EFFECT OF PLASMA MIRROR IN THE BREAKDOWN OF AIR IN A CO_2 LASER CAVITY

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We report here observation, for the first time, of the formation of a plasma mirror and self-modulation of laser radiation during infrared breakdown of air in a laser cavity. It was observed that a smooth lasing pulse of 10 μsec duration and a high power density is transformed in the pre-breakdown state in the focal region of a compound resonator into a series of regular pulses of 400 - 500 nsec duration. When a certain threshold value is exceeded, breakdown occurs, and the generation-pulse modulation ceases to be regular. The plasma-density increase accompanying the development of the generation pulse produces a plasma mirror. The generation pulse then becomes smooth.

Breakdown of air by CO_2-laser radiation has by now become easy to produce through the use of transverse-discharge systems [1 - 3]. The breakdown by a 200-nsec laser pulse in the focus of a compound resonator was observed in [4]. The short duration of the laser pulse has made it possible to observe only the quenching of the generation at the onset of the breakdown. This quenching was attributed in [4] to absorption in the plasma. At a much longer duration, new effects can be observed.

The experiment was performed with a transverse-excitation CO_2 laser of 5 m length, delivering in the free-running mode radiation pulses of 10 μsec duration with energy 10 J. The use of a compound resonator with a lens and a short-focus mirror makes it possible to increase considerably, in a region of 5×10^{-2} cm diameter, the threshold for the breakdown of air at atmospheric pressure by radiation of 10.6 μ wavelength [3]. The plasma produced in the focal region of the compound resonator was investigated both with a photomultiplier and by frame-by-frame photography with a high-speed camera. The structure of the generation pulse was investigated with a Ge-Zn receiver both in the pre-breakdown state and in breakdown.

When the laser radiation intensity approaches the breakdown threshold, self-modulation of the radiation occurs in the pre-breakdown state. The total duration of the generation increases from 10 to 30 μsec, the pulse is transformed into a practically regular series of short pulses (Fig. 1). The intensity of each of the latter increases to a maximum value within a time on the order of 100 nsec, followed by just as abrupt a quenching of the generation.

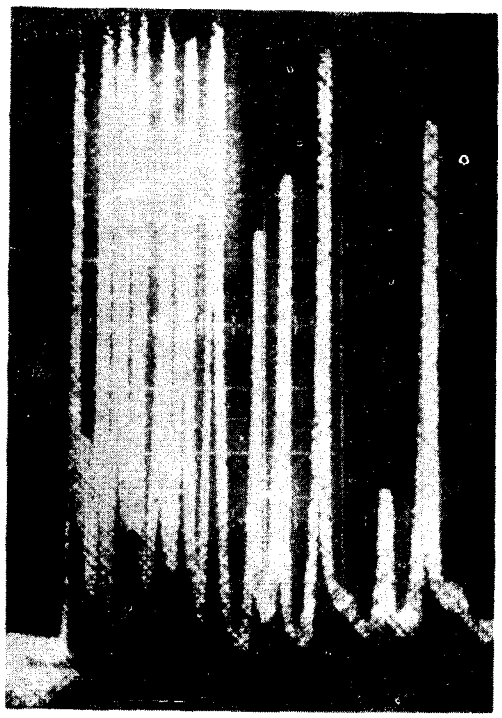

Fig. 1. Structure of CO_2-laser radiation pulse at the pre-breakdown power level inside the resonator. One division equals 10 μsec.

The generation is quenched as a result of self-defocusing occurring in the focal region of the resonator. The self-focusing is due to a decrease of the refractive index as a result of the development of the electron cascade in the pre-breakdown state. An electron density $(5 - 10) \times 10^{-16}$ cm^{-3} suffices to quench the generation. The absorption losses do not play a decisive role,

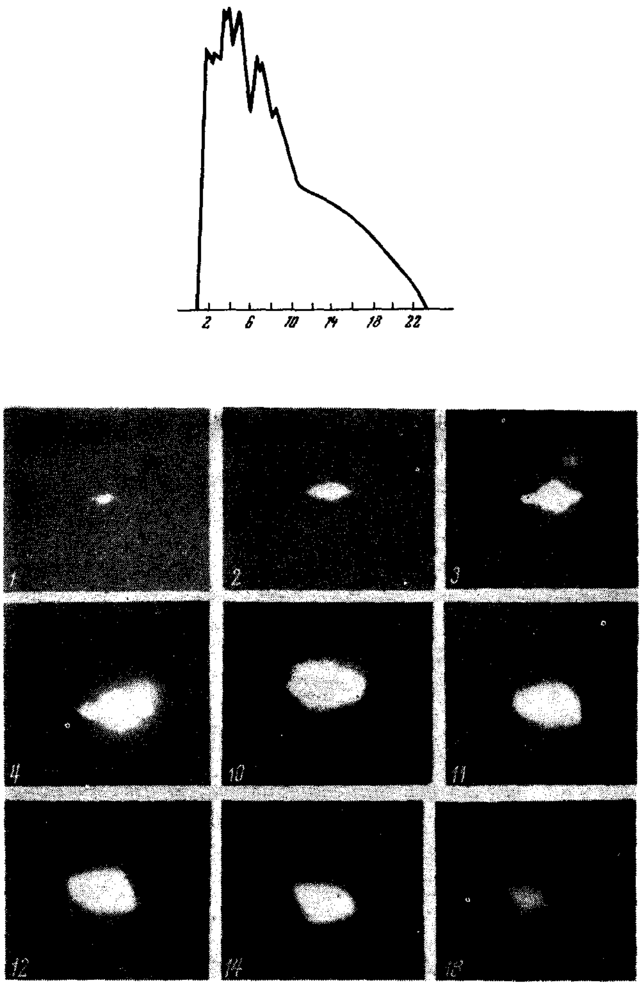

Fig. 2. Selected high-speed photographs and the corresponding variation of the plasma luminosity, obtained with the aid of a photomultiplier. The exposure time of each frame is 3.6 μsec.

and the increase of the refractive index by the excitation of the atoms and molecules is relatively small. Generation resumes after a time equal to the characteristic relaxation time of the entire system. Self-modulation of this type was observed earlier [5], when transparent crystals in which self-focusing occurred were placed in the focus of a compound resonator.

Self-modulation leads to an increase of the peak intensity, and this facilitates the attainment of the breakdown threshold. After the threshold is reached, breakdown occurs in the focal region. During the breakdown, the self-modulation of the radiation has a chaotic character, owing to the inhomogeneity of the plasma spark. The luminosity of the plasma follows, with a slight delay, the variations of the laser power. Figure 2 shows oscillograms of the luminosity and corresponding selected high-speed photographs.

The total lifetime of the plasma is 80 μsec. The plasma grows rapidly along the optical axis of the resonator and expands in the radial direction. The spike structure of the radiation pulse is maintained until the plasmoid assumes a stationary shape, which is broadened in the part that faces the active medium of the laser. This part of the plasmoid acts like a semitransparent mirror, and this ensures stability of the laser generation. The plasma boundary is sharply delineated on the side of the active medium, and its shape is determined by the intensity distribution in the cross section of the laser beam. On the opposite side, the plasma cools and its volume decreases.

The effect of the plasma mirror during the breakdown of the air inside the CO_2 laser resonator occurs when the action of several generation spikes cause the density of the plasma electrons to increase to such an extent that the reflection coefficient at the CO_2 laser frequency exceeds a certain value determined by the gain in the active medium of the laser. In our case the gain exceeded 100, and the self-excitation conditions were therefore satisfied by a very large margin at 10% reflection. Such a value of the reflection coefficient is attained already at an electron density 7×10^{18} cm^{-3}.

We note that a control experiment, during the course of which an arc discharge was struck in the focal region of the laser cavity, has shown that generation does actually occur in the laser when one of the laser mirrors is replaced by a plasmoid.

Thus, breakdown of air at atmospheric pressure by a pulse of 10-μ radiation of long duration has made it possible to observe such effects as self-modulation of the laser radiation in the pre-breakdown state and formation of a plasma mirror. The nature of these types of self-action is decisively influenced by the change of the real part of the dielectric constant of the medium under the influence of radiation from a high-power CO_2 laser.

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INVESTIGATION OF MAGNETIC FIELD EXCITED IN A METAL BY HEAT FLOW

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As is well known, stationary heat flow cannot produce a magnetic field in an ideal single crystal. However, if the structure is not ideal, as shown by the experiments described below, a field perfectly accessible to modern measurement methods can be produced in the sample.

The instrument used for the investigation is shown in Fig. 1a. The magnetic field was measured with a superconducting magnetic flux quantum meter (SMFQM) analogous to that described by Zimmerman [1]. As is well known, the SMFQM makes it possible to measure a magnetic flux up to 10^{-10} Oe-cm^{-2}. In the experiment, the setup was adjusted in such a way that the heaters H_1 and H_2 drew equal amounts of power. In this case, on switching from H_1 to H_2, the state of a sample located under the coupling loop would change only if heat flow were present.

The first object of the investigation was chosen to be tin. The samples were made of metal of highest purity. The thermal conductivity of the sample at T_c was ~50 W-cm^{-1}deg^{-1}. A typical SMFQM chart is shown in Fig. 1b. H_1 and H_2 designate which of the heaters is turned on, G indicates when the current is