FORMING OF THE ELECTRIC DISCHARGE IN A THREE-ELECTRODE XeCl-LASER IN THE REGIME WITH A PRELIMINARY MULTIPLICATION OF ELECTRONS

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We present here a study of characteristics of a three-electrode, dual-discharge XeCl-*laser operated in the regime with a preliminary multiplication of electrons. Use of that type of the discharge formation enabled us to essentially decrease the voltage at the primary capacitors of the energy storage units, to achieve a perfect matching between the pump power supply electric circuitry and the load, and thus to increase the laser efficiency up to* 3.7%.

Recently the development and design of the electric-discharge excimer lasers based on dual-discharge schemes has attracted much attention of the researchers. Use of such schemes enables one to essentially improve matching between the pump power supply and the load, owing to a decrease in the voltage at the primary capacitors of the energy storage, and thus to significantly increase the laser efficiency. At present two schemes are known to be in use for forming the dual-discharge. One of them is a two-electrode system with a magnetic commutator in the main discharge circuitry.[1] Use of that scheme in a XeCl-laser with a small discharge aperture enabled[2] achieving a record efficiency of 5%. In Ref. 3 one may found a description of a pulse-periodic XeCl-laser, built up using this approach, that delivers up to 1.54 kW mean power with the efficiency of 3.6% in a single pulse and 2.2% when operated in a pulse repetition mode. The other scheme of the dual discharge formation uses a three-electrode construction of XeCl-laser.[4–6] The lasing efficiency achieved in such a scheme reached 2.8%. It is worth noting here that the three-electrode lasers with the dual discharge are yet little studied though they promise certain advantages, as compared to the two-electrode ones. Among the advantages we should like to note the absence of a magnetic commutator in the main discharge circuitry, as well as much lower (by several times) energy of a control pulse required. In addition this scheme provides for this laser to be operated in the master oscillator-amplifier mode.

The experiments we describe in this paper continue our earlier investigations[6] and are aimed at increasing the laser efficiency and reducing the charging voltage at the main pump power supply.

In this laser the main pump power supply is connected to two main electrodes while the discharge ignition is being done with a low-energy, high-voltage pulse applied to the central control electrode. The capacitative energy storage of the main power supply of the laser is charged during several microseconds. In this case the two discharge gaps undergo the breakdown in a succession thus providing for two lasing channels. However, in the scheme with two equally spaced discharge gaps[6] there appeared a time lag of 100 to 200 ns, in which the breakdown occurred in the second gap at a reduction of the E/P ratio down to 1.3 kV/(cm·atm). That, in turn, led to deterioration of the discharge quality and to a decrease in the lasing efficiency.

To avoid this unwanted effect we made use of the principle of preliminary multiplication of electrons in the electric field[7] similarly to the approach in Refs. 8 and 9. In so doing, we have managed to decrease voltage at the main capacitative energy storage by about 2 times, as compared to that in Ref. 6, while providing the discharge ignition at the electric field strength applied to the gaps being below 0.5 kV/(cm·atm).

Figure 1 depicts the block-diagram of the electric circuitry of an electric-discharge excimer laser with a central control electrode.

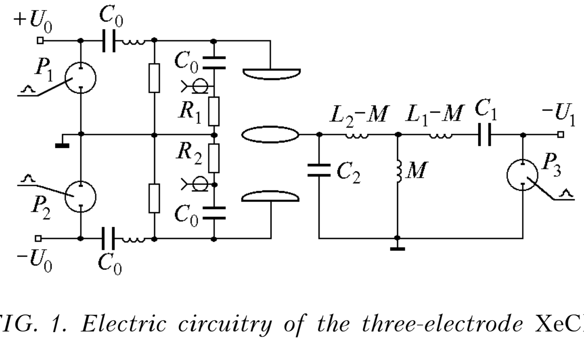

FIG. 1. Electric circuitry of the three-electrode XeCl-*laser.*

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To produce some initial electrons we have used a double-side spark preionization. The spacing between the gap forming electrodes was 3.5 cm. The width and length of the discharge region were 2 and 50 cm, respectively.

The main electrodes of the discharge chamber are connected to the capacitative energy storage assembled from KVI–3 ($2C_0$ = 880 nF) capacitors. The inductance of the discharge circuit was 50 nH. The capacitative storage is charged during about 50 μs interval up to ±12 kV from a lumped capacitor of K75–48 type.

To ignite the discharge we used a pulse Tesla transformer with C_1 = 3.4 nF, C_2 = 2 nF, and U_1 = 30 kV, the capacitor C_2 being distributed over the discharge gap. This capacitor is connected with the central control electrode. The ratio between the amplitudes of the first and second half wave at the output of Tesla transformer (C_2) is 0.5. During the first half wave there occurs multiplication of electrons in the second channel, from the number density of electrons created by UV preionization (~10^7 cm^{-3}) up to 10^{12} to 10^{13} cm^{-3}, while the high-current discharge stage occurs during the second half wave.

The lasing characteristics have been studied in the mixture of HCl (2 Torr), Xe (20 Torr), and Ne (4 atm). The laser resonator consists of two plane mirrors with dielectric coatings that have the reflectivity of 99 and 25% at 308 nm wavelength. Simultaneously these mirrors serve as windows of the discharge chamber. Laser radiation pulse has been recorded with an SDF–10 photocell, while its energy being measured with an IMO–2N calorimeter. The current-voltage characteristic of the discharge was measured using low inductance resistance shunts (R_1 and R_2) and a resistance voltage divider.

Figure 2 presents typical oscillograms of the voltage pulse at the central electrode, current pulse, and of the output emission pulses in both laser channels.

The Table I gives the measured values of the laser pulse energy in two laser channels.

TABLE I.

U_0, kV	8	9	10	11	12
e_1, J	0.39	0.68	0.91	1.13	1.2
e_2, J	0.28	0.51	0.71	0.85	0.88
e_0, J	0.67	1.19	1.62	1.98	2.08
Efficiency, %	2.3	3.2	3.6	3.6	3.2

C o m m e n t s . U_0 is the absolute value of the voltage at the dual polarity source of charging the main capacitative energy storage; e_1 is the energy delivered from laser channel that undergoes the breakdown first; e_2 is the energy delivered from the laser channel that undergoes the breakdown second; e_0 is the sum energy delivered from both channels; the efficiency is counted relative the energy stored in the capacitative storage of the main and impulsing circuits.

It is worth noting here that at $U_0 \le \pm 8$ kV the electric strength of the gas mixture allowed the charging of the capacitative energy storage to be performed in a static mode when it is connected with the main electrodes of the chamber. It is also important to note that no breakdown occurred even with the UV preionization.

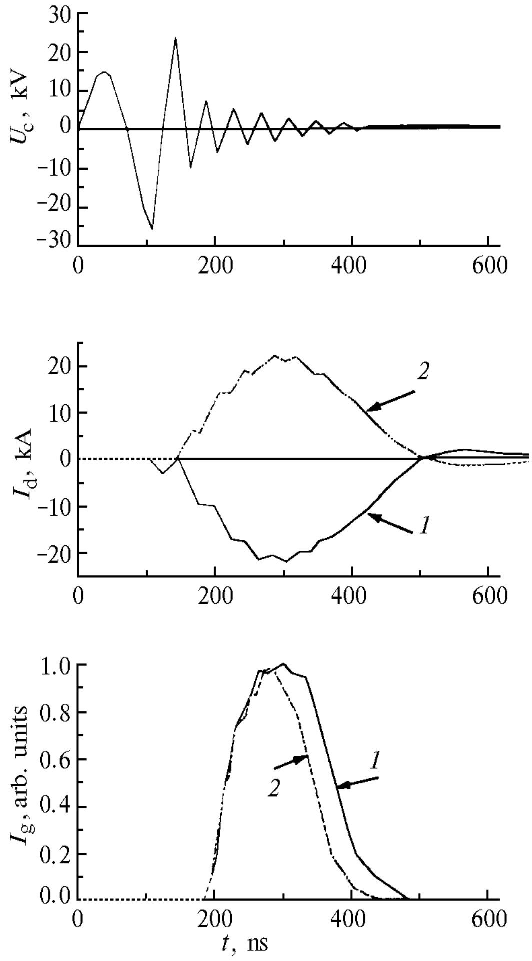

FIG. 2. Oscillograms of the voltage pulse at the central electrode and of electric current and generation pulses in the first (1) and second (2) channels, respectively. $U_0 = \pm 11$ kV, U_1 = 30 kV.

One can see from the Table that a decrease in the lasing efficiency occurs at a decrease of the voltage, to which the main energy storage unit is charged, below ±10 kV. It is important that such a decrease has also been observed at a much higher Q factor of the resonator. Analysis of the voltage and current oscillograms showed that though, at $U_0 < \pm 10$ kV, no delay occurred in the breakdown of the second discharge gap, the leading edge of the discharge current pulse became longer, up to 40 ns. It is likely that this is caused by insufficient electron density in the second gap that is being created at the stage of the discharge formation. In this situation an increase in the amount of energy stored in the discharge power supply circuit by 1.5 times (C_1 = 5 nF, C_2 = 3.55 nF, U_1 = 30 kV) enabled us to avoid the stretching of the pulse leading edge. As a result, we managed to obtain 0.76 and 0.66 J energy per pulse in the two laser channels, respectively, with the mean lasing efficiency being about 3.7%. At this partial pressure of the halogen containing substance the impulsing circuit provided the discharge to be formed at $U_0 = \pm 7$ kV (E/P = 0.5 kV/(cm·atm) at the discharge gaps). However, under these conditions the current pulse duration increased up to 0.7 μs, simultaneously followed by a drastic fall off of the lasing energy. Lowering the partial pressure of HCl down to 1.2 Torr enabled us to form a diffuse discharge with the current half-period of 350 ns duration and provide at the same time perfect matching between the power supply and the load.

It is important to note that the discharge quality (lasing energy), that could be achieved in the regime with a preliminary multiplication of electrons, strongly depends on the voltage to which the capacitative energy storage of the impulsing circuit is charged. Thus, a decrease or an increase of U_1, regarding its optimal value, by 2 to 3 kV resulted in a noticeable fall of lasing energy.

Increasing the capacitance of the main storage ($2C_0$) by 1.5 times at $U_0 = \pm 9$ kV resulted in only 20% growth of the output laser emission. In that case the half-period duration of the current increased by 25%. As the interferometric observations of the discharge have shown, the fall off of the lasing efficiency is caused by deterioration of the discharge stability at its diffuse stage.

To elucidate the causes of lasing energy difference in two discharge channels, when using this particular version of the capacitative storage, we have measured the transverse distributions of the emission from the near zone of the laser channel. To do this we have placed a 2 mm-wide slit-shaped diaphragm in front of the output mirror (with R = 25%). The diaphragm may be oriented perpendicularly or in parallel to the plane of electrodes.

In so doing we have recorded the distributions of the laser emission across and along the discharge gap of the laser. The succession in initiating the discharge in the two laser gaps has been being changed by alternating the polarity of the main capacitative storage.

Figure 3 presents the distributions of the emission from the laser channels recorded in the near zone. As seen from Fig. 3, the half-width of lasing zone in the second channel is by 30% narrower than that in the first one. This is obviously due to differences in the discharge formation in the two channels. Since the shape of electrodes used had the Chang profile one should certainly expect the electron density distribution to have maximum in the discharge gap center, in accordance with the electric field strength. As a matter of fact, the distribution of the emission in the second channel confirms this regularity. At the same time, one may clearly see a dip in the distribution of the emission, at the gap center, from the channel that first undergoes the electric breakdown. The difference in the discharge formation is that the breakdown of the first gap causes the appearance of a 50-ns-duration current prepulse (see Fig. 2) in this channel due to recharging of the peaking capacitor C_2. In this situation, there occurs a faster dissociative recombination of electrons, during the current fall off, in the region where the concentration of vibrationally excited HCl molecules is higher, that is in the discharge gap center. As a result the electron density distribution has a dip in the discharge center. In Refs. 10 and 11 one may find a more detailed discussion of the effect the vibrational kinetics of HCl can produce on spatial distribution of the XeCl-laser emission.

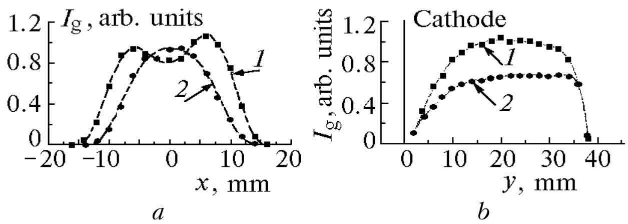

FIG. 3. Distribution of the XeCl-*laser emission in the near zone: across the discharge gap width (a) and along its height (b).* $U_0 = \pm 9$ kV: *Channel No. 1 is that which undergoes the breakdown first, other channel being the second one.*

It is likely that the difference in the lasing energy between the first and second laser channels is due to different widths of the discharge and, as a consequence, different specific pump power. It is important that there occurred earlier termination of lasing in the second channel what is caused by earlier occurrence of the discharge instabilities there.

Thus, from what have been discussed above, it follows that the use of a preliminary multiplication of electrons in the laser chamber of a three-electrode electric-discharge XeCl-laser with equal discharge gaps provides for the discharge formation at the voltage below the static breakdown threshold. At a specific energy deposition into the discharge of 0.08 J/cm^3 and pump power of 350 kW/cm^3 we have achieved 3.6 to 3.7% lasing efficiency.

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