
SHORT
COMMUNICATIONS

Dynamics of Al_2O_3 Particles Accelerated in the Field of a Submillisecond Pulse from an YAG : Er Laser

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Abstract—The effect of the laser energy density on the velocity of sapphire particles accelerated in the field of a submillisecond pulse from an YAG : Er laser is reported for the first time. An original velocity-measuring system is described. It is shown that the acceleration of sapphire particles immersed in water (suspension) requires an energy that is nearly half as great as that needed to accelerate the particles containing the water adsorbed by the surface (powder). It is found that the particle velocity is nonuniformly distributed over the period of the laser pulse action. © 2005 Pleiades Publishing, Inc.

The idea of light pressure dates back to Kepler, who postulated in 1619 that, because of light pressure, the tail of a comet is always directed away from the Sun. The corpuscular theory of light of Newton made the idea of light pressure more plausible and stimulated many attempts to measure it experimentally. In the 18th and 19th centuries, all attempts to discover the light pressure or find a force that cannot be assigned to convection in air failed. Crookes in 1873 believed that he had discovered light pressure in a partially evacuated chamber, although actually he had invented a radiometer. Finally, the existence of light pressure free of disturbing thermal effects was proved by Lebedev in Russia and Nichols and Hull in the United States [1]. Advances in the laser technology have caused a rebirth of interest in light pressure. As early as in 1962, Askar'yan [2] showed that an intense light beam may have a strong influence on charged and polarizable particles and that the associated forces may change sign in going through the resonant frequency of polarization. Application of such an effect for preventing the particle concentration difference, for particle transport, and for producing rarefied or condensed areas in different media was noted. At the same time, Askar'yan and Moroz [3] demonstrated that light absorption by a particle irradiated may generate three types of forces related to (i) heating and motion of the medium itself, convective drag; (ii) heating of the medium by the absorbing surface of the particle, radiometric pressure; and (iii) pressure due to the evaporation of the particle itself, light-reactive pressure. All the effects listed may exceed the light pressure by many times and show up in experiments with a high probability. It is noteworthy

that the reactive pressure may be as high as 10^{12} atm. Such a pressure may be used, in particular, for accelerating microparticles [4] to velocities on the order of 10^6 – 10^8 cm/s to produce micrometeors, particles that release a high local energy when colliding with a target or with each other. These particles may be applied for processing composites (including biological composites) when the potential of conventional and laser-assisted technologies is exhausted. For example, a flux of laser-accelerated Al_2O_3 particles may be applied for increasing the rate of processing the enamel of human teeth [5]. In this case, the water surrounding the particles (suspension) or adsorbed by them (powder) effectively absorbs radiation at a wavelength of 2940 nm and vaporizes, favoring the light-reactive motion of the particle. In this work, we for the first time experimentally investigate the effect of laser energy density on the velocity of hard sapphire particles accelerated in the field of a submillisecond pulse from an YAG : Er laser. The energy sufficient to accelerate the particles of different size is estimated, and the particle velocity variation with time after the laser action is determined.

In the experiments, we used a prototype of an YAG : Er free-running 100-mm-long laser of diameter 6.3 mm operating at 2940 nm. The pulse FWHM was 250 μs . The radiation passes through a CaF_2 lens and is focused into a spot of diameter $600 \pm 50 \mu\text{m}$. In this way, an energy density of 250 J/cm² was achieved. As hard particles, we used Swam-Blast ultrapure Al_2O_3 powder. The rated density of the particle material was 3.97×10^3 kg/m³. The diameters of the particles were 12, 27, 40, and 160 μm . Both the suspension and pow-

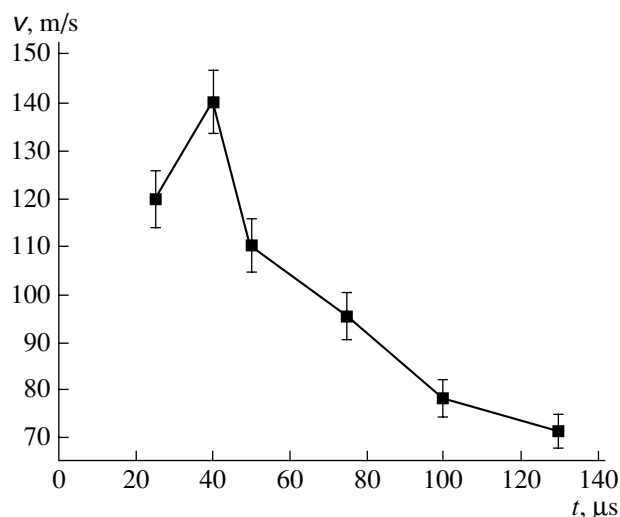


Fig. 1. Variation of the particle mean velocity with time after the YAG : Er laser pulse has been switched on (the Al_2O_3 particle diameter is $12\text{ }\mu\text{m}$, the energy density is 135 J/cm^2).

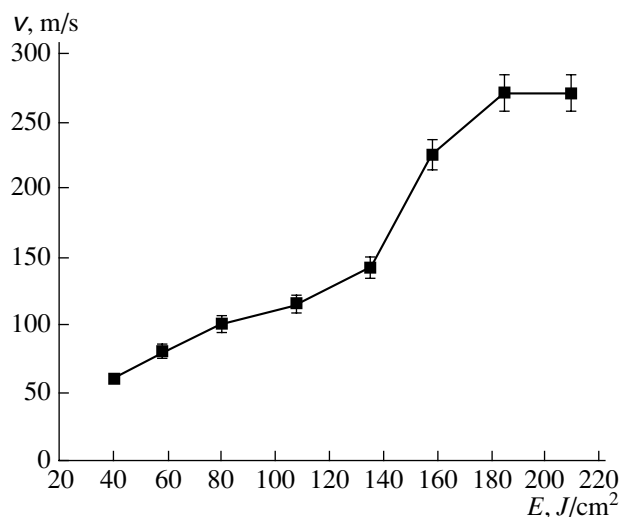


Fig. 2. Variation of the particle mean velocity with YAG : Er laser energy density (the Al_2O_3 particle diameter is $12\text{ }\mu\text{m}$). The velocity was measured $40\text{ }\mu\text{s}$ after the laser pulse had been switched on.

der were studied. The suspension was prepared in proportion 300 mg of the particles per 0.2 ml of water. The particles (suspension or powder) were placed in a glass cell with a sapphire bottom. The thickness of the particle bed was $200 \pm 50\text{ }\mu\text{m}$. The laser radiation was focused on the contact plane between the particles and cell bottom. The radiation-accelerated particles left the space of interaction and were photographed with a MINTRON high-sensitivity controlled-shutter video camera interfaced to a computer and a synchronizer. The optical axis of the objective of the video camera was directed normally to the direction of laser beam propagation and passed through the space of particle-radiation interaction. The synchronizer generated a laser-starting sync pulse and a frame sync pulse. Interval Δt_1 between the time of the frame pulse (t_0) and the time of the laser pulse (t_1) may be varied. The exposure time, i.e., the time over which the shutter is open, may be varied from $100\text{ }\mu\text{s}$ to 2 ms (in the experiments, it equaled $500\text{ }\mu\text{s}$). We could also vary interval Δt_s between the time of the frame pulse (t_0) and the time of shutter opening (t_s). Thus, over a time interval of $500\text{ }\mu\text{s}$, we could record events taking place within time Δt_s . Cutting Δt_s made the image of particles flying apart disappear from the monitor, while a small increase in t_s returned the image to the monitor. This time instant (t_1) was taken to be the beginning of particle motion. Estimating the difference between t_1 and t_1 , we determined the delay between the beginning of the laser pulse and the beginning of particle motion. Then, increasing t_s , we could record the accumulation of particles flying apart within time Δt that is the difference between t_s and t_1 . The computer controlled the synchronizer, as well as photo

acquisition, storage, and processing. The images were used to measure the length of the most intense tracks of pulse-field-heated particles flying almost normally to the bed. In this way, we minimized the error in determining the track length due to the angular divergence of the particles. Dividing the track length by Δt , one can easily find the mean velocity of the particles over this time period.

In the experiments, we determined the threshold value of the laser energy at which particles of different diameters start moving. It turned out that the energy density 0.3 J/cm^2 suffices to accelerate particles of diameter $12\text{ }\mu\text{m}$ from the suspension. To accelerate these particles from the powder, 0.7 J/cm^2 is required. To accelerate particles of diameter $27\text{ }\mu\text{m}$ from the powder, it is necessary that the energy density be 1.5 J/cm^2 ; for those of diameter $40\text{ }\mu\text{m}$, 2.2 J/cm^2 ; and for those of diameter $160\text{ }\mu\text{m}$, 6.0 J/cm^2 . That is, the energy density required for sapphire particles to be accelerated from water (suspension) is roughly half as high as that needed for the particles containing water adsorbed by the surface (powder) to be accelerated. It was established experimentally that the particle velocity varies within the time of laser action (Fig. 1), increasing with laser energy density (Fig. 2). Over the time of laser action, the velocity of $12\text{-}\mu\text{m}$ Al_2O_3 particles first sharply grows, reaches a maximum (by the 40th microsecond), and then declines gradually. Moreover, the particles go on moving after the pulse is switched off. It should be noted that such behavior was also observed for particles of the other diameters. In the field of a sub-millimeter pulse from an YAG : Er laser, a nonabsorbing Al_2O_3 particle surrounded by surface-adsorbed

water (powder) may be accelerated to a velocity of 275 m/s, which corresponds to a kinetic energy of about 0.27 μJ for the 12- μm particles. This energy suffices to destroy a very hard material, such as tooth enamel [5].

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