OPTICALLY INITIATED DIRECTIONAL ELECTRICAL BREAKDOWN IN GAS

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It is shown experimentally that optical initiation of a directional electric breakdown in gas requires a simultaneous (within ~ 10 nsec) application of intense ultraviolet radiation along the entire discharge channel and a constant electric field. The earlier suggestion that the plasma trail of the ultraviolet beam is the cause of the directional breakdown is inot in agreement with the results of this experiment.

THE observation of a directional electric breakdown in gas along a collimated high-intensity ultraviolet beam was reported in[1]. The directional character of the breakdown was determined by the fact that the angle between the axis of the discharge channel and the direction of the constant electric field vector reached 30°. The suggestion was made that the formation of a plasma filament along the trail of the ultraviolet beam followed by a streamer breakdown is one of the possible mechanisms of this phenomenon.[1)] Another possible mechanism has ultraviolet photons participating in the ionization of gas while simultaneously photons and electrons accelerated by the constant electric field collide with molecules. It is shown in[3] that the probability of excitation of atoms and molecules in these triple collisions is sometimes too high to be neglected in the analysis of experimental data.

This report presents the results of two experiments that further develop our concept of the optically initiated directional electric breakdown. Both experiments used an open air gap and a source of coherent ultraviolet pulses with a quantum energy of 3.5 eV[4] (the pulse length was $\tau = 13 \pm 1$ nsec and light intensity in the collimated beam was about 3 GW/cm^2 which is two orders below the optical breakdown threshold).

The geometry of the first experiment is shown in Fig. 1. The light beam from source 1 enters the discharge gap through a circular opening 2 mm in diameter cut in one of electrodes 2, bypasses the second electrode, turns through 270° in three TIR quartz prisms 3, again enters the discharge gap through a hole in the second electrode, and finally leaves the gap. The cylindrical brass electrodes in the plane of the paper approximate the profile of the Rogowski loop and the beam never touches the electrode metal along its entire path.

Figure 1 shows that the mutually perpendicular intersecting segments of the plane beam trajectory formed by the caustics of 11-cm quartz lenses 4 close the interelectrode gap along the heavy broken line.

In the absence of ultraviolet radiation gap breakdown occurred at 15 kV measured with a C-96 electrostatic voltmeter (5) along the shortest straight path (7 mm) between the electrodes (see dashed line in Fig. 1).

This picture changed radically when the ultraviolet beam was present. The breakdown voltage dropped to

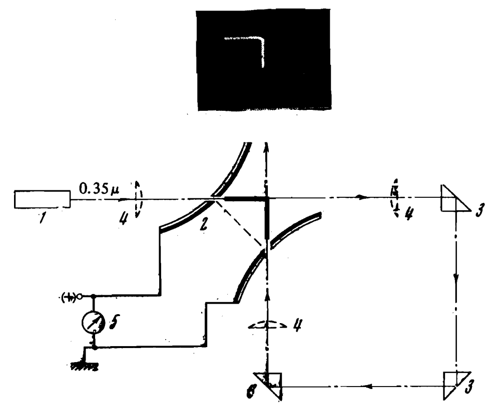

FIG. 1

13 kV and the discharge channel assumed a broken shape (see photograph in Fig. 1) that repeated the beam trajectory and significantly deviated from the direction of the electric field vector. The broken shape of the discharge channel remained even if the beams failed to coincide within less than 1 mm at their intersection point in the direction normal to the plane of the paper. The observed singular shape of the discharge channel is a convincing evidence of the directional nature of the optically initiated electrical breakdown established in[1].

The geometry of the setup shows that the optical pulse travels along the second of the mutually perpendicular segments shorting the electrodes somewhat later than along the first. This delay time Δt is proportional to the optical length of the closed trajectory segment formed by the prisms. When Δt was varied it turned out that breakdown along the broken channel could be initiated only for $\Delta t \leq 8$ nsec, while for $\Delta t > 8$ nsec the phenomenon was not observed all the way to the breakdown threshold voltage. Given the light pulse length of $\tau \approx 13$ nsec, this fact seems to indicate that a directional breakdown in a constant electric field requires synchronization of the initiating ultraviolet radiation over practically the entire length of the discharge channel.

In the second experiment, as in[1], we studied optical initiation of electric breakdown between plane parallel electrodes shorted by an ultraviolet beam directed at an angle to the electric field vector (Fig. 2). The electrical circuit contained two consecutive gaps forming a capacitive voltage divider with a ratio 1 : 95. Thus in the

[1)]Vaill and others [2] erroneously maintain that the directional character of breakdown is ignored in [1].

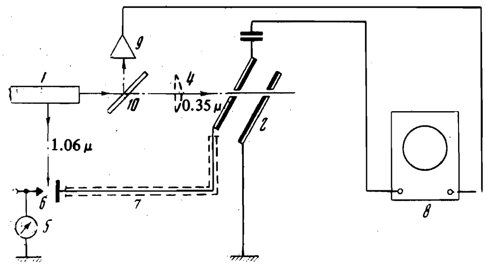

FIG. 2

pre-breakdown state the total circuit voltage was applied with an accuracy to 1% across gap 6 having tip-plane electrodes. The discharge in this gap, playing the role of a switch, was started by an intense light pulse with a wavelength of 1.06 μ split off the first stage of radiation source 1. The discharge across the switch caused a jumpwise change in the gap ratio, corresponding to application of an electric pulse with an amplitude up to 15 kV and rise time of about 10 nsec (from 0.1 to 0.9 of the amplitude) across the investigated gap 2. Variation of the length of coaxial cable 7 in the electric circuit allowed us to vary the delay time Δt between the optical and electrical pulses across gap 2 with an accuracy to 2–3 nsec, as checked with C-1-7 oscilloscope 8. The optical pulse was recorded by FEK-22-SPU coaxial photocell 9. Spontaneous breakdown of the 7 mm gap occurred with a pulse voltage of 15 kV in the direction of the electric field vector, i.e., perpendicularly to the electrode plane. Synchronization of the optical and electrical pulses at 13.5 kV produced an initiated breakdown whose channel axis deviated 18° from the direction of the electric field vector. The directional character of the breakdown remained when the delay time was varied up to $\Delta t \approx 12$ nsec. For $\Delta t \geq 15$ nsec initiated directional breakdown was not observed up to the breakdown threshold voltage. It follows that for an optical pulse length of $\tau \approx 13$ nsec and electrical pulse front length of 10 nsec the initiated directional breakdown requires a simultaneous presence of intense optical radiation and electric field across the discharge gap.

The results of both experiments cast a doubt on the assumption made in[1] that the plasma trail in the interelectrode gap is the cause of directional breakdown since the decay time of plasma in air with a concentration of the order of 10^{13} cm^{-3}[1] significantly exceeds (see[5]) the characteristic delay time $\Delta t \approx 8$–15 nsec in both experiments. At the same time the experimental data call for a more detailed theoretical analysis of triple collisions of the photon-electron-atom type[3] as a possible mechanism of optically initiated directional electric breakdown.

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