EXPERIMENTAL STUDY OF VAPOR CONDENSATION EFFECT ON THE SOLID-PARTICLE AEROSOL TRANSPARENCY UPON EXPOSURE TO THE INTENSE LASER RADIATION

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The experimental results of measurements of the solid aerosol transparency upon exposure to an intense cw CO_2—laser beam under condition when secondary particles appear due to condensation are presented. The dependences of resultant optical thickness on the initial one, on the size of initial aerosol particles, and on the intensity of heating beam are obtained. In the experiments with a single particle it was found that there appears a spherical layer around the particle where the secondary aerosol particles are formed due to condensation. It was also established that the sizes of secondary aerosol particles are independent of the sizes of initial particles and of the intensity of heating beam over the investigated range.

Intensive evaporation of an aerosol particle caused by radiative heating may result In vapor condensation and formation of a secondary particle cloud.[1,2] The results of experimental study of the vapor condensation of a water-droplet aerosol and ice crystals upon exposure to a CO_2—laser beam have been reported in Ref. 2. In contrast to Ref. 2, we study a solid particle sublimation (an evaporation excluding a liquid phase) for more intense radiation. The results of direct measurements of the sizes of the secondary particles are also presented.

In our experiments the particles of NH_4Cl (ammonium chloride) which sublimated at a temperature of 338°C and melted at 520°C were taken as an observed object. It is important that ammonium salts exhibit thermal instability and dissociate into ammonia and hydrochloride upon heating.[3] The given reactants practically are not acting with air and again produce a compound upon condensation.

To carry out the experiments, the powders of particles with different sizes were produced by the screening into size grades. Table *I* presents the main parameters of these powders. An aerosol cloud of the initial powder particles was formed by means of a USDN—2T commercial ultrasound disperser. A focused CO_g—laser beam and a coaxial probing beam of a He—Ne laser passed through the aerosol cloud in a horizontal plane. The particles tossed by the disperser were detected in the interaction region over the course of approximately 5 ms. The probing He—Ne laser beam was directed with the help of a CsJ plate into a FÉU photo—multiplier, and an interference filter with the maximum of transmittance at a wavelength of 0.63 μm was used to cover the CO_2 laser beam. The FÉU signal was recorded by a storage oscillograph. The switching time of the electromagnetic shutter of a KIPR CW CO_2 laser (with a maximal output power of 1 kW) was about 20 ms. The intensity of the heating beam I ranged from $5.2 \cdot 10^6$ to $2.6 \cdot 10^8$ W/m^2 by means of mlsalignement of one of the cavity mirrors.

Table I.

Mean radius $\bar{R}$, μm	Degree of monodispersity α
24	0.51
48	0. 12
80	0.24
107	0. 16
132	0.13

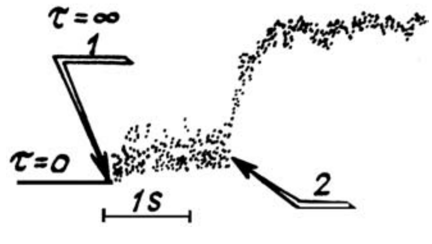

Fig. I

The experiments were carried out under standard atmospheric conditions. A typical time sweep, which characterize the dynamics of the aerosol transparency, is shown in Fig. 1, In which the lowest position of the ray of oscillograph is relevant for a zero value of the optical thickness τ, and the upper straight line marks $\tau = \infty$. Arrow *1* indicates the start of the pulverizing of the initial aerosol, arrow *2* indicates the start of the action of the high-power laser beam.

A distinctly visible cloud of secondary particles always appeared in the interaction region upon exposure to the high—power laser beam. In the course of the experiments, the secondary particles were collected on a special backing to determine their sizes for the subsequent statistical analysis.

The measurements performed with the help of a microscope have shown the mean radius $\bar{r}$ of the secondary

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particles to be 0.74 μm with the rms error in determining the particle size distribution $\sigma = 0.03$ μm (Fig. 2). The aerosol formed by the secondary particles appears to be monodisperse with the degree of monodispersity $\alpha = 0.042$. Essential is a fact that the value of $\overline{r}$ is independent of the initial particle sizes, at least in the interval from 24 to 132 μm for the probing radiation intensity ranging from $5.2 \cdot 10^6$ to $2.6 \cdot 10^8$ W/m^2.

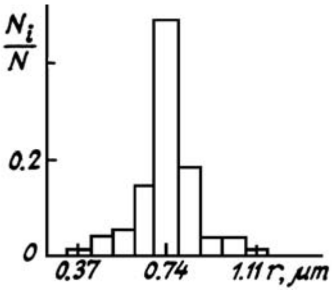

Fig. 2.

The high degree of monodispersity of the secondary aerosol indicates the fact that the production of new particles was caused by vapor condensation during evaporation of the initial particles upon exposure to the beam but not by the fragmentation of initial particles. The analysis of possible mechanisms of variations in the transparency of the disperse medium showed the condensation predominated.

For two different powders with radii $\overline{R}$ to be equal to 8 μm and 132 μm the threshold values of I were obtained: for smaller values of I the variations in the optical thickness were not observed. These two values of I are about $5.4 \cdot 10^8$ and $8.4 \cdot 10^8$ W/m^2, respectively.

In contrast to the data of Ref. 2 a short–time clearing of aerosol just after the start of the laser action was not observed in our experiments. In the above–mentioned paper ice crystals were used which melted upon heating and ЗОГ auk to droplets, thereby increasing the transparency of the medium for a short time, and then these droplets evaporated resulting in supersaturation and vapor condensation and the subsequent formation of the secondary particles.

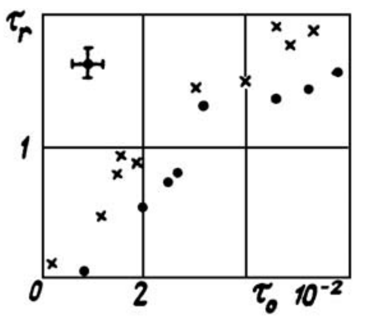

Fig. 3.

Figure 3 presents the resultant optical thickness τ_r as a function of the initial thickness τ_0 for the primary particles with a radius $\overline{R} = 132$ μm for two different Intensities of the CO_2–laser beam. As can be seen from Fig. 3, the resultant optical thickness τ_r increases with the increase of both the initial optical thickness of the medium, i.e., the particle number density, and the value of I. This can be explained by a higher probability for particles with higher number density to be detected in the interaction region, while the increase in the beam intensity results in an increase of the evaporation rate of the particles. The both mechanisms provide an increase of the vapor amount and subsequent increase in the secondary particle number in the process of condensation.

The special experiments were performed to determine the time t_{ev} over which the particle is completely evaporated. A single particle was placed on the NaCl backing which was practically transparent for radiation with the wavelength $\lambda = 10.6$ μm, and the dynamics of the evaporation process was recorded by a SKS–1M high–speed motion picture camera. Eperiments showed the values t_{ev} were about 80 and 120 ms for particles with radii R to be equal to 145 μm and 261 μm, respectively, and for the intensity I of the CO_2–laser beam to be equal to $5.1 \cdot 10^7$ W/m^2. As was mentioned above, in studying the condensation in aerosol cloud the initial particle was detected in the interaction region over the course of about 5 ms. In this time its radius R remained practically unchanged and no clearing would be observed.

It then follows that the results of measurements of τ_r and τ_0 make it possible to calculate the value of the volume aerosol extinction coefficient k by the secondary particles using the formula[4]

$$k = \frac{1}{l} [\, \tau_r - \tau_r]$$

where l is the thickness of the disperse medium. Figure 4 shows k as a function of the initial optical thickness τ_0 for $l = 2.5 \cdot 10^8$ W/m and different values of $\overline{R}$. All the experiments with a single particle revealed the appearance of a spherical layer around the particles with the radius being equal to (10–12) R. Appropriate conditions of condensation are reached and at this distance intensive producing of the secondary particles occurs. This conclusion is in agreement with the results of Ref. 5, in which the same condensation mechanism was described theoretically.

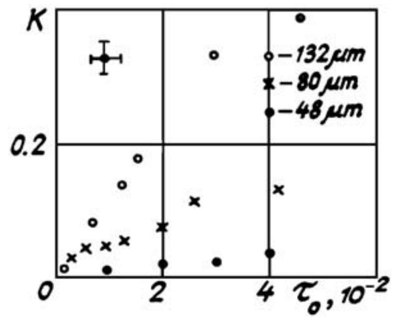

Fig. 4.

In conclusion it should be noted that the independence of the secondary particle sizes on the sizes of the initial aerosol particles under Investigation essentially simplifies the analysis of the intense laser beam propagation through polydisperse aerosol taking a condensation process into account.

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REFERENCES

1. A.V. Kusikovskii and S.S. Khmelevtsov, Izv. Akad. Nauk SSSR, Ser. FAO **11**, No. 4, 362 (1975).
2. O.A. Volkovitskii, V.V. Denisov, E.V. Ivanov, and M.P. Kolomeev, in: Tr. Ins. Exper. Meteor. Akad. Nauk SSSR, Obninsk, No. 13 (58), 95–107 (1976).
3. N.L. Glinka, *General Chemistry* (Khimiya, Leningrad, 1974), 704 pp.
4. M. Born and E. Volf, *Principles of Optics*, 4*th* ed. (Pergamon Press, Oxford, 1970).
5. G.V. Lyamkina and A.M. Shalduk, in: *Interaction of High-Power Laser Radiation with Aerosol* (Novosibirsk State University, Novosibirsk, 1989), pp. 71–79.