OPTICALLY-INITIATED DIRECTED ELECTRIC BREAKDOWN IN A GAS

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Submitted 7 August 1968
ZhETF Pis. Red. 8, No. 8, 417 - 419 (20 October 1968)

The advances in generation of intense coherent ultraviolet radiation [1] uncover a possibility of observing plasma traces of an ultraviolet beam in a gas and various associated electric phenomena. These include in first order [2] a directional electric breakdown along a prolonged ionized channel (plasma column), and also reflection of radio waves from the column or their propagation along the column. It is known that analogous phenomena are observed in optical breakdown of a gas by laser radiation in the infrared or visible band [3,4] at high optical energy density ($\sim 10^5$ MW/cm^2) [5]. An increase of the light frequency (up to the ultraviolet), which increases the photoionization probability), should lead to an appreciable lowering of the necessary energy density and to a possibility of experimentally separating these phenomena from optical breakdown.

Estimates [2] of the degree of ionization

$$n/n_0 \approx (\pi/2)(I_0/\hbar\omega)\omega\tau[1+(\gamma_s/w_s)]^{-1}$$

in a plasma column produced in a gas having an ionization potential I_0 under the influence of a short pulse of ultraviolet radiation with duration on the order of τ, photon energy $\hbar\omega$, electric field intensity F, and ionization probability

$$w_s \approx \omega(I_s/\hbar\omega)^{3/2}\exp(I_s/\hbar\omega)(2\gamma)^{-2\langle I_s/\hbar\omega+1\rangle}\int_0^z \exp y^2 dy$$

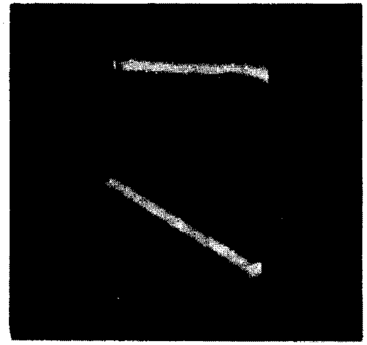
for the case of ionization with transition into an intermediate state with ionization potential I_s and radiation width γ_s can be obtained from formulas (1) and (43) of [6] by rounding $(I_0 - I_s)/\hbar\omega$ to unity and omitting the coefficients $a_s \sim 1$ and $A \sim 1$ (here

$$\gamma = (\omega/eF)\sqrt{2mI_s} >> 1, \quad z = \sqrt{2\langle(I_s/\hbar\omega)+1\rangle - 2(I_s/\hbar\omega)},$$

<x>-integer part of x, and e and m - charge and mass of the electron). Numerical estimates with the aid of these formulas show that under the influence of ultraviolet with photon energy 4.7 eV and energy flux density on the order of several hundred megawatts per square centimeter one can expect formation in air of a plasma column with a degree of ionization on the order of 10^{-5} and more.

In our experiment, a collimated ultraviolet beam of wavelength 0.265 μ (fourth harmonic of neodymium-laser emission), pulse duration 10 nsec, and beam cross section 0.005 cm^2 was made to pass without tangency through slots in two plane-parallel brass electrodes separated by an air gap of 1 cm. The angle between the beam and the normal to the electrode surface could be varied.

Spontaneous breakdown of the interelectrode gap in the absence of a beam occurred at a voltage V_{SB} = 17 kV along the normal to the electrode plane. Under the influence of a beam with energy density about 300 MW/cm^2, the breakdown voltage along the normal dropped to 13 kV. When the beam is inclined to the electrodes, at voltages lower than V_{SB}, the breakdown followed the beam up to an angle 32° to the normal. The figure shows spontaneous breakdown in a normal direction and breakdown directed along the beam at an angle 30° to the normal (the electrode plane is vertical). At beam inclination angles exceeding 32°, partially directed breakdown took place, whereby the inclined spark channel showed a kink in the normal direction near the cathode.



The directed breakdown could be readily reproduced under the experimental conditions at an energy density exceeding 300 MW/cm^2. If the observed directed breakdown initiated by an intense ultraviolet beam can be interpreted as being the consequence of a development of a positive streamer, then the ion density in the column can be estimated according to the assumptions of [7], at about 10^{13} cm^{-3}. There is apparently also an analogy between the directed-breakdown phenomenon and the development of a discharge along the track of an ionizing particle in a spark chamber [8].

It should be noted that the energy flux density of the initiating beam is at least two orders of magnitude lower than the energy density needed to produce a light spark.

The estimated ion density in the plasma column, 10^{13} cm^{-3}, corresponds to a critical wavelength on the order of 1 cm. Thus, observation of the aforementioned phenomena of reflection and propagation of radiowaves is possible in the microwave band, in agreement with the estimates of [2].

The authors thank M. F. Stel'makh for stimulating attention and A. I. Kovrigin for a useful discussion.

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