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INVESTIGATION OF SLIDING SPARKS BY THE SCHLIEREN METHOD

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Sliding sparks (SS) are used for photoionization of active media of TEA CO_2 lasers, excimer lasers [1], and initiation of chemical lasers [2]. In long active laser media or at high pressures, SS are a very convenient method of preionization.

At the same time, one of the requirements which the source of preionization must meet is that the perturbation of the active medium must be minimum, especially in repetitive pulse lasers with high pulse repetition frequency. The optimal quality of the active medium is also very important when the lasing pulse duration in optical pumping of the SS is long [3].

The purpose of this work is to study the optical perturbations of the medium when SS are employed for preionization or optical pumping of the active medium in lasers.

The experiments were performed on a schlieren setup (Fig. 1). The objective lenses 3 and 4 were 30 cm in diameter and had a focal length f = 106 cm. A nonuniformity a—b was placed between the objectives. The high-quality objectives 6 and 7 with a very uniform light field, just as the remaining optical elements, were carefully aligned; otherwise it is impossible to obtain images of weak perturbations of the medium. The optimal diameter of the diaphragm was 5-2.5 mm. The ÉV-45 pulsed light source 2 (radiation duration of 250 µsec, Planck radiator at $T = 4 \cdot 10^4$ °K) transilluminated the nonuniformity under study. The schlieren motion pictures were made with the help of a fast SFR-2M camera 8. The power supply for the SS was a capacitor bank with a capacitance C = 1-3 µF, which was discharged through a commutated discharger 1 on the first winding of an IKT pulsed cable transformer with a transformer ratio of 1:10.

The SS were formed on the flat surface of a film dielectric 9, 0.8 mm thick (Fig. 1b), covering a metallic sheet 10 (initiator). The discharge gap a—b had a square-shaped protuberance and the transverse section of the spark channel was recorded on an 8-cm-long flat section of this proturberance. The discharge developed in a stable manner along the controlling strip 11; the method for controlling the development of the SS is described in detail in [4]. For monitoring the reproducibility of the conditions of discharge the voltage and current in the discharge gap were displayed on an oscillograph by a divider D and a Rogowski loop RL. The voltage oscillogram, corresponding to the photographic frames in Fig. 2b-d, is shown in Fig. 1c. The arrow marks the moment of breakdown.

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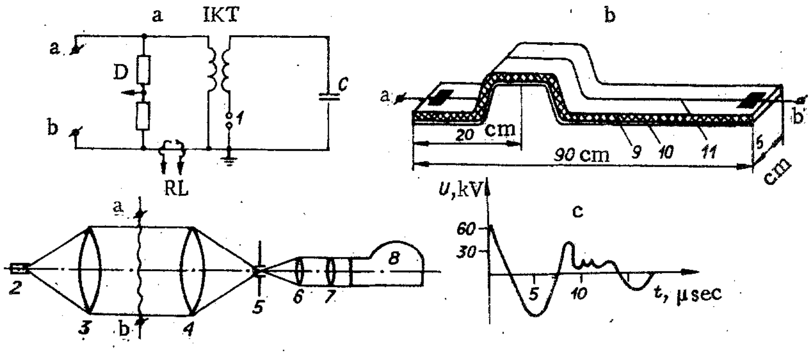

Fig. 1

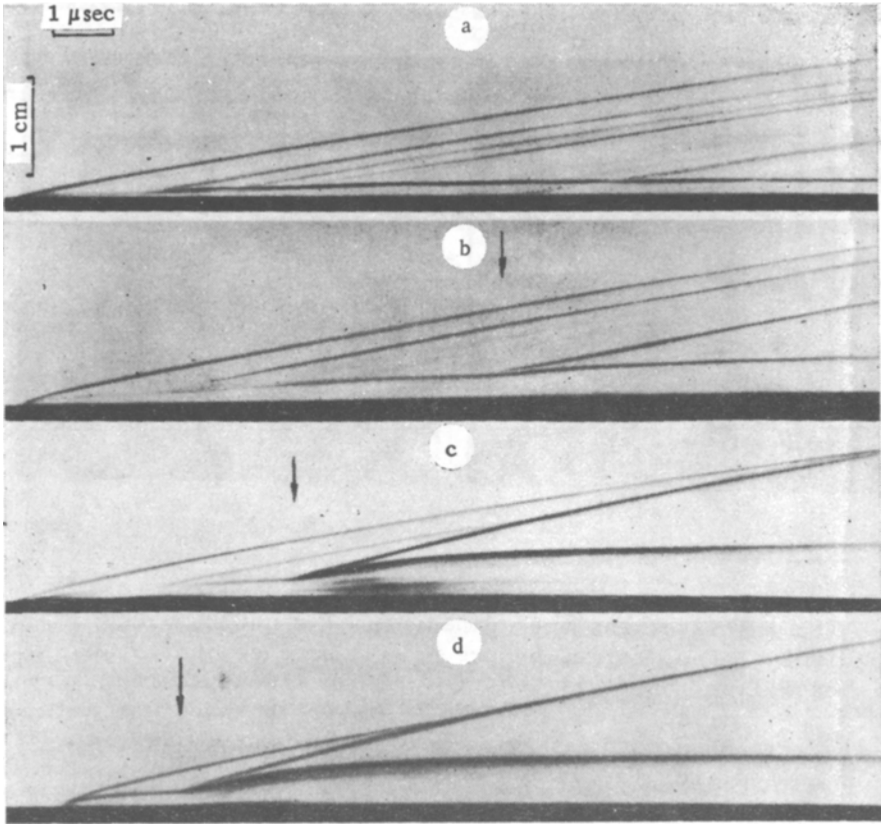

Fig. 2

At the streamer stage the SS moves along the surface of the dielectric in a stepped manner [5, 6], which enables the appearance of optical nonuniformities already at the prebreakdown stage of the discharge. To clarify this, with the help of the SFR-2M we made photographs of the SS channel from the side at different distances from the high-voltage electrode. In Fig. 2a, b the slit of the camera is placed at a distance of 10 cm, and in Fig. 2c, d, at distances of 45 and 75 cm, respectively, from the high-voltage electrode. The voltage on the secondary winding of the IKT is U_2 = 50 kV for Fig. 2a and U_2 = 60 kV for the remaining figures.

Figure 2a shows a series of photographic frames of the channel of an incomplete SS. More than 10 weak shock waves (SW), with an irregular character as a function of time, can already be seen at this stage. This is the first observation of SW in the incomplete (streamer) stage of the discharge.

The irregular character of the SW in Fig. 2a can be explained by the fact that under our discharge conditions, i.e., when power is supplied to the SS by a cosinusoidal alternating voltage, SW are created by two processes: by an increase in the surface capacitance C accompanying the motion of the streamer, which gives rise to a current surge, formation of a new streamer step, and an SW moving away from it; by a change in the polarity of the applied

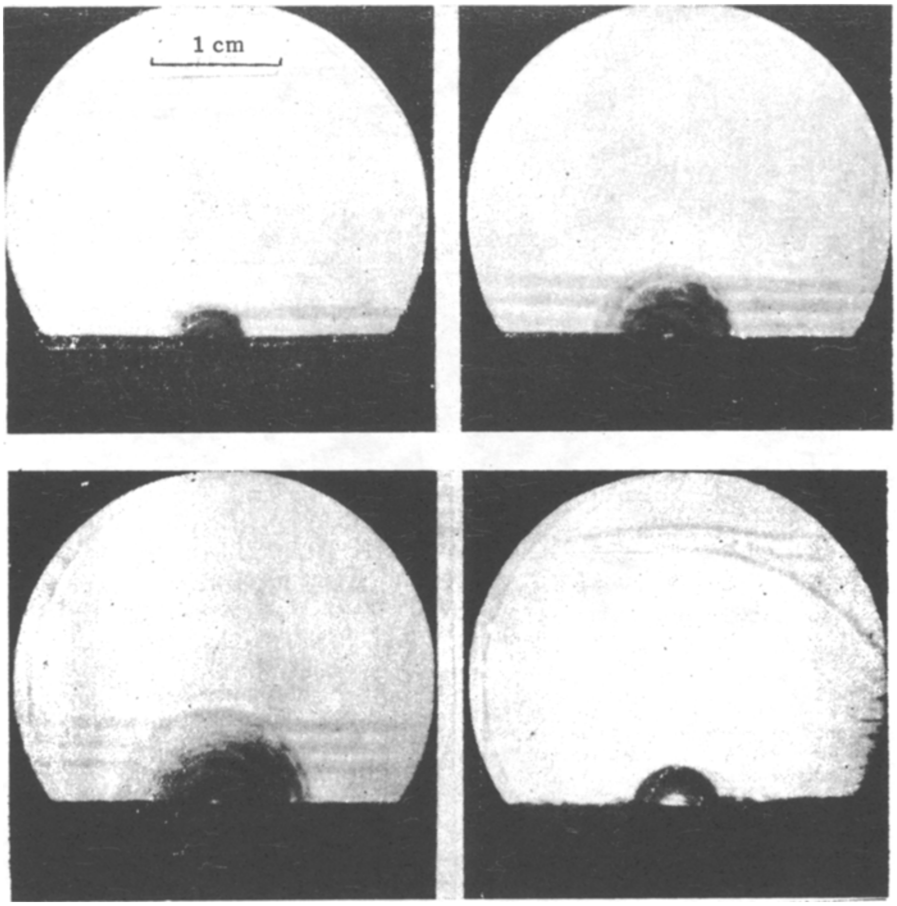

Fig. 3

voltage, which recharges the surface capacitor and also gives rise to SW. Correspondingly, the current through the initiator has two components: I = UdC/dt + CdU/dt, where U is the voltage on the capacitor plates, formed by the plasma surface charge and initiator, C is the capacitance of this capacitor, and t is the time. When the capacitor is recharged, the current surge I ∿ CdU/dt gives rise to SW, the time interval between which is equal to the half-period of the voltage. If SS are formed on a wide short plate, i.e., the effect of the component UdC/dt is eliminated, regular SW can be obtained. Irregular SW appear with the formation of each new streamer step, so that the number of SW decreases from the high-voltage to the opposite electrode (Fig. 2b-d), while the SS channel up to the moment of breakdown will appear to be a collection of half cylinders, whose length and diameter decrease from the high-voltage to the grounded electrode.

The existence of SW suggests that the theory of the expansion of the channel of a spark discharge developed in [7, 8] can be used to explain the formation of a stepped leader of the sliding discharge. The gas-kinetic theory in [7] is based on the assumption that the expansion of the sparked channel is driven by the rapidly liberated energy in a thin (about 0.1 mm in diameter) channel, while the boundaries of the channel act on the surrounding gas in a manner similar to a cylindrical "piston" and move with supersonic velocity causing the formation of SW. The exterior zone of the channel — the SW front — propagates with the highest velocity. In Fig. 2 the initial expansion velocities of the streamer channel lie in the range 1-2 km/sec, depending on the magnitude of the applied voltage. The maximum velocities which we observed reached 5 km/sec. The boundary of the heated ionized plasma at the very beginning of the discharge almost coincides with the front of the SW, and then separates from it, at first expanding with a lower velocity and then remaining immobile up to the formation of the next step in the stepped leader (or surge in the current of the component CdU/dt). Under our conditions the diameter of the SS channel is less than 0.1 mm (the limit of resolution of the recording apparatus) and the current density can reach values of 1 MA/cm^2 and higher. The energy liberated in the streamer channel, however, is not large. Therefore, the velocity of the SW decreases to the values of the sound velocity over a path length of the order of 3-5 mm.

From the gas-kinetic theory of expansion of a spark channel it follows that inside the conducting channel the gas density must be several orders of magnitude lower than the density of the unperturbed gas, decreasing increasingly toward the axis of the channel. As a result, a zone with a high specific conductivity can form on the channel axis. To clarify this, schlieren motion pictures of the transverse cross section of the spark channel on a flat 8-cm-long area were made. The motion picture (Fig. 3, time interval of 5.4 μsec) reveals a zone with low optical density, which can be interpreted as a zone with a low temperature. It is likely that at the initial moment of the discharge this is a zone with low gas density, which is later filled by cold gas from the region on the boundary of the sparked channel and the dielectric surface (the last frame in the motion picture of Fig. 3 was made 200 μsec after the beginning of the discharge).

It is evident from Fig. 3 that the SS channel expands uniformly in all directions; this contradicts the data of [9]. Aside from the SW from the main channel, SW from lateral branches, arising simultaneously (within the limits of the resolution of the recording apparatus), can be seen.

Thus the SS are a source of perturbations of the gaseous medium in both the completed and incomplete stages of the discharge. The perturbations appear because of the nature of the formation of the SS and the form of the voltage applied to the discharge gap. The characteristic propagation velocities of these perturbations range from 0.4 to 1 km/sec. This circumstance should be taken into account when employing SS as a source of preionization of laser media or as a source for optical pumping.

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