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HOLOGRAPHIC INVESTIGATION OF A LASER SPARK

G. V. Ostrovskaya and Yu. I. Ostrovskii
A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
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The hologram of a rapidly occurring process, obtained during a definite phase of its development, contains information concerning the structure of the wave front scattered and refracted by the object, and in many cases can be subsequently investigated by the same methods as the object itself, but under stationary conditions.

In the present work we have used holography to investigate a laser spark in air - the plasma produced by focusing radiation from a ruby laser operating in the giant pulse mode ($\Delta t \cong 40$ nsec, $E \cong 0.8$ J, lens focus 2.5 cm). The holograms were photographed by the Gabor single-beam method [1]. Gabor's scheme actually coincides with the scheme for obtaining shadow projections in coherent light [2,3]. To obtain the holograms we used the unabsorbed part of the laser beam that produced the spark. Apparatus with an optical delay line made it possible to obtain during one flash of the spark three holograms, corresponding to different phases of the process (40, 80, and 120 nsec after the instant of spark occurrence). One of the holograms is shown in Fig. 1a.

Fig. 1. a - Hologram of a laser spark, obtained 120 nsec after its occurrence; b - reconstruction of the image of the plasma contour; c - focal spot.

The spark images were reconstructed in the parallel beam of an He-Ne laser ($\lambda = 6328$ Å) (Fig. 2). A point screen A located at the focus of the lens L_3 eliminated the zeroth order and an appreciable fraction of the light from the virtual image, by the same token greatly improving the characteristics of the Gabor single-beam method. The system of Fig. 2 is simultaneously also a Schlieren system, in which the image is constructed by rays deflected by phase inhomogeneities of the object, making them visible. The Schlieren photograph of the spark,

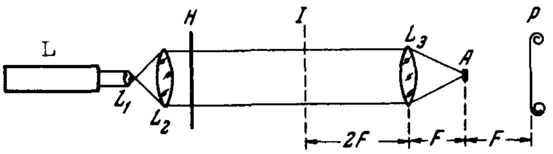

Fig. 2. Scheme for obtaining holographic Schlieren photographs. L - laser, L_1, L_2 - telescopic system to broaden the beam, H - hologram, I - plane of real image, L_3 - lens with focal distance F, A - point screen, P - photographic film

reconstructed in this manner, is shown in Fig. 1b, which shows the plasma contour from which the plasma dimensions can be determined.

It has been observed that at a certain distance f from the plane of the real image, the laser beam is gathered into a narrow bright line [1)] (Fig. 1c). The distance f changes noticeably for holograms corresponding to different instants of time: from 8 cm for 40 nsec to 14 cm for 120 nsec. This effect can be explained by considering the spark as a cylindrical lens and the observed bright line as its focal spot. Then f corresponds to the focal distance of this lens. By determining f, we can calculate the refractive index n of the plasma from its measured radius R (0.07 cm for 40 nsec and 0.13 cm for 120 nsec), using the thin-lens formula

$$n - 1 = -R/2f \tag{1}$$

If we assume that the refractive index is determined in this case by the density of the electron gas:

$$n - 1 = -4.46 \times 10^{-14} \lambda^2 N_e, \tag{2}$$

then we can estimate the average electron concentration in the laser-spark plasma. Formula (2) is applicable, inasmuch as the frequency of the laser radiation is approximately one order of magnitude larger than the frequency of the electrostatic plasma oscillations.

The thin condensed layer of air in the front of the shock wave and the corresponding rarefaction of the gas behind the front operate in the same way as a negative lens. However, the optical strength of such a hollow cylindrical lens amounts to only several per cent of the observed value, even if it is assumed that the entire gas mass subtended by the explosion wave is gathered in a thin layer at the surface of the front.

It must also be noted that formula (1) is valid only for paraxial rays and that the scattering ability of the peripheral zones of the lens is made larger by spherical aberration. However, owing to the decrease in the concentration of the electrons and the presence of gas condensation on the front of the shock wave, the increase in the refractive index of the edge regions of the plasma has the opposite effect. The sufficient sharpness of the focus offers evidence that the aberrations are relatively small and the use of formula (1) introduces no essential errors in the results.

Our measurements gave for Ne a value (2 - 3) x 10^{19} cm^{-3} for all the investigated phases of spark development, this being in agreement with the previously determined [4,5] electron concentration ((3 - 5) x 10^{19} cm^{-3}).

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1) The lens L_3 and the screen A (Fig. 2) were removed from the system.

SELF-FOCUSING OF A HOMOGENEOUS LIGHT BEAM IN A TRANSPARENT MEDIUM, DUE TO WEAK ABSORPTION

Yu. P. Raizer
Institute of Mechanics Problems, USSR Academy of Sciences
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When a light beam propagates in a medium having a dielectric constant that depends on the electric field of the wave like $\epsilon = \epsilon_0 + \Delta\epsilon$, where $\Delta\epsilon = \epsilon_2 E^2 > 0$, the beam exhibits a tendency to become self-focused [1-3]. A nonlinearity of this type is brought about by the Kerr effect and electrostriction [3], and in many substances the equilibrium value of $\Delta\epsilon_{str}$ is larger (sometimes even much larger) than $\Delta\epsilon_{Kerr}$. An effect which is the inverse of striction gives absorption of light. Even in very weak absorption, the thermal expansion exceeds the striction compression of the substance after a short time. If the field in the beam decreases from the axis towards the periphery, then the thermal increment $\Delta\epsilon_{th}$, which is also proportional to E^2 but is negative, exerts a defocusing action on the beam.

It will be shown below that when a homogeneous light beam is absorbed, nonstationary motion of the substance, due to heat release, leads to such a density distribution that, in contrast with the usual influence of heating, a tendency arises toward self-focusing of the beam.

Assume that a parallel beam of radius R enters the medium at the instant t = 0 and the amplitude of the light wave within the limits of the beam is constant along the radius and in time. Let us see how the density ρ of the medium changes in the light channel. In first approximation we shall disregard here the field redistribution connected with the resultant refraction of the rays, and the diffraction spreading of the beam boundaries.

When $E^2(r)$ = const, the radial external force acts only on the surface of the channel and its value (per cm^2) is $p_{str} + p_{th}$, where

$$p_{th} = \Gamma I \kappa_\nu (t - t_z), \quad I = \sqrt{\epsilon_0}\,\frac{cE^2}{4\pi}\ ; \quad p_{str} = -\rho\,\frac{\partial\epsilon}{\partial\rho}\,\frac{E^2}{8\pi}\ . \qquad (1)$$

Here p_{th} is the increase in pressure, at the instant of time t, resulting from heat release