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Abstract

Full Text

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Investigation of Optical Breakdown in Air, Caused by Ultrashort Pulses, Using an Image-Converter Photchronograph

In work ⁽¹⁾, breakdown in air caused by a series of ultrashort pulses of laser radiation was investigated by photographing the plasma clot that was formed and the radiation pulses scattered by it. From the distance between the breakdown points, the average propagation velocity of a spherical shock wave in the plasma was determined; at the same time, it was suggested that the maximum velocity may differ appreciably from the average. To investigate the dynamics of spark development over the entire interval between laser pulses, experiments were carried out using an image-converter photchronograph.

In the experiments a photchronograph of the FER-2 type was used. Photorecording was performed from the screen of a UMI-92 image converter with a silver-oxygen-cesium photocathode.

The image of the spindle-shaped plasma clot was projected onto the time slit of the photchronograph in such a way that the axis of the spark coincided with the slit. The part of the spark image cut out by the slit was swept over the image-converter screen in a direction perpendicular to the axis of the slit.

Fig. 1. Block diagram of the setup. 1 –laser; 2 –mirror with reflection coefficient $R = 10\%$; 3 –spark formed in the focus of the lens; 4 –photchronograph; 5 –spark gap in the photchronograph trigger circuit; 6 –camera

To generate a series of ultrashort pulses we used a neodymium laser operating in the mode-locking regime. The duration of the pulses of this laser was measured in work ⁽³⁾ and could reach 10^{-12} sec. The pulse repetition period was 13 nsec. The energy of a pulse train was 2 J.

Since a bleaching filter was used in the laser, the initial instant of laser generation was not controlled within $100 \mu\text{sec}$, and therefore the laser signal under investigation itself was used to trigger the sweep of the photchronograph. In

Fig. 2. Streak photographs. The sweep direction is from right to left. The sweep duration in Figs. A and B is 100 nsec; in Fig. B, 30 nsec. The direction of the laser beam is from top to bottom

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order to observe the initial stage of spark development, it is necessary that the dead time of the sweep trigger be no more than 20 nsec, whereas in the FER-2 photochronograph this time is about 150 nsec. Therefore the triggering and sweep system of the photochronograph was modified for the present experiment. As a key element, a spark gap was introduced into the sweep circuit. The sweep was triggered directly by the laser beam igniting the spark gap*. A special feature of this scheme is that the spark

* The ignition of a spark gap of an electro-optical shutter by a laser beam, for the purpose of reducing the delay time, was reported in work (4).

the spark gap was used not as a sensor for obtaining the trigger pulse, but directly as a circuit element of the sweep generator. Such a triggering system made it possible to ensure a minimum delay time between the arrival of the triggering radiation pulse and the start of the sweep, $\tau = 10 \div 15$ nsec. This technique made it possible to record the initial phase of development of optical breakdown in air. The experimental arrangement is shown in Fig. 1.

Fig. 2. Streak photographs. The sweep direction is from right to left. The sweep duration in Figs. **A** and **B** is 100 nsec; in Fig. , 30 nsec. The direction of the laser beam is from top to bottom.

In the streak photographs we obtained, the dynamics of spark development are clearly visible. The plasma velocity, measured from the streak photographs, has a sharp maximum, reaching $4 \cdot 10^7$ cm/sec during a time interval of 2 nsec adjacent to the moment of the laser pulse, whereas the average plasma velocity is $7 \cdot 10^6$ cm/sec, which agrees with the velocity given in (1).

Since the main expansion time of the hot plasma at a velocity of $4 \cdot 10^7$ cm/sec occurs after the laser pulse has already ceased, the temperature can be estimated from the formula (1, 5)

$$T = 1.25 \cdot 10^{-2} V^{8/7} \text{ } ^\circ\text{K},$$

which gives the value of the ion temperature $T = 6 \cdot 10^6$ °K.

We emphasize that such a calculation of the temperature presupposes the gas-kinetic nature of the velocity measured by us. It should also be noted that calculation by this formula gives an underestimated value of the temperature (6).

Near the moment of the laser pulse, strong laser light scattered by the plasma is observed, which interferes with observation of the plasma's own glow; this laser light was suppressed by a special light filter.

In the streak photographs presented, various aspects of the fine structure of the dynamics of spark development are clearly visible. In Fig. 2A, splitting of the spark and its initial phase are recorded. The high resolving power of the FER-2 instrument makes it possible to record the dynamics of the interaction of an ultrashort laser pulse with the spark plasma. In the streak photograph of Fig. 2, where the total sweep is 30 nsec, it is seen that the bright breakdown region moves for a time of ~ 1 nsec in the direction of the laser beam with a velocity of $\sim 10^8$ cm/sec.

In Fig. 2B, the sites of optical breakdowns scattering the laser light are visible. The measured propagation velocity of the luminous region in the initial stage of breakdown is of the order of $3 \cdot 10^8$ cm/sec. Apparently, this velocity is not the velocity of gas-kinetic expansion, but is associated with photoionization by the radiation of the hot plasma. This mechanism was discussed in [5].

It follows from the data obtained that spark formation by ultrashort light pulses is a complex physical process, a detailed discussion of which will be given in the following article.

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

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