EXPERIMENTAL STUDY OF THE CHARACTERISTICS OF A SOUND PULSE GENERATED BY THE PLASMA FORMATION INITIATED BY A SOLID AEROSOL PARTICLE EXPOSED TO LASER RADIATION

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Results of experimental study of the characteristics of a sound pulse generated by the plasma formation initiated by a solid aerosol particle exposed to laser radiation with a wavelength of 1.06 μm *are presented as functions of particle size and material. Linear dependence of amplitude and duration of a positive pulse half-period on the particle size is established. It is also demonstrated that the pulse characteristics depend significantly on the particle material.*

One of manifestations of nonlinear interaction between high-power laser radiation and atmospheric aerosol is sound pulse generation by local plasma formations initiated by aerosol particles exposed to laser radiation. The characteristics of the laser-induced acoustic signals were investigated in a number of papers in the real atmosphere and under laboratory conditions (see, for example, Refs. 1–4). However, in these papers a material of particles, initiating laser breakdown, was not considered. The dependence of amplitude and duration of acoustic pulse on the size and material of the aerosol particle initiating the plasma formation was investigated by the author earlier in Refs. 5 and 6. In these experiments, the size (the effective diameter) of aerosol particle changed from 7 to 630 μm. It was established that for micron-sized atmospheric aerosol particles the dependence of amplitude A and duration τ of a positive half-period of acoustic pulse on the effective particle diameter a are linear and have the form

$$A = A_0 + k_A a; \quad (1)$$

$$\tau = \tau_0 + k_\tau a. \quad (2)$$

In the present paper, the feasibility of diagnostics of a material of aerosol particles from data of opto-acoustic measurements is studied. Experiments with K_2SO_4, CaO, $CaCO_3$, $BaCl_2$, KCl, $FeSO_4$, Na_2CO_3, and KNO_3 particles 630 μm in diameter and with SiO_2 and SiC particles whose diameters were changed from 7 to 630 μm were carried out. The particles of fixed sizes were prepared and calibrated at the Yurginskii Abrasive Factory.

Block diagram of the experimental setup is shown in Fig. 1. A laser breakdown was initiated by focusing of radiation of the GOS–1001 laser *2* with a wavelength of 1.06 μm, a pulse duration of 1 ms, and energy in a pulse up to 1 kJ at a distance of 50 cm. Radiation was adjusted with the help of an LGN–105 cw laser. The laser beam diameter was measured with the use of a metal screen placed in the focal plane and was equal to 7 mm. In the focus, the particle *6*, initiating the plasma formation, was suspended on a needle point. The needle did not initiate a laser breakdown, which was checked by photos of the caustic region without a particle and by indications of devices. To monitor the laser output power, the laser power meter *4* was used, at the input of which 1.5% of the total laser energy was directed with the help of the plane-parallel plate *3*.

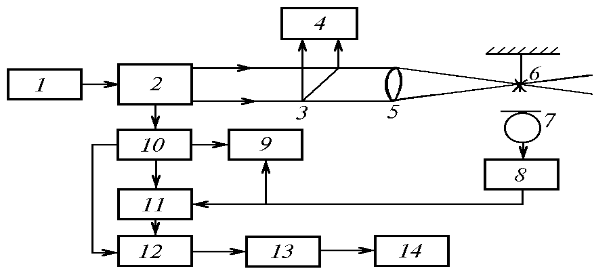

FIG. 1. Block diagram of the experimental setup intended for investigation of the characteristics of acoustic pulse generated by the plasma formation initiated by a solid aerosol particle exposed to laser radiation comprising LGN–105 laser with a wavelength of 0.63 μm *(1), GOS–1001 high-power pulsed laser with an active element fabricated from glass doped with neodymium (2), K–8 plane-parallel plate (3), IMO–2H laser power meter (4), shot-focus lens (5), particle initiating the plasma formation (6), MK–221 receiving microphone with MV–201 amplifier (7), PSI 00017 precision impulse sound level meter (8), S8–17 oscillograph (9), G5–54 generator (10), tape recorder (11), ATP–10 ten-bit analog-to-digital converter (12), K–16 CRATE-controller (13), and Elektronika–60 microcomputer with standard peripheral devices (14).*

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The block of registration and processing of acoustic signal included the receiving microphone *7*, placed at a distance of 15 cm from the particle under the laser beam caustic to avoid many re-reflections, and the precision impulse sound level meter *8*, a signal from an amplifying output of which was fed into a processing system, comprising the ADC *12* with a maximum sampling frequency of 1 MHz and the 64 Kbyte memory, the interface *13*, the computer *14*, and the storage oscillograph *9* used for visual monitoring. The ADC was actuated by a laser triggering pulse that was fed into the generator *10*, where a pulse of external ADC triggering was generated, or with the help of the second MK–221 microphone with the MV–201 amplifier, placed at a distance of 10 cm from the laser beam axis. A signal from the second microphone was fed into the second PSI 00017 precision impulse sound level meter. A signal from the amplifying output of the second precision impulse sound level meter was also fed into the generator *10*.

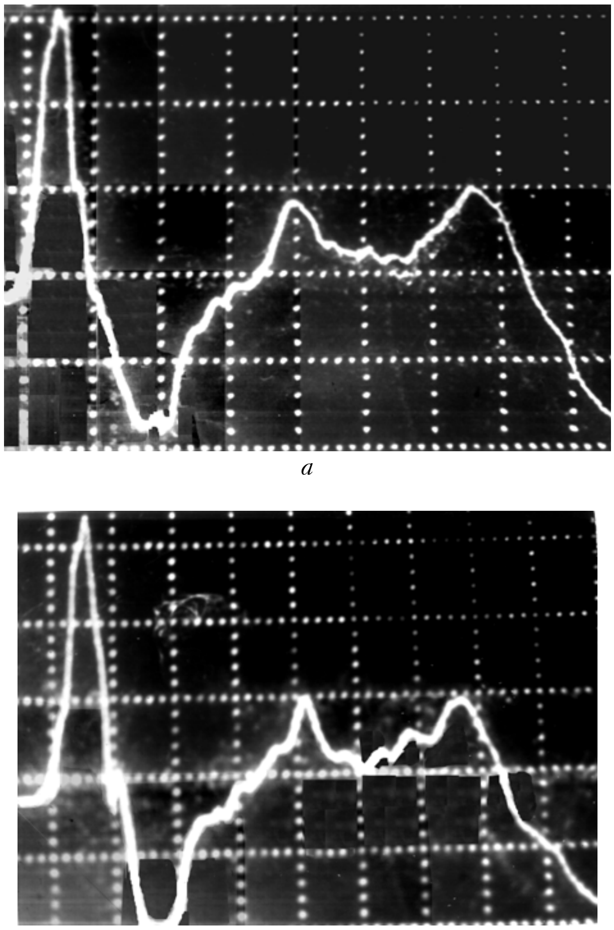
After filling of the RAM with the 64 KByte memory, built-in in the ADC, its next triggering was blocked to save the information, and a query for data transfer in the computer was generated. Through the K–16 CRATE-controller the signal entered the computer, where it was processed by the given algorithm after each laser shot.

The computer was equipped with standard peripheral devices. For visual monitoring, a display was used. From the amplifying output of the precision impulse sound level meter a signal was fed into a storage oscillograph, which was actuated by a triggering pulse synchronously to a pulse of ADC triggering.

Dependences of amplitude and duration of a sound pulse generated by the plasma formation on the effective diameter of the aerosol particle, initiating this plasma formation, were investigated. In Fig. 2 are shown the waveforms of acoustic signals generated by plasma formations initiated by SiO_2 particles 160 μm in diameter for two individual realizations. Good reproducibility of acoustic measurements has engaged our attention. A conclusion of Ref. 1 that an acoustic pulse generated by the plasma formation initiated by a solid aerosol particle exposed to laser radiation has the form of an N-wave is also supported. Thus, the sound pressure level at the point of observation can be written as

$$p(t) = \begin{cases} 0, & t < t_1 = (R_0 - r_p)/c, \\ \dfrac{p_0\,(R_0 - ct)}{2R}, & t_1 \le t \le t_2 = (R_0 + r_p)/c, \\ 0, & t > t_2, \end{cases} \quad (3)$$

where R_0 is the distance from the plasma formation center to the receiving microphone, r_p is the radius of the plasma formation, c is the velocity of sound in air, p_0 is the initial pressure level in the region of compression, determined by the amount of laser energy absorbed by the particle and hence depending on the material of the particle.



a

b

FIG. 2. Waveforms of acoustic signals (individual realizations). The ordinate scale division is 1 V*, and the abscissa scale division is* 0.5 ms.

As seen from Fig. 2, electrical analogs of sound pressure amplitudes were 3.1 and 3.4 V for positive half-periods of signals and 1.8 and 2 V for their negative half-periods. Durations of positive and negative half-periods were 0.5 and 0.6 ms and 1.25 and 1.1 ms, respectively. Hence, unlike the results reported in Refs. 1 and 3, where the amplitudes of positive and negative half-periods were equal according to formula (3) for a laser breakdown induced by Cn_2 or GOS–1001 lasers, in our case $A_+ = 1.7\,A_-$ for both realizations. Durations of half-periods, unlike Ref. 1 and formula (3), were $\tau_- = 2.5\,\tau_+$ for the first and $\tau_- = 2.1\,\tau_+$ for the second realization. It should be noted that an inequality of amplitudes and durations of half-periods of acoustic signals was also pointed out in Ref. 4, where it was found that $A_+ = 1.2\ A_-$ and $\tau_- = 1.5\,\tau_+$ for a breakdown induced on a particle by a Cn_2 laser. Stretching of the negative half-period was also indicated in Ref. 3 with identical amplitudes of

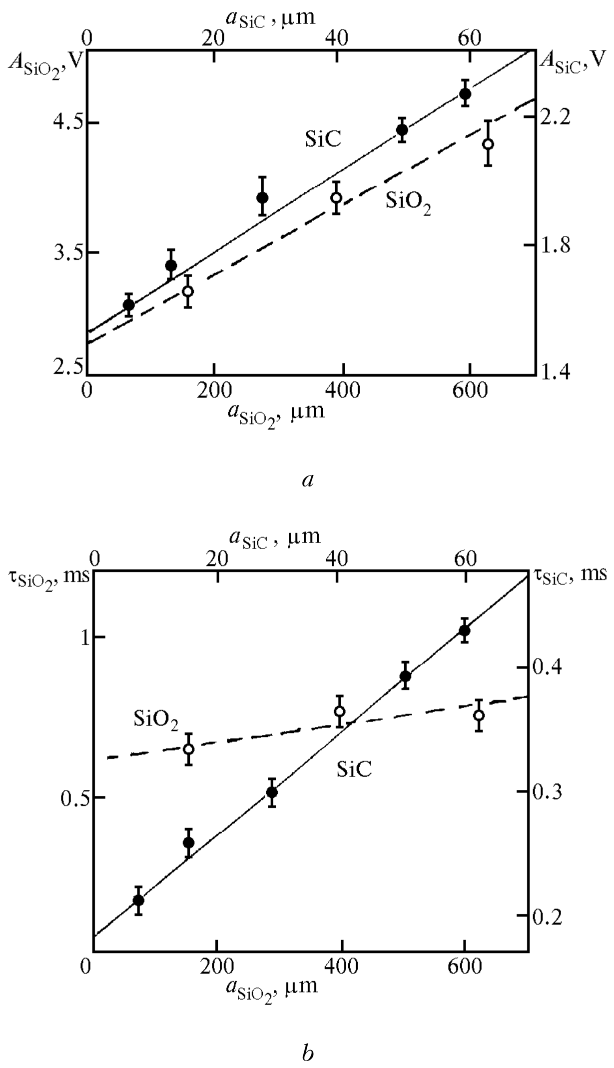


FIG. 3.

positive and negative pulse half-periods, where it was found that $\tau_- = 2.1\,\tau_+$ for the SiO_2 particle 400 μm in diameter initiating a breakdown upon exposure to radiation of a GOS–1001 laser. This agrees with our data for a SiO_2 particle 160 μm in diameter, obtained in the second realization.

In Fig. 3 dependences of amplitude and duration of the first positive half-period of an acoustic pulse on sizes of SiO_2 and SiC particles are shown. For each particle of the fixed size (7, 14, 28, and 60 μm for SiC and 160, 400, and 630 μm for SiO_2) the data were averaged over 10 individual measurements. Vertical bars indicate standard deviations from average values. It can be seen that the observed dependences are linear, as follows from formulas (1) and (2), with coefficients of proportionality $k_A = 0.0026$ and 0.012 V/μm and $k_\tau = 0.0003$ and 0.004 ms/μm for SiO_2 and SiC particles, respectively, i.e. they differ essentially. The coefficients A_0 are equal to 2.7 V for SiC particles and 2.75 V for SiO_2 particles; the coefficients τ_0 for these particles are equal to 0.06 and 0.62 ms, respectively.

Amplitudes and durations of positive half-periods of acoustic pulses for various particles of the fixed size (630 μm) are given in Table I. For each material the data, given in the table, were averaged over 10 individual measurements. The variance of the results and the 95% confidence level are also indicated here.

The data presented in Table I also demonstrate essential dependence of the amplitude and duration of positive half-periods of acoustic pulses, generated in laser breakdown, on the material of particles.

Based on the obtained results, a conclusion can be made that the characteristics of acoustic signals generated in laser breakdown, in contrast to the optical ones, essentially depend on the material and sizes of particles, which allows one to put and to solve inverse problems on diagnostics of the structural characteristics and elemental composition of aerosol particles from the data of opto-acoustic measurements.

TABLE I. Dependence of amplitude and duration of a positive half-period of acoustic signal, generated by the plasma formation initiated by the particles 630 μm *in diameter exposed to laser radiation, on a material of particles.*

Material	Amplitude $\langle A \rangle$, V	Duration $\langle \tau \rangle$, ms	Variance σ		95% confidence level	
			σ_A	σ_τ	Amplitude	Duration
K_2SO_4	0.428	0.356	1.17×10^{-2}	5.47×10^{-3}	-6.84×10^{-3} $+1.53 \times 10^{-2}$	-1.62×10^{-2} $+3.64 \times 10^{-2}$
Na_2CO_3	0.440	0.364	2.53×10^{-2}	1.60×10^{-2}	-3.16×10^{-2} $+7.08 \times 10^{-2}$	-2.00×10^{-2} $+4.48 \times 10^{-2}$
$CaCO_3$	0.446	0.374	1.02×10^{-2}	4.89×10^{-3}	-1.43×10^{-2} $+1.45 \times 10^{-2}$	-6.83×10^{-3} $+1.53 \times 10^{-2}$
$FeSO_4$	0.462	0.384	1.72×10^{-2}	1.85×10^{-2}	-2.15×10^{-2} $+4.01 \times 10^{-2}$	-2.31×10^{-2} $+5.18 \times 10^{-2}$
CaO	0.466	0.390	4.84×10^{-3}	1.41×10^{-2}	-6.84×10^{-3} $+3.95 \times 10^{-2}$	-1.78×10^{-2} $+1.53 \times 10^{-2}$
KNO_3	0.404	0.392	4.89×10^{-3}	9.79×10^{-3}	-6.11×10^{-3} $+1.37 \times 10^{-2}$	-1.22×10^{-2} $+2.74 \times 10^{-2}$
$BaCl_2$	0.584	0.580	1.96×10^{-2}	4.00×10^{-2}	-2.73×10^{-2} $+6.13 \times 10^{-2}$	-5.00×10^{-2} $+1.12 \times 10^{-1}$
KCl	0.504	0.600	5.42×10^{-2}	4.47×10^{-2}	-6.77×10^{-2} $+1.51 \times 10^{-1}$	-5.58×10^{-2} $+1.25 \times 10^{-1}$

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