OBSERVATION OF EXTENDED LASER-PRODUCED SPARKS

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An extended laser-produced spark has been observed in argon in a laser radiation field focused by a conical lens. The breakdown develops along the extended axial caustic. Certain possible applications of conical focusing of light beams are indicated, including the production of discharges.

WHEN focused by lenses with long focal lengths high-power laser radiation can produce a long spark, sometimes extending over several meters.[1]

In the present work another possibility is indicated for the production of a long spark; the spark is essentially a long continuous discharge whose longitudinal dimension is much greater than its transverse dimension. In this case, lenses with spherical surfaces are replaced by a lens with a conical refracting surface. The possibility of using a conical lens for the realization of nonlinear optical effects has been discussed earlier in[2]. It was noted there that a system of this kind can be used to obtain extended linear regions of high field in which a laser-produced breakdown can occur.

A system of this kind has been realized experimentally. In Fig. 1, in order to illustrate the field distribution we show a photograph of the emission of the axial caustic in a luminescent liquid. This same system has been used to produce a long, thin, laser-produced spark in compressed argon. The gas and the gas pressure are chosen to facilitate the development of breakdown. The radiation from a ruby laser (15 MW) is focused on a conical lens which is located inside the argon chamber. The laser-produced spark is photographed through the side windows of the chamber. Typical photographs are shown in Fig. 2. The radiation path is from left to right. At a pressure of 47 atm a plasma spark is observed (Fig. 2a); the geometric configuration of this spark is similar to the usual kind of spark that is observed with a spherical lens. The maximum dimension of the spark along the axis of the system is approximately 1.5 mm. Fig. 2b shows two breakdown foci with a distance of approximately 3 mm between centers. An unusual feature here is the presence of satellite radial structure in the discharge. At a pressure of 60 atm a series of point discharges appears along the axis of the conical lens (Fig. 2c). A continuous extended spark of intense emission is formed at a pressure of approximately 90 atm. The length of the spark in the field of view of the circular window of the chamber is approximately 30 mm (Fig. 2d).

We now consider the focusing, by a conical lens, of a laser beam with a divergence angle β and an input power density P_0. The density at the axis of the lens is approximately

$$P \approx 2P_0\theta / \beta. \qquad (1)$$

Here, θ is the slope angle of the ray with respect to the axis after refraction. When $\theta \ll 1$, we have approximately

$$\theta \approx (n-1)\alpha, \qquad (2)$$

where n is the refractive index of the lens material and α is the angle at the base of the conical lens.

In the experiments reported here the parameters are as follows: $\theta \approx 1/3$, $\beta \approx 0.56 \times 10^{-2}$, $P_0 \approx 10^7$ W/cm^2. Thus, the power density at the axis is $P \approx 2 \times 10^9$ W/cm^2. This value is somewhat in excess of the threshold value for the power density of laser-produced breakdown with a spherical lens at the indicated gas density.

We can also indicate the value of the field in an optical wave close to the axial caustic in focusing of an ideal beam:

$$E(r, x) \approx E_{\text{вх}}\theta\sqrt{2\pi kx}\,J_0(kr\sin\theta)\,e^{ikx\cos\theta}, \qquad (3)$$

where $k = 2\pi/\lambda$, r is the distance from the axis, x is the coordinate along the axis measured from the vertex of the cone, J_0 is the Bessel function $[J_0(0) = 1]$ and E_{in} is the field at the input to the lens. It is interesting to note that in contrast with the case of a nonideal beam [(Eq. 1)], in the focusing of an ideal beam the field intensity at the axis increases with distance from the vertex of the conical lens ($|E| \sim \sqrt{x}$).

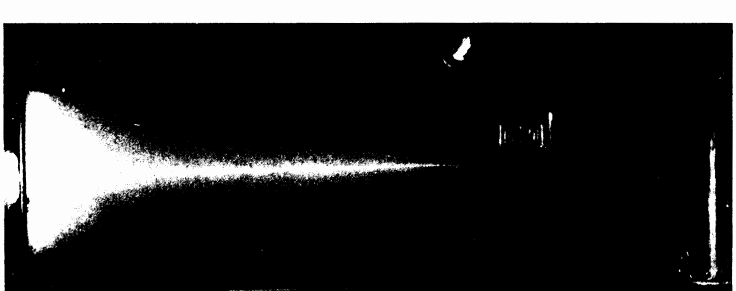

FIG. 1. Photographs showing the emission from the axial caustic in a luminescent fluid.

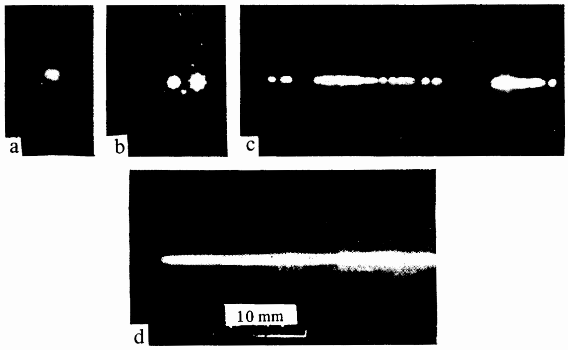

FIG. 2. Photographs showing sparks developing along the axis of a conical lens at different pressures. All photographs are taken from the side.

We note that the velocity of the breakdown front in this system can reach extremely large values and can even exceed the velocity of light since the development of the spark is determined primarily by the field distribution at the axis. The simultaneous development of breakdown over extended distances is also possible.

The application of conical focusing of light for the production of an extended spark exhibits the following advantages as compared with the usual focusing methods.

1. The breakdown foci that are formed do not hinder the injection of optical energy at other points along the axis since the optical energy is injected at rather large convergence angles. This feature leads to a more uniform distribution of energy along the length.

2. The rapid evolution of energy at the axial caustic can be used to simulate linear explosions and cylindrical shock waves.

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[1] N. G. Basov, V. S. Boĭko, O. N. Krokhin and G. V. Sklizkov, Dokl. Akad. Nauk SSSR 173, 538 (1967) [Sov. Phys.-Dokl. 12, 248 (1967)].

[2] B. Ya. Zel'dovich and N. F. Pilipetskiĭ, Izvestiya vyssh. uch. zaved., (News of the Higher Schools), Radiofizika 9, 95 (1966).

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