DYNAMICS OF DEVELOPMENT OF A CONCENTRATED DISCHARGE EXCITED BY ELECTRICAL EXPLOSION OF A TUNGSTEN WIRE

V. P. Isakov

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Concentrated discharges in rarefied gases have been studied in [1-3], and have found use, roughly from the middle sixties, as radiative sources for pumping optical lasers [4], particularly for pumping iodine photodissociation lasers. The interest in these lasers stems from the fact that the molecular absorption bands corresponding to their dissociation are comparable in width with the absorption bands of solid-state lasers, while the radiative lines in the gas lasers are much narrower, i.e., for iodine lasers the effective for conversion of wide-band radiation into coherent radiation should be higher than for solid lasers. However, the band of photodissociation of CF_3I, C_3F_7I molecules and of similar substances used in iodine lasers lies mainly in the ultraviolet range (at wavelengths shorter than 300 nm), and therefore the usual pumping sources, pulsed lamps for example, are little suited to photodissociation lasers.

A suitable source of pumping for this case might be a concentrated gas discharge directly in the laser medium [5, 6]. A discharge usually has a brightness temperature of $(3-4) \cdot 10^4 \,^{\circ}C$ for an injected energy of 10^3-10^4 J. The rate of propagation of the discharge boundary reaches up to 1.5 km/sec. A capacitor bank is the primary energy storage.

To increase the energy, the radiative pumping power and the brightness temperature it is suggested that one use an explosive electrical source, but, because of the special features of the current pulse in the load of this kind of source, one must study a number of topics in the dynamics of developmnt of the discharge (optical thickness, brightness temperature, speed of propagation of the discharge boundary, etc.).

With this objective the present paper has suggested methods based on an investigation of a concentrated discharge in air at a pressure of $(0.1-2) \cdot 10^5$ N/m^2 in a capacitance circuit and has compared the discharge with the characteristics of the discharge from an explosive electrical source, described in [7]. The timewise and energy parameters of the sources are close in the two cases. For example, a quarter period of the E-circuit discharge with a short circuit is about 5 μsec. The energy injected into the wire and the discharge is 7 kJ. The time for subsequent doubling of the current of the explosive electrical source is also ~5 μsec, and the energy injected into the wires of the short circuit and the load is on the order of 10 kJ.

The experiments were carried out in the cylindrical laser cuvette or tube shown in Fig. 1. At low pressures from $0.1 \cdot 10^5$ to $0.5 \cdot 10^5$ N/m^2 the air was mixed with the gas SF_6 in the ratio 50 × 50%, in order to increase the electrical strength. The gas discharge was initiated by electrical explosion of the tungsten wire 8 of diameter from 0.04 to 0.3 mm, the wire was stretched between the clamps 6 to which was supplied the energy of the capacitor bank of 25 μF at voltage 30 kV via the cable 2. Each row of the bank was switched by means of a separate multi-electrode spark discharge device [8]. The laser cuvette was made of stainless steel of internal diameter 200 mm and comprised three sections bolted together using vacuum-type rubber gaskets. The ends of the tube were covered by glass shields 5 and the exit windows 4 through which the optical output was taken along the wire direction. The output of the discharge across the wire direction was taken via window 7, located in the central part of the tube, the pumping system was attached via tap 10, and tap 9 was used to introduce the buffer gas and set up the required atmosphere. The pressure in the system was monitored with the aid of the manometer 1 and the vacuum lamp 3.

In the experiments the discharge current was measured by a Rogovsky coil was subsequent integration in an RC network, and the voltage was measured by a capacitance divider. The size and the speed of motion of the glowing region of the plasma were measured by a type SFR-2M high-speed photo-recorder (HPR), taking data in both the framing regime and in the slot sweep
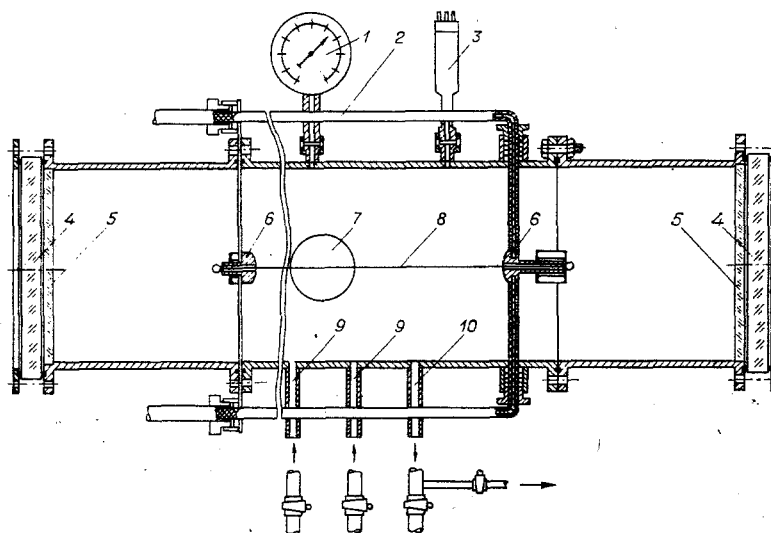
Fig. 1

(streak camera) regime, through the exit windows 4 and window 7. The light flux was regulated by means of neutral filters and an iris diaphragm.

The active resistance of the discharge and the energy injected into the discharge were calculated, analogously as in [4], from the formulas

$$U(t) = I(t) R(t) + [L_0 + L_p(t)] \frac{dI}{dt} + \frac{d[L_0 + L_p(t)]}{dt} I(t),$$

$$E(t) = \int_0^t RI^2 dt.$$

Here U, I, and R are the voltage, the current and the resistance in the discharge gas; L_0 and L_p are the inductances of the discharge circuit and the discharge; E is the energy injected into the discharge. The quantities U(t), I(t), dI/dt, and L_0 were measured directly, L_p was determined from the well-known formula [9] for a coaxial system and was compared with the value, measured with a Q-meter (type VM 311 E), of the inductance of a coaxial section of the required diameter, made of copper foil.

Figure 2 shows a typical photographic sweep of the wire explosion process, where 1 is the shock wave (SW) in air, 2 is the boundary of the current layer of the gas discharge, and 3 is the flight of products of the wire explosion. The measured velocities are: SW 730 m/sec, initial velocity of the gas discharge boundary 550 m/sec. The boundary velocity gradually fell: at 10 μsec it was 480 m/sec, and at 15 μsec it was 480 m/sec. The velocity of the wire explosion products was 125 m/sec.

The optical transparency of the plasma was determined as follows. In the lower half of the window 7 we set up a mirror, and in the top half an optically absorbing material (we pasted on a piece of black velvet). Thus, the radiation from the top half of the discharge region was incident directly on the objective of the HPR, while the lower region was illuminated by self radiation reflected from the mirror, the result being that the shock wave SW 1 (Fig. 2) propagating in the lower region, absorbing the discharge radiation, became clearly visible in the recorded picture. A supplementary shock wave appeared on the shadowgraph streak pictures obtained by the schlieren method. The difference of optical densities of different sections of the HPR pictures was recorded with a type MF-4 microphotometer, and from this difference we evaluated the optical density of the plasma, which we needed to know, in order to correctly estimate the plasma temperature.

The brightness temperature of the radiation was determined with a type EV-45 reference source, radiation as a black body, made up by the technique of [10], and including capacitors,
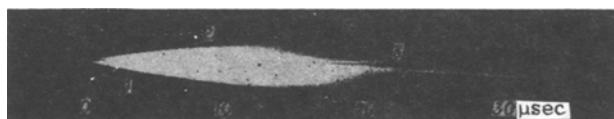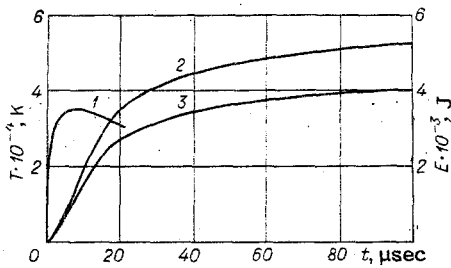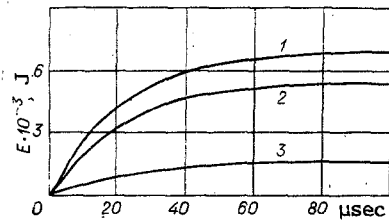

Fig. 2

Fig. 3

Fig. 4

textolite capillaries and carbon igniters of the same quality as in [10, 11]. The image of the capillary of the reference source of width no more than 0.4 mm was truncated by a slot diaphragm and glass light filters transmitting the radiative region 450-480 nm, and in some cases we used an interference filter at 470 ± 2.5 nm. In order to constuct a film blackening curve, as was pointed out in [12], in each experiment we took a picture of the reference source with the light passing through a step attenuator mounted in the frame of the HPR, following which the HPR was rotated about a vertical axis and the picture of the gas discharge was taken on a second frame (in some experiments without the step attenuator). The reference source and the wire to excite the discharge were positioned at the same distance from the HPR. Thus, in each experiment we could construct the film blackening curve and compare the brightness temperature of the reference source with the temperature of the gas discharge, which included unavoidable errors associated with the different conditions of film development. Curve 1 of Fig. 3 shows the variation of brightness temperature with time for wavelength 470 nm.

The total relative energy was measured with a type IMO-2 calorimetric sensor, and the dependence of radiative energy on time was recorded by a pyroelectric sensor (with a surface area sensitive to radiation of 10.6 mm^2, and sensitivity of 38.4 V·cm^2/J) capable of recording radiation in the range 40-1100 nm [13].

Curve 2 of Fig. 3 corresponds to an oscillogram of radiant energy with the radiation falling directly on the pyroelectric sensor, and curve 3 corresponds to the case when the glass mounted in the window cuts off the short-wave part of the radiation with a boundary at 300 nm. The transmission boundary of the glass was determined from measurement of the absorption coefficient by using a type IMO-2 sensor to record the incident radiative power from a constant light source, with a different part of the spectrum cut off by a set of interference filters. Thus, from curves 2 and 3 one can evaluate how much of the radiant energy lies in the region with wavelength less than 300 nm.

Figure 4 shows the dependence on time of the total electrical energy 1 injected into the plasma, the radiative energy 2, and the energy expended in exploding the wire, along with the UV energy, 3.

In further experiments a gas discharge between planar electrodes was fed from a small explosive-magnetic source in a transformer scheme without a circuit breaker. The difference between these experiments and those described in [7] is that the tungsten wire exciting the discharge was set up in lieu of the circuit breaker.

Figure 5 shows a framing HPR picture of such a discharge. It can be seen that energy has been successfully transmitted from the explosive-magnetic source to the gas discharge initiated by explosion of a tungsten wire of 0.3 mm diameter. The discharge is highly stable for 10 μsec and then is attenuated sharply, indicating a rapid cessation of current. The energy injected into the discharge is 16 kJ, and the electrical power reaches 3.2·10^{10} W. The rate of energy injection is considerably greater than when a capacitor bank is used, since, from the estimates of the HPR pictures, the speed of propagation of the gas discharge boundary reaches 5 km/sec. This means that the gas discharge can have a high brightness
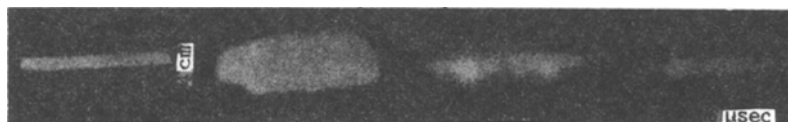

Fig. 5

temperature compared with the case when the E-circuit is used. The measured maximum temperature in this case reached 60,000°C.

In addition, it has been established that when the E-circuit is used the fraction of short-wave radiation is 20% of the total, and when the discharge is fed from an explosive wire source this increases to 40%, which indicates that this type of source shows promise for shifting the spectral maximum of the radiation to the shorter-wave region.

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