# PHYSICS

S. D. KAITMAZOV, A. A. MEDVEDEV, Academician A. M. PROKHOROV

1968

SovietRxiv

## Abstract

## Full Text

# PHYSICS

S. D. KAITMAZOV, A. A. MEDVEDEV, Academician A. M. PROKHOROV

# STUDY OF OPTICAL BREAKDOWN IN AIR BY A LASER OPERATING IN THE MODE-LOCKING REGIME

The study of breakdown in air by a laser is usually carried out with the aid of an optical quantum generator operating in the giant-pulse regime with a duration of about 20 nsec. It was shown [1,2] that during the pulse a detonation supersonic wave propagates toward the laser beam with a velocity of about $10^7$ cm/sec. This motion of the front of hot plasma toward the laser beam gives the spark a characteristic spindle-shaped form.

In our work, breakdown in a gas produced by a series of ultrashort light pulses was studied for the first time. Since the intervals between the pulses are much greater than the duration of the pulses themselves, the mechanism of spark formation should differ from that considered in [1,2].

In the course of the experiment we varied the length of the neodymium-laser resonator from 0.5 to 5 m and obtained a series of ultrashort pulses with intervals from 4 to 33 nsec. The number of pulses in a train was about 10, with a total energy of 1 J. Lenses with focal lengths of 52 and 170 mm were used to obtain the spark.

The experiments showed that the spark formed by a series of ultrashort pulses has a periodic structure, in which each thickening corresponds to a separate light pulse (Fig. 1a). When the spark is photographed through an infrared light filter (Fig. 1b), only those regions of the spark are recorded where strong scattering of the laser beam by the plasma occurs, i.e., at the breakdown sites. It is seen from this figure that breakdown occurs at different points. The following explanation may be given for such a breakdown pattern. After breakdown and the cessation of the action of the laser radiation, a spherical shock wave propagates in all directions from the breakdown point. Behind the front of the shock wave, owing to the high temperature, the gas is ionized. Breakdown from each subsequent light pulse occurs at the place* where the laser pulse encounters the front of the shock wave produced by the preceding pulse, i.e., closer to the laser. Knowing the distance between two successive breakdown points and the time between two successive pulses, one can find the average velocity of motion of the ionization front in each interval. Thus, with an interval between pulses of 4.7 nsec, the average velocity of motion of the plasma front at the beginning

Figure 1

Figure 1: Figure 1

of the train was $8 \cdot 10^6$ cm/sec.

**Fig. 1.** Direction of the laser beam from left to right.

The velocity of the ionization front depends on the energy of the light pulse. As the experiments showed, when the laser energy is decreased by a factor of 2, the distance between the breakdown points decreases by 10–12%. Comparison of this result with Sedov' s theory for a point explosion confirms that, in our case, spherical shock waves propagate, for which—

* We assume that in our case the photoionization mechanism does not play a substantial role.

the distance is proportional to $(E/\rho)^{1/5}$, where $E/\rho$ is the specific energy of the plasma.

The shock-wave velocity measured by us makes it possible to determine the ion temperature ($T_i$) of the plasma. It is known that, for normal density and the temperature range $5 \cdot 10^5 \div 10^6\,^\circ$K,

$$T_i = 1.25 \cdot 10^{-2} u^{8/7}\,^\circ\mathrm{K} \quad (^{2,3}),$$

where $u$ is the shock-wave velocity. For the value measured by us, $u = 8 \cdot 10^6$ cm/sec, we obtain $T_i \approx 1 \cdot 10^6\,^\circ$K. Since $8 \cdot 10^6$ cm/sec is equal to the average velocity over the interval between pulses, it may be assumed that at the breakdown point the temperature is higher than that calculated by us.

The velocity of plasma propagation between successive breakdown points decreases toward the end of the pulse train. This is explained by the fact that toward the end of the train the pulse energy decreases, and, in addition, the subsequent breakdown points gradually move away from the focus of the lens. (The latter circumstance is substantial when short-focus lenses are used.)

At large time intervals between pulses (15–33 nsec), the distance between breakdown points is practically independent of the time interval and is equal to $\approx 0.55$ mm. This is explained by the fact that the maximum ionization volume is determined by the pulse energy. Thus, for a pulse energy of 0.1 J, the maximum ionization volume is $\approx 0.5$ mm$^3$.

The short duration of the light pulses emitted by a laser operating in the mode-locking regime makes it possible to obtain in the focus of a lens an energy-flux density greater than $10^{13}$ W/cm$^2$. As shown in papers ($^4$, $^5$), at such densities, in the formation of optical breakdown in air the mechanism of the multiphoton anti-Stokes effect and single-photon ionization may play a noticeable role. In this case the threshold for spark formation should depend on the peak power, and not on the average power, as occurs at relatively small energy fluxes. We intend to investigate specially the role of multiphoton processes in spark formation by ultrashort light pulses.

In conclusion, the authors express their deep gratitude to F. V. Bunkin and P. P. Pashinin for discussion.

Physical Institute named after P. N. Lebedev
Academy of Sciences of the USSR

Received
14 III 1968

## CITED LITERATURE

[1] S. L. Mandel' shtam, P. P. Pashinin, A. M. Prokhorov et al., ZhETF, **49**, 127 (1965).
[2] V. V. Korobkin, S. L. Mandel' shtam, P. P. Pashinin, A. V. Prokhindeev, A. M. Prokhorov et al., ZhETF, **53**, 116 (1957).
[3] Yu. P. Raizer, ZhETF, **48**, 1508 (1965).
[4] F. V. Bunkin, M. M. Fedorov, ZhETF, **51**, 796 (1966).
[5] F. V. Bunkin, A. M. Prokhorov, ZhETF, **52**, 1610 (1967).

*Note: Figure translations are in progress. See original paper for figures.*

*Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.*