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INVESTIGATION OF LIGHT SPARK AND OF OTHER OPTICAL EFFECTS IN FOCUSING OF LIGHT BY A LENS WITH A CHANNEL ON THE AXIS

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This article describes a new method and results of diagnostics of rapid nonlinear effects in the focus of powerful light, performed with the aid of a longitudinal beam. In our case the main and diagnostic beams were produced with a lens having a hole or a polished curvature on its axis. Such a lens produces, besides the main beam that converges at the focus (and diverges rapidly past the focus), also a paraxial parallel beam, the shadowing of which makes it possible to investigate processes occurring in the focus of the lens (a light spark in a gas, breakdown of dense media, nonlinear refraction, etc) during the course of the light flash itself.

The experimental setup is shown in Fig. 1. The beam of a laser with a prism Q-switch and with a power up to 50 MW passed through a drilled lens. The focus of the lens was inside a metallic pressure vessel with glass windows, filled with various gases (pressure from fractions of an atmosphere to several atmospheres). In certain experiments the focus of the lens was inside a liquid-filled cell or inside a transparent solid. The focal length of the lens was 4 cm, the diameter of the hole on the axis was 3 mm, and the diameter of the beam on the lens was 15 mm, i.e., the energy of the beam emerging through the hole was only several per cent of the total light energy. The shadow image was recorded at distances 10 - 20 cm from the spark by photography on film, followed by photometry.

Figure 2 shows photographs of the shadows produced by light sparks in various dense media.

Figure 3 shows the distribution of the light-energy density q(r) of the axial beam, obtained by calibration of the film density, for shadows of light sparks in various gases and at various pressures.

The shadowing of the beam may be due to absorption of the light, accompanied by refraction or surface reflection by the spark plasma. The small differences between the images of the shadow at two distances from the spark (L = 10 and 20 cm) shows that the beam divergence at these distances is $\theta \lesssim 10^{-2}$ rad, making it possible to estimate the properties of the plasma near the boundary of the shadow-producing object: $\delta\theta \sim \ell\omega_p^2/\tau\omega^2 \sim 10\omega_p^2/\omega^2 \lesssim 10^{-2}$ (where ℓ and r are the effective longitudinal and transverse dimensions of the refracting region), i.e., $\omega_p^2 \sim 10^{-3}\omega^2$ or $n_e \simeq m\omega_p^2/4\pi e^2 \simeq 4 \times 10^{18}$ cm^{-3}.

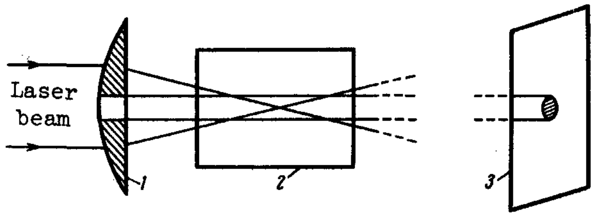

Fig. 1. Experimental setup

Besides strong absorption, the plasma may

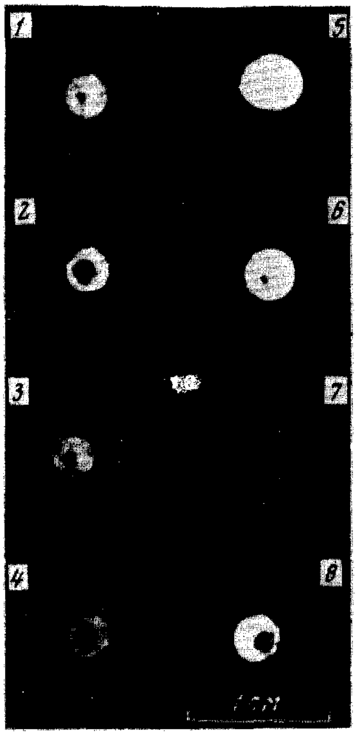

Fig. 2

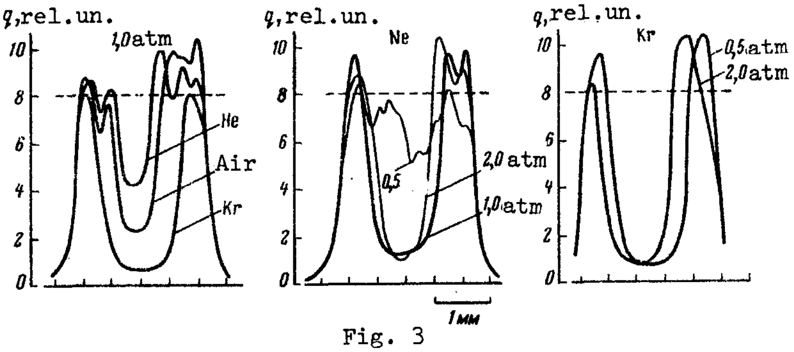

Fig. 3

Fig. 2. Photograph of shadows from light sparks in He (1), Ne (2), air (3), Kr (4) at 1 atm pressure, and of shadows produced by focusing in glass (5, no shadow), oil (weak shadowing, 6), toluene (7, strong shadowing), and water (8). All curves are for a laser power of 50 MW.

Fig. 3. Distribution of light energy for shadows from light sparks: a - He, air, and Kr at 1 atm, b - Ne at 0.5, 1, and 2 atm., c - Kr at 0.5 and 2 atm. All for a laser power 50 MW.

cause also strong reflection (total internal reflection?) from the plasma surface at sufficiently large angles, $\theta > 10^{-1}$. This requires a refractive-index discontinuity $\delta n \geq \theta^2$, hence $\omega_p \geq \theta\omega$ or a plasma density $n_e \geq 10^{-2} n_{e.cr} \geq 4 \times 10^{19}$ cm^{-3}. (The glancing angle of incidence of the light on the surface of the plasma cone is close to the focusing angle - the ratio of the beam radius on the plasma to the focal length of the lens.)

We can introduce a shadow cross section with dimension a(t) and obtain information concerning the form of this function from the energy density distribution q(r) in the shadow of the spark. Indeed, if the dnesity of the light flux I(t) is given, then

$$q(r) \simeq \int_0^{t_r} I(t)\,dt, \quad q(0) \simeq \int_0^{t_D} I(t)\,dt,$$

where t_r is determined from the relation $a(t_r) \approx r$ and $a(t_D) \approx a_D \approx \sqrt{L\lambda}$ is determined from the condition that the shadow appear on the axis (that the shadow not be weakened by diffraction).

In our case $a_D \approx \sqrt{L\lambda} \approx 3 \times 10^{-2}$ cm, which exceeds by several times the radius of the focal spot, i.e., the shadowing is due mainly to farther-reaching consequences of the energy release at the focus.

It is usually assumed that the flux density increases linearly during the initial stage of the pulse, $I(t) \approx \dot{I}t$ when $t < T$; this yields $q(r) \approx \dot{I}t_r^2/2$. It is frequently assumed that the pulse form is close to half a sinusoid, $I(t) = I_0 \sin(\pi t/2T)$. In this case $q(r) = (4TI_0/\pi) \times \sin^2(\pi t_r/4T) = q_0 \sin^2(\pi t_r/4T)$, where q_0 is the energy density of the unperturbed flux.

For a wide class of processes of interest to us we can assume $a(t) \approx A(t - t_{br})^k \approx At^k$ far from the threshold ($t_{br} < t_D$), where A can depend on the parameters of the medium and on the energy release. Then $t = (a/A)^{1/k}$ and $q(r) = q_0 \sin^2 [(\pi/4T)(r/A)^{1/k}]$, i.e., $q(r)$ yields information on k and A, i.e., on the mechanism of the process causing the shadowing.

To determine k we plotted $\log \sin^{-1}(q/q_0)^{1/2}$ against $\log 2r$ for various gases and obtained the values of k from the slope $\tan\psi = 1/k$. It turns out that for Kr and Ne k is close to 0.5, whereas for air and He it is close to unity.

We have considered the most probable processes. The width of the shadowing region decreased with increasing pressure, just as the velocity of a shock wave or an optical-detonation wave decreases the photoionization region is decreased.

For quasispherical plasma spreading we have $(d/dt)\rho_0 a^3 \dot{a}^2 \approx W(t)$; for a contribution with sinusoidally varying power $W = W_0 \sin(\pi t/2T)$ we get from this for $t < 2T$ the value $a \approx (w_0 T^3/\pi^3 \rho_0)^{1/5} \sin^{4/5}(\pi t/8T) \sim t^{4/5}$; when $t \leq T$, this model is valid for sparks that are small or commensurate with the dimensions of the shadowing. These cases include apparently air and He.

For long sparks with large longitudinal development rates, a better description is obtained by assuming a quasicylindrical contribution with an instantaneous energy release $Q_1 = dQ/dz = W/\dot{z}$. In this case $(d/dt)\rho_0 a^2 \dot{a}^2 \approx W_1(t)$ we obtain $a \approx (Q_1/\rho_0)^{1/4} t^{1/2}$. For example, for radiative transfer of the breakdown front along a beam cone $W(t)/\pi r^2 \sim I_{br} = B/\rho_0$ we get for $W = \dot{W}t$ the relation $z = r/\tan\theta = (\rho \dot{W} t)^{1/2}/\tan\theta$, i.e., $\theta_1 \approx \theta/z \sim (\dot{W}T/\rho_0)^{1/2} \tan\theta$, i.e., $a \sim t^{1/2} \rho_0{}^{3/8}$, making dependence on t and on the density ρ_0 for Kr and Ne close to the experimental results $k \approx 0.5$ and $a(\rho) \sim 1/\rho_0{}^{0.5 \text{ to } 0.3}$.

These results demonstrate the efficacy of this new simple diagnostics method (we obtain the dependence of the time variation from integral distributions). We note the diagnostics of the transverse spreading of a spark by a longitudinal beam was never performed before.

This diagnostics method can be supplemented with investigations of the axial beam with the aid of a coaxial photocell or a photomultiplier or a calorimeter, in the presence of a spark or without a spark, making it possible to obtain additional information on the evolution of the shadowing process (signal $\mathcal{E}(t) \sim I(t)\,[a_0^2 - a^2(t)]$). We note that an insert made of a material that produces a second harmonic, placed in the hole of the lens, can also increase the efficiency of the diagnostics.

It is also possible to register not only the breakdown, but also the nonlinear variation of the refractive index in the focus of a laser.

ABSOLUTE CALORIMETER FOR THERMAL MEASUREMENTS WHILE HEATING OR COOLING

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In many thermodynamic measurements it is of interest, and sometimes necessary, to study processes that occur when the investigated system is being heated or when it is gradually cooled. The presently available calorimeters do not make it possible to perform such experiments. The main difficulty lies in an exact registration of the amount of heat drawn from the sample.