Electric field of a laser spark ignited near a conducting target

N. I. Goncharov, V. I. Konov, T. M. Murina, P. I. Nikitin,
A. M. Prokhoerov, V. M. Sidorinn, and V. A. Chudnenko

P. N. Lebedev Physics Institute, USSR Academy of Sciences

(Submitted August 31, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **26**, No. 7, 551–554 (5 October 1977)

A double electric-field burst was observed in the breakdown of air by laser radiation near a conducting target. The appearance of the electric field is attributed to the separation of the charges on the front of the optical detonation wave and to a shock wave propagating from the plasma.

PACS numbers: 52.50.Jm, 52.35.Tc, 52.80.Mg

Following the observation[4] of the magnetic dipole moment of a laser spark, a number studies have been made of the spontaneous magnetic field of a laser plasma. An indication that laser spark in air has an electric dipole moment was given in[2] but no study was made of th electric field near the spark. In the present work we observed a double burst of the electric field at probe placed near the plasma of air breakdown initiated by the emission from a neodymium lase on the surface of a conducting target.

In the experiment we used a laser with a pulse energy $E_0 \approx 10$ J and a duration at half-heigh 25 nsec. The radiation was focused with a lens having a focal length $f = 10$ cm. The area of th irradiated spot on the surface of the target was ≈ 2 mm^2. Metallic and dielectric targets were use The probe was a segment of the central conductor of a cable with a wave resistance 150 matched to the input of a broadband amplifier. The braid of the cable and the conduction targ was grounded. The signals were registered with an S1-70 oscilloscope.

Typical signals obtained from a stripped probe 1 cm long, located at a distance $r = 12$ m from the laser-beam axis and at a distance $z = 4$ mm from the surface of a copper target are show

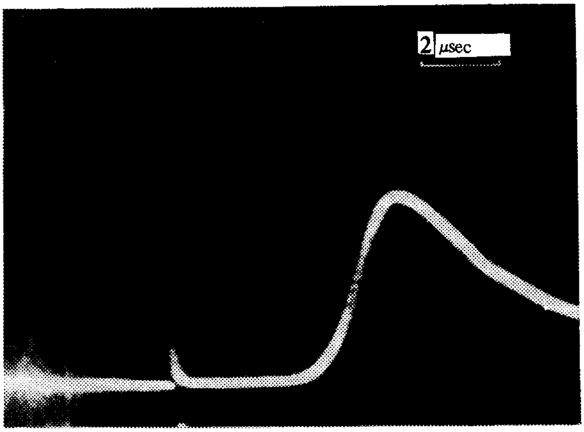

FIG. 1. Characteristic oscillograms of signals from a stripped probe.

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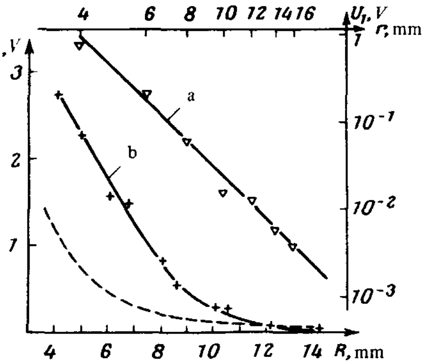

FIG. 2. a) Dependence of the amplitude U_1 of the first signal on the distance r to the laser-beam axis; b) dependence of the amplitude U_2 of the second signal on the distance R to the effective center of the explosion (dashed curve—calculated).

Fig. 1. The leading front of the first signal coincided in time with the laser pulse. The amplitude ıd shape of this signal are independent of whether the probe was stripped or left in the dielectric sulation. The second signal was registered only with a stripped probe at the breakdown of the air ;ar the conducting target. A number of experiments with different screens and filters have shown at in our case the influence of the photoeffect from the surface of the probe can be neglected.

The first probe signal produced at the instant of the laser pulse is due in our opinion to the paration of the charge on the front of the optical detonation wave. At a radiation intensity 2×10^{10} W/cm^2 the plasma front propagates in the detonation regime with a velocity ~70 a/sec.[3] The electron temperature behind the detonation-wave front can reach $T_e = 5\times 10^5$K, d the thickness of the optical detonation wave front, approximately equal to the laser-radiation sorption length, is ~ 10^{-3} cm.[3] On the front of the optical detonation wave there exists apprecia- gradients of n_l and T_e. This causes the electrons, which are more mobile than the ions, to erupt rward.[4] The electric field in the front of the optical detonation wave can be estimated from the rmula

$$E_f = \frac{\nabla P_e}{n_e e} = \frac{\nabla T_e}{e} + T_e \frac{\nabla n_e}{n_e} , \tag{1}$$

ıere e is the charge and $P_e = n_e T_e$ is the electron pressure (T_e in eV). For the conditions of our periments we obtain from (1) $E_f \sim 10^5$ V/cm. The electric-field forces lines are closed outside e plasma region. The signal from a probe placed in the external electric field registers the riation of the potential in the probe circuit. The probe-signal amplitude is related with the aximum field E at a given point where the formula $U = R_L S_{\rm eff} E/4\pi\Delta t$, where R_L is the resistance the probe circuit, $S_{\rm eff}$ is the effective probe area. In our case, at $R_L = 150$ Ω, $S_{\rm eff} = 0.1$ cm^2, and $= 3\times 10^{-8}$ sec we obtain the relation E[V/cm]$=2.2\times 10^4 U$[V] for the relation between the ectric field and the probe signal. Figure 2 (curve a) shows the dependence of the amplitude of the st pulse registered by the probe on the distance r at $z = 4$ mm in a logarithmic scale. The line awn through the experimental point has a slope ≈4. Extrapolation of the measured values of the ectric field in the front of the optical detonation wave agrees with the field E_F calculated from).

We proceed now to the examination of the second signal. Measurements for different probe sitions r and z have shown that the time delay at t_d of the second signal relative to the start of the er pulse corresponds to the time necessary for the shock wave produced in the air breakdown to ıch the probe. With r and z as coordinates, we plotted the contours of constant time delay of the cond signal, which outline adequately the front of the spherical shock wave at different instants time (Fig. 3). The effective center of the shock wave is located at a distance $z = 3$ mm from the get. The values of t_d at $r > 4$ mm agree well with the formula for a point-center of explosion:

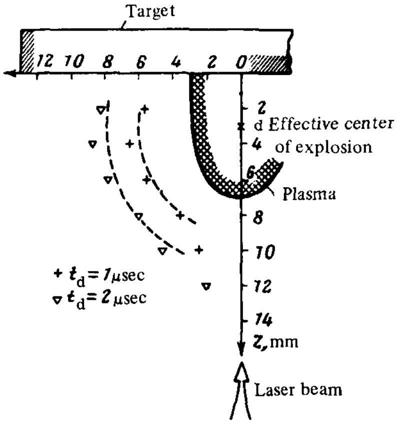

FIG. 3. Contours of probe positions at constant time delays of the second signal relative to the start of the laser pulse.

$t_d = (\rho_0/E_0)^{1/2}R^{5/2}$, where ρ_0 is the density of the cold air, E_0 is the energy of the laser pulse, and R the distance from the center of the explosion and the nearest point of the probe. The dashed curve in Fig. 3 are the calculated values of the positions of the shock-wave front at 1 and 2 μsec followin the laser pulse.

The front of the free shock wave (far from the target) is polarized as a result of the separatio of the charges and constitutes an electric double layer. The resultant potential jump on the shoc wave front can be estimated[4] by the expression

$$\Delta\phi = \phi_1 - \phi_0 \approx \frac{T_{ef}}{e}\,, \qquad ($$

where ϕ_0 is the potential of the unperturbed air ahead of the shock-wave front, ϕ_1 is the potenti behind the front of the free shock wave, T_{ef} is the temperature of the electrons in the front of th shock wave, and ρ_1/ρ_0 is the shock compression. However, the edge of the shock-wave front, whic glides over the grounded conducting target, cannot be polarized. The surface current induced i the grounded target presents separation of the charges on the edge of the shock-wave front th glides along the target. Therefore the potential behind the shock-wave front near the target will n have a discontinuity and is equal to ϕ_0. Then a potential drop equal to $\Delta\phi$ is produced along th shock-wave front itself, and is determined from (2). Thus, when the shock wave reaches the prob a potential difference $\Delta\phi$ is produced between the probe and the grounded target and consequent an electric current flows over the shock-wave front, which is a fair conductor, and gives rise to second signal on the oscilloscope screen. Curve b in Fig. 2 shows the dependence of the amplitu of the second signal on the distance to the effective center of the plasma shock wave. The san figure shows (dashed) a curve calculated from (2) and plotted under the assumption that T coincides with the temperature of the gas behind the shock-wave front. This interpretation of th second signal is confirmed by a number of experiments in which the plasma of breakdown in a was ignited without a target and on a dielectric target. In these cases, to observe the second sign i.e., to produce a potential drop along the shock-wave front, a second grounded probe w introduced. The second signal was produced whenever the shock-wave front short circuited th two probes.

We note that the registration of the second signal can be used as a method for the diagnosti of shock waves; this method yields information on the spatial picture of the shock-wave front, o the law governing its propagation, and on the temperature behind the front.

The authors thank A.I. Barchukov and F.V. Bunkin for useful discussions.

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