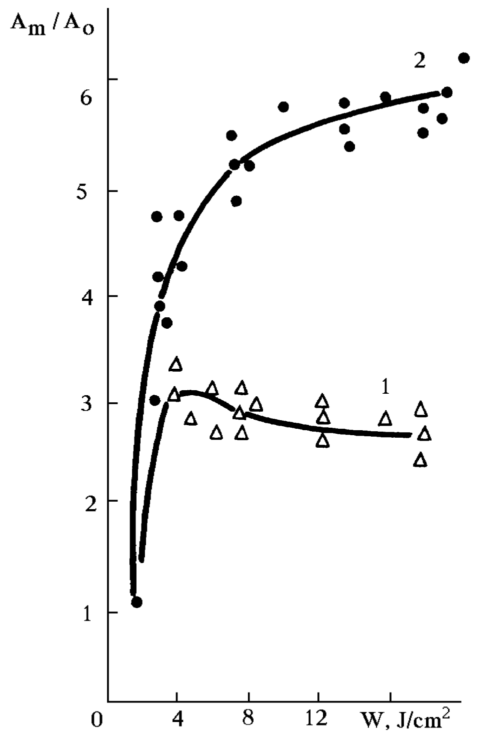

FIG. 2. The dependence of the maximum amplitude of the scattered signal at $\lambda = 0.49$ μm *on the energy density in the beam of the* CO_2*–laser radiation: polydisperse aerosol approximated by the gamma distribution with the parameters* $a_m = 4$ μm *and* $\mu = 1$ *(1) and* $a_m = 10$ μm *and* $\mu = 1.21$ *(2).*

A plot of A_m vs the energy density in the heating pulse for aerosol of different disperse composition is shown in Fig. 2. As can be seen from the figure, the medium turbidity, directly related to the explosion of the aerosol particles, increases with energy of heating radiation for the large–droplet aerosol (curve *2*). It can be explained by the fact that with increase of the energy absorbed by the aerosol particle its layers located at radial distances larger than α_a^{-1} from its coat are heated up to the temperature of explosive effervescence. As a result, the greater mass of a large particle changes to the submicron fraction which strongly polluted the medium and results in the corresponding increase in the amplitude of the backscattered signal. For the finely disperse aerosol (curve *1*) the energy density of ~ 6–8 J/cm^2 is sufficient for complete fragmentation of particles and with further increase in the energy the amplitude of the scattered signal drops due to the more complete explosive vaporization. The saturation in curve *1* can be explaned by the same reason.

Figure 3 shows the dependence of the time t_{ps} describing the position of the bending point in the time base of the amplitude of the scattered signal on the laser energy density for the three types of aerosol. For the submicron fraction of the aerosol particles (curve *1*) the increase in the heating pulse energy starting from the threshold up to 20 J/cm^2 results in the reduction of the time, required for the amplitude of the scattered signal to reach its peak value, from 1.2 to 0.3 μs, which is associated with increase in the rate of energy inflow into a droplet, the more complete explosive vaporization, and the more efficient vaporization of fragments upon exposure to the tail of the laser pulse due to the increased energy content. The coarse fraction of the aerosol particles delays t_{ps} (curves *2* and *3*) in comparison with the submicron fraction of the uniformly absorbing aerosol since a more complete vaporisation of the large nonuniformly absorbing particles requires a greater amount of energy. Moreover, the explosion of the layers located at a distance from the particle coat results in increase of the time of separation of fragments.

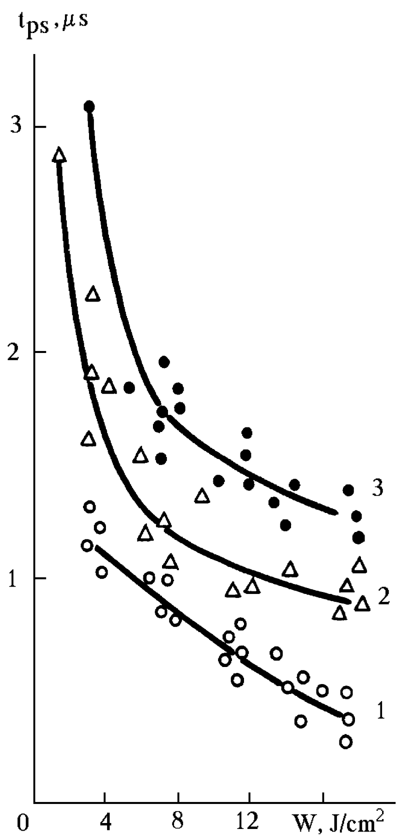

FIG. 3. The dependence of the time for the amplitude of the scattered signal to reach its peak value on the energy density in the pulse of the CO_2 *laser: monodisperse erosol with* $\overline{a} = 2.7$ μm *(1), polydisperse aerosol approximated by the gamma distribution with the parameters* $a_m = 4$ μm *and* $\mu = 1$ *(2), and* $a_m = 10$ μm *and* $\mu = 1.21$ *(3).*

Figure 4 illustrates the scattering properties of the secondary aerosol medium which has been formed after the explosion and vaporization of the aerosol particles. For the submicron fraction of aerosol (curve *1*) the increase in the energy contribution unambiguously results in degradation of the scattering properties of fragments. Heating up of the total volume of the uniformly absorbing particles in the case in which the energy reaches its threshold value results in the complete evaporation of particles already upon exposure to the leading edge of the pulse. Intensive vaporization of

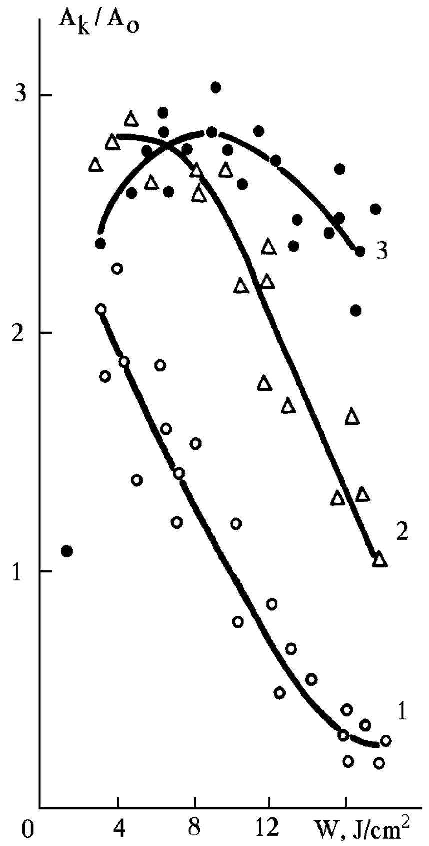

FIG. 4. The dependence of the amplitude of the scattered signal after the explosion of the particles on the energy density in the pulse of the CO_2*–laser radiation: monodisperse aerosol with* $\overline{a}$ = 2.7 μm *(1); polydisperse aerosol approximated by the gamma distribution with the parameters* a_m = 4 μm *and* μ = 1 *(2) and* a_m = 10 μm *and* μ = 1.21 *(3).*

fragments upon exposure to the tail of the pulse provides the more complete vaporization and decrease of the water content of the secondary medium. For the large–droplet aerosol the tendency toward the decrease of the water content starts to manifest itself only when the energy reaches the value sufficient for complete evaporation of the large particles. We can infer from comparison with the data from Ref. 8 on the amount of the absorbed energy required for complete evaporation of large particles that the change in the behavior of the maximum A_m and final A_f amplitudes of the signal scattered from the explosive polydisperse aerosols is associated with the complete evaporation of the largest fraction of the particles.

Thus it was experimentally determined that there exists the dependence of the amplitude of the scattered signals of the laser illumination within the region of interaction between the high–power radiation at λ = 10.6 μm and the water droplet aerosol on the local energy density in the heating beam as well as on the microstructure of the aerosol located within the region occupied by the beam.

REFERENCES

1. N.N. Bochkarev, Yu.E. Geints, A.A. Zemlyanov, A.M. Kabanov, et al., Opt. Atm. **1**, No. 10, 111–112 (1988).
2. A.V. Kuzikovskii, L.K. Chistyakova, and V.I. Kokhanov, Kvantovaya Elektron. **8**, No. 10, 2090–2096 (1981).
3. V.E. Zuev and A.A. Zemlyanov, Izv. Vyssh. Uchebn. Zaved., Fizika **25**, No. 2, 53–66 (1986).
4. Yu.E. Geints, A.A. Zemlyanov, V.A. Pogodaev, and A.E. Rozhdestvenskii, Opt. Atm. **1**, No. 3, 27–34 (1988).
5. R.G. Pinnick, A. Biswas, R.L. Armstrong, et al., Appl. Opt. **29**, No. 7, 918–925 (1990).
6. V.A. Pogodaev and A.E. Rozhdestvenskii, *in*: *Abstracts of Reports at the Second Meeting on Atmospheric Optics,* Tomsk Affiliate of the Siberian Branch of the Academy of Sciences of the USSR, Tomsk (1980), pp. 7–8.
7. A.P. Prishivalko, *Optical and Heat Fields inside the Light Scattering Particles* (Nauka i Tekhnika, Minsk, 1983), 190 pp.
8. V.E. Zuev, A.A. Zemlyanov, and Yu.D. Kopytin, *Nonliniear Optics of the Atmosphere* (Gidrometeoizdat, Leningrad, 1989), 253 pp.