Experimental studies of discharges with automatic corona preionization in XeCl lasers

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Experimental results on volume discharges and lasing in XeCl lasers with automatic corona preionization are reviewed. It is shown that a proposed plasma electrode is promising for excimer lasers with argon mixtures. Application of multicircuit power supply for self-maintained discharge is a promising direction in the development of excimer lasers emitting long pulses.

Introduction

First electric-discharge excimer lasers were operated in XeF, KrF, and ArF molecules, among which the KrF medium was considered as most efficient. In Ref. 1 it was shown that lasing in XeCl could be obtained with pumping by an electric discharge no longer than 20 ns. Such a discharge is usually called fast discharge. In Ref. 2 the output energy was increased significantly due to pumping by a doubled fast transverse discharge. In Refs. 3–7 a XeCl laser was studied for the case of excitation by a fast discharge with automatic corona preionization. The conditions of fast pumping were provided by use of a double Blumlein generator.[5] It was shown that XeCl laser in its efficiency is highly competitive with XeF and KrF lasers. It turned out that the chemical composition of the halogenide ($CHCl_3$, CF_2Cl_2, and CCl_4) in this laser significantly affected the power and duration of the output pulses.[7] The best halogenide is likely the HCl, since it contains no carbon. References 8 and 9 reported obtaining of the output energy higher than 0.1 J per pulse in the case of spark preionization of the discharge and HCl halogenide.

According to analysis of excitation conditions of excimer lasers,[10] electric-discharge lasers with the UV preionization are pumped by a fast discharge living less than 35 ns, and laser pulses have correspondingly the same duration.

However, physical properties of laser transitions in XeCl and XeF excimer molecules gave hope for obtaining longer laser pulses when using longer pump pulses. As known, the properties of laser beams with ~ 1-μs-long duration differ in principle from the properties of the ~ 30-ns-long beams, because the time longer than 0.1 μs is enough for the mode structure of radiation to be formed.

Actually, up to 400-ns and 200-ns-long volume discharges were obtained in the mixtures He:Xe:CCl_4(NF_3) and Ar:Xe:CCl_4, respectively, with a two-circuit power supply with the spark preionization.[11,12] In this case, the duration of XeF and XeCl laser pulses increased up to 130 and 170 ns, respectively. These results showed the promise of research aimed at obtaining pumping conditions for long discharges providing for long (up to 1 μs) laser pulses. The choice of a source of preionization, peculiarities of evolution of high-pressure long volume discharges, influence of He, Ne, and Ar buffer gases, as well as halogenides on both the discharge and kinetics of the formation of active molecules remained open questions for such discharges.

In this paper, I consider the results of experimental studies of the properties of volume discharges with corona preionization in XeCl lasers. These results could allow one to formulate the conditions for long-pulse pumping. One of such conditions is the use of a multicircuit power supply.

1. Results of experimental studies of self-maintained volume discharges in the He(Ar):Xe:CCl_4 mixtures excited with a single-circuit power supply

1.1 Experimental setup

Volume discharges were studied in gas mixtures He(Ar):Xe:CCl_4, as well as in the gas mixtures without halogenides (to compare the properties). The experiments were conducted with the use of a single-circuit power supply with automatic corona preionization and the active volume $V = D \times H \times L = 1 \times 0.4 \times 4$ cm^3 (where D is the interelectrode gap, H is the electrode width, and L is the electrode length) at the pressure from 0.1 to 4 atm (Refs. 7 and 13).

The setup circuitry is shown in Fig. 1*a*. We used a discharge cell with a 2.6 cm wide cathode and an anode made as a rod of 1 cm in diameter. This configuration of electrodes provided high homogeneity of the 0.4-cm wide discharge. The setup allowed recording of the integral pattern of the discharge glow in both longitudinal and transverse sections of the discharge. The degree of discharge homogeneity as a function of the gas components and the energy deposited into the active media can be judged from the recorded pictures. The energy consumed for discharge commutation and preionization did not exceed 25% of the energy accumulated in a capacitor.

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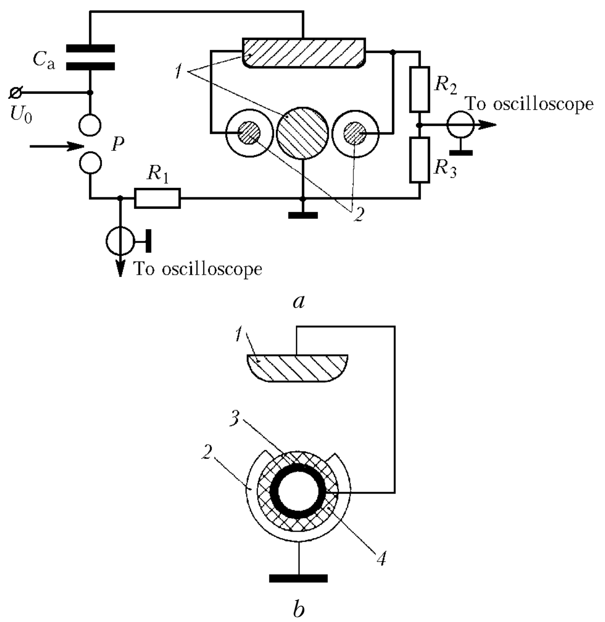
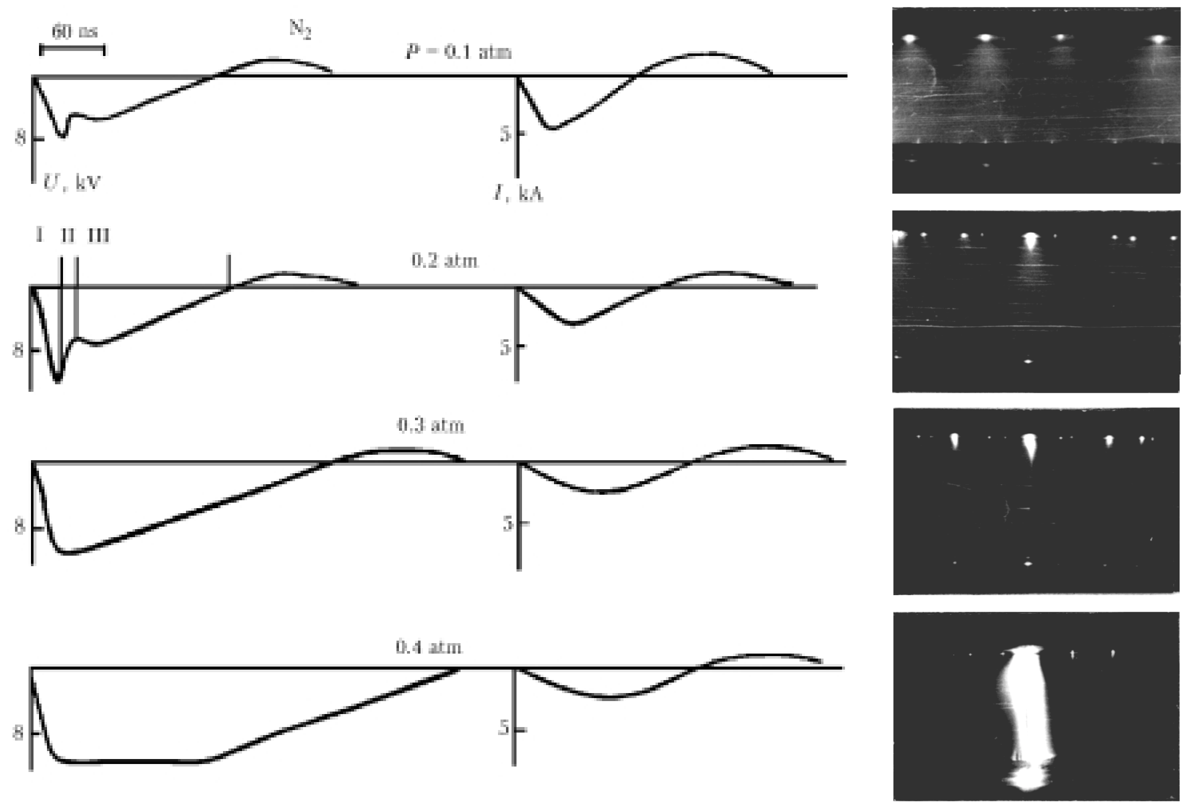


Fig. 1. Circuitry of the setup with the UV preionization (*a*) for studying self-maintained volume discharge in gas mixtures He(Ar):Xe:CCl_4: main electrodes *1* and auxiliary electrodes *2*; design of plasma electrode (*b*) with corona preionization: anode *1*, cathode *2*, auxiliary electrode *3*, and quartz tube *4*.

1.2. Peculiarities in evolution of the volume discharge in gaseous N_2 and He

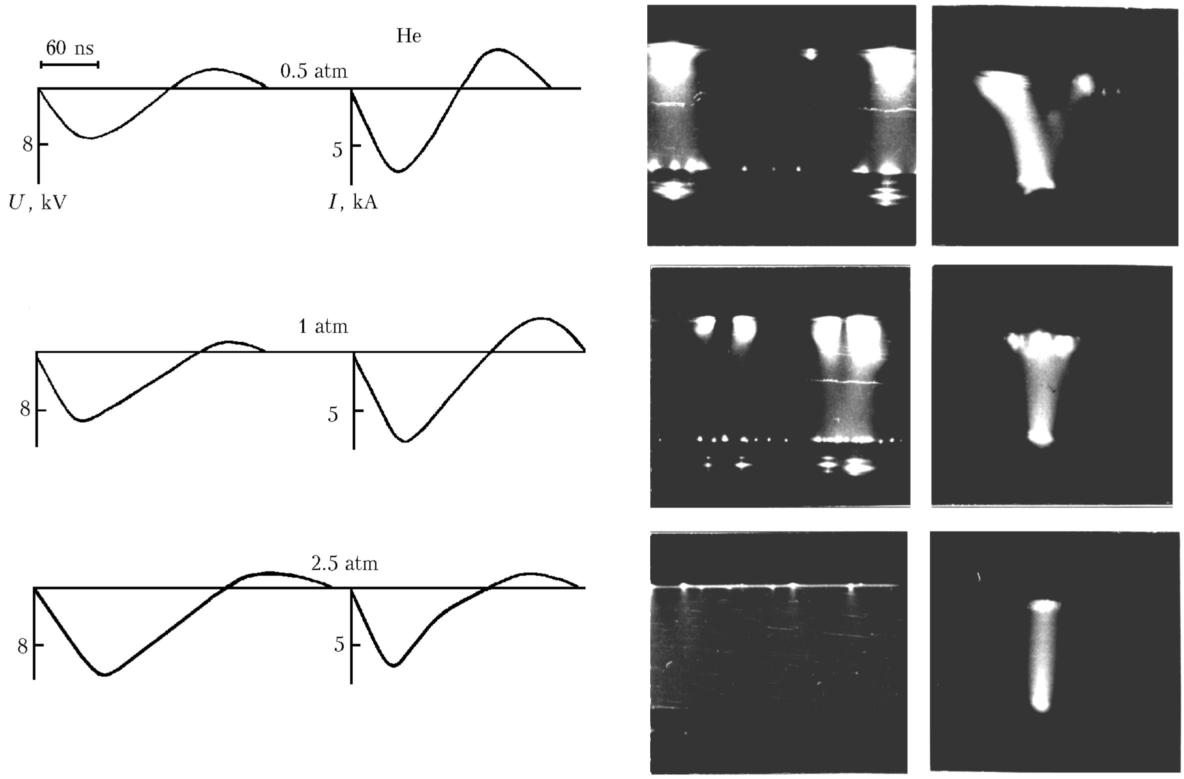
One can distinguish three characteristic stages in the voltage oscillograms (Fig. 2), the voltage increase up to the breakdown voltage (*1*), fast voltage decrease (*2*) characteristic of fast excitation of a nitrogen laser, and slow voltage decrease (*3*) or the quasistationary stage. The duration of the first stage was equal to 30 ns and determined by the inductance and capacitance of the discharge circuit, as well as by the type and intensity of the source of preionization, and properties of the gas. The breakdown voltage remained constant (~ 12 kV) at the pressure higher than 0.2 atm and depended only on the intensity of the source of UV preionization.

The qualitative pattern of evolution of the high-voltage volume discharge in N_2 is well illustrated by photographs of its integral glow. At the pressure up to 0.1 atm, a homogeneous glow discharge with uniformly distributed cathode spots was observed. At the pressure higher than 0.2 atm, one of the cathode spots intensified. Clustery discharges evolve on the spot front and then spread toward the anode. At the pressure higher than 0.4 atm, the main cathode spot closed the discharge gap.



a *b* *c*

Fig. 2. Typical (for nitrogen) oscillograms of voltage across the gap (*a*) and discharge current (*b*), as well as photographs of integral discharge glow along the electrodes (*c*) depending on pressure at the discharge voltage U_0 = 15 kV.



a *b* *c* *d*

Fig. 3. Typical (for helium) oscillograms of voltage across the gap (*a*) and discharge current (*b*), as well as photographs of integral discharge glow along the electrodes (*c*) and in cross section (*d*) depending on pressure at the discharge voltage U_0 = 15 kV.

Comparing the oscillograms and photographs, we can see that as the pressure increases, the volume stage of the discharge is restricted to development of cathode instability due to almost halving the E/N ratio (E is the electric field strength, and N is the concentration of active particles). The criterion of existence of a volume discharge in a gap is the presence of the quasistationary stage in voltage oscillograms.[14] It follows herefrom that the volume discharge in nitrogen was maintained up to the pressure of 0.3 atm.

As is seen from typical oscillograms observed in a mixture with helium (Fig. 3), the growth stage of the voltage across the gap elongated up to 60 ns. It was a peculiarity of the discharge in He that neither pronounced and nor quasistationary stage were observed, in contrast to that observed earlier in nitrogen. Starting from the pressure of 1.5 atm, the breakdown voltage remained constant (~ 12 kV) independent of the He pressure and depended only on the parameters of the source of UV preionization. With the increasing pressure, the discharge became more homogeneous. This indicated to close matching of impedances of the power supply and the discharge plasma. According to the oscillograms of voltage and discharge current, at the pressure higher than 2.5 atm almost all energy of the power supply came into the gas in the first half-cycle of discharge.

The qualitative pattern of the evolution of high-pressure volume discharge in He is well illustrated by the photographs of its integral glow across the electrodes. At the pressure ~ 0.5 atm, diffuse cathode spots evolved at the edges of the electrode (with the highest increase of the field strength) and closed on the anode thus forming a free space at the center of the electrode. At the pressure ~ 1 atm, the number of cathode spots increased and their area was twice as large as that of the anode spots. The volume discharge evolved only at the central part of the electrodes. The glow surfaces of the anode and cathode had close areas starting from the pressure of 1.5 atm, and these areas remained constant as the pressure grew up to 4 atm. Thus, the homogeneous volume discharge in He under the given experimental conditions was maintained at the pressure from 1 to 4 atm.

1.3. Peculiarities of volume discharge in heavy inert gases: Ar, Xe, and Kr

In the longitudinal section of the electrodes (Fig. 4), the ordinary mode of discharge (I) in Ar kept up to the pressure of 0.3 atm. The criterion of this stage was the presence of cathode and anode spots uniformly distributed over the electrodes. However, in the photographs recorded in the cross section of the discharge (Fig. 4*d*), we observed small spots, isolated from the main discharge, on the cathode opposite to the preionizers (see Fig. 1*a*).

At the pressure higher than 0.3 atm, in the cross photographs of the discharge, we observed spatial redistribution of the discharge channel, namely, an extra discharge channel arose between the cathode and a plasma on the surface of a dielectric of the source of UV preionization. In this configuration of the electrodes, the plasma on the surface of the dielectric plays the part of an anode with the increased electric field strength. The electrical properties of the discharge changed with the appearance of the extra channel.

Thus, in argon at the pressure higher than 0.6 atm the discharge terminated between the cathode and anode and evolved only from the cathode to the surface plasma of the source of UV preionization (III). Small luminous spots were observed on the electrodes of the main gap. As long as the discharge between the cathode and anode existed, three characteristic stages similar to the stages in nitrogen were observed in the voltage oscillograms. The stage of the voltage growth in argon was half as long as that in He (30 ns), i.e., it was close to the characteristic stage in nitrogen. With the appearance of the extra channel, the stage of fast decrease was absent in the voltage oscillograms. Consequently, in argon we observed two principally different types of discharge: at low ($P < 0.3$ atm) and high ($P > 0.3$ atm) gas pressure.

The observed phenomenon of spatial redistribution of the discharge can be explained in the following way. At low pressure, the UV radiation from the plasma formed on the surface of the dielectric relatively homogeneously excites and ionizes the gas in the gap. Therefore, the discharge evolves between the main electrodes. It is an ordinary discharge. As the gas pressure increases, the mean free path of photons decreases, and electronic avalanches are mostly initiated in the area between the cathode and the plasma on the surface of the dielectric that plays the part of the anode with the increased electric field strength. This leads to the development of the main discharge in the gap between the cathode and the surface plasma of the corona discharge. This is a new type of discharge, because the presence of two primary and one auxiliary electrode was needed for it to occur. These electrodes provided the conditions for the main discharge to occur in the gap between the primary electrode and an auxiliary (plasma) one.

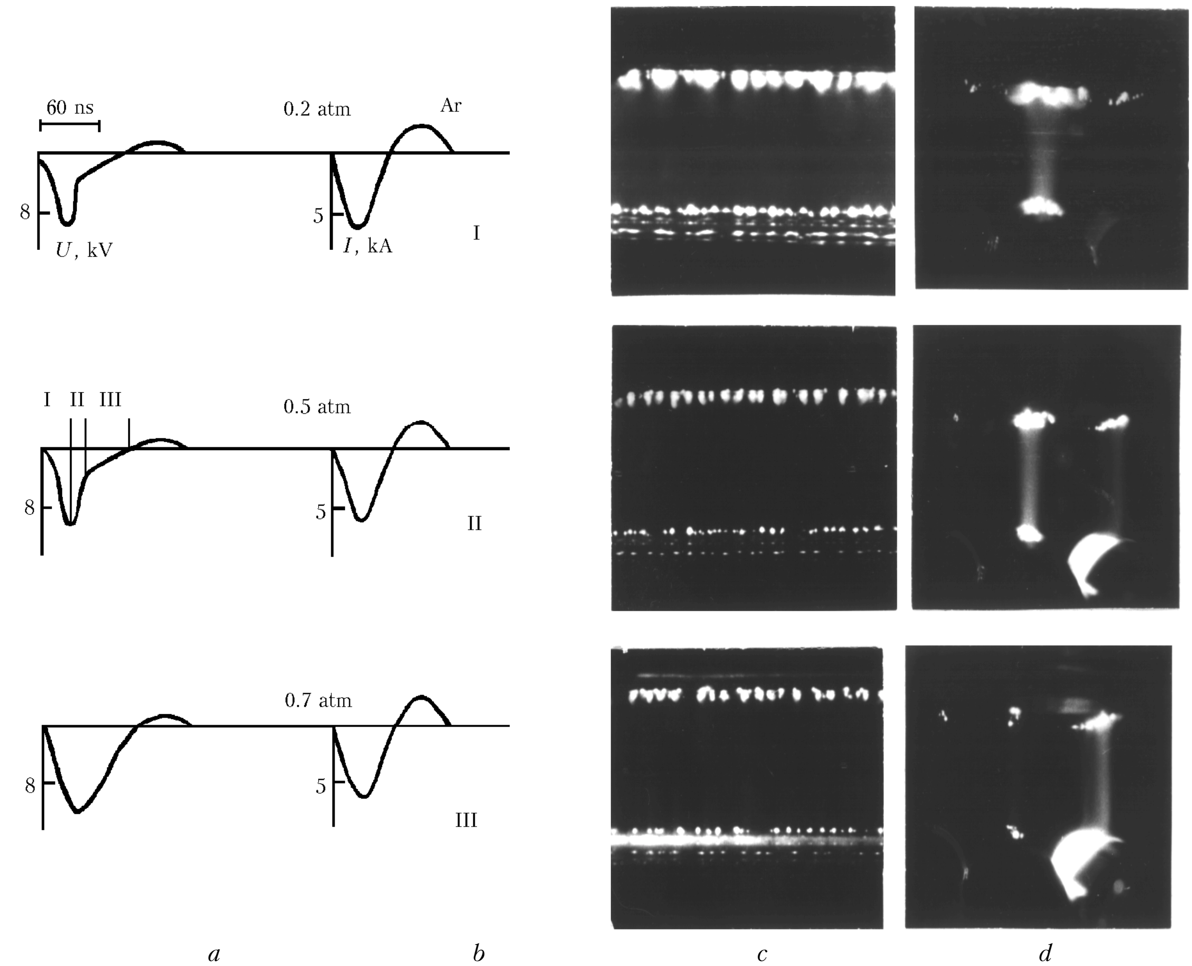


Fig. 4. Typical (for argon) oscillograms of voltage across the gap (*a*) and discharge current (*b*), as well as photographs of integral discharge glow along the electrodes (*c*) and in cross section (*d*) depending on the pressure at the discharge voltage $U_0 = 15$ kV, where I, II, and III are characteristic stages of evolution of the volume discharge.

Thus, the plasma formed by the source of corona discharge can serve an electrode of the main discharge gap. The discharge of the new type was formed only in heavy inert gases Ar, Xe, and Kr. This is connected with the processes of their photoexcitation and photoionization by shortwave radiation from the plasma of the corona discharge.[13,15] In particular, the volume discharge in Ar was maintained up to the pressure of 1 atm.

1.4. Discharges in two- and three-component mixtures with helium

Similar studies were conducted in two- and three-component mixtures (Fig. 5). As the pressure of the He:Xe mixture increased, the sizes of the cathode spots decreased, but their number increased. The homogeneous volume discharge was observed up to the pressure of 4 atm at the Xe partial concentration not higher than 5%. Three stages were observed in the oscillograms of the voltage across the gap. The quasistationary stage for the gas mixtures is of particular interest, because it was absent in pure helium.

The cathode spots in the He:CCl_4 mixtures were several times larger than in He:Xe. Filamentary channels closing on the anode came from them. At the pressure of 2.5 atm and higher, several main diffuse channels and a few filamentary channels were observed. The number of the filamentary channels depended on the concentrations of both CCl_4 and He. The volume discharge occurred up to 1.5 atm at the concentration of CCl_4 no higher than 0.1%.

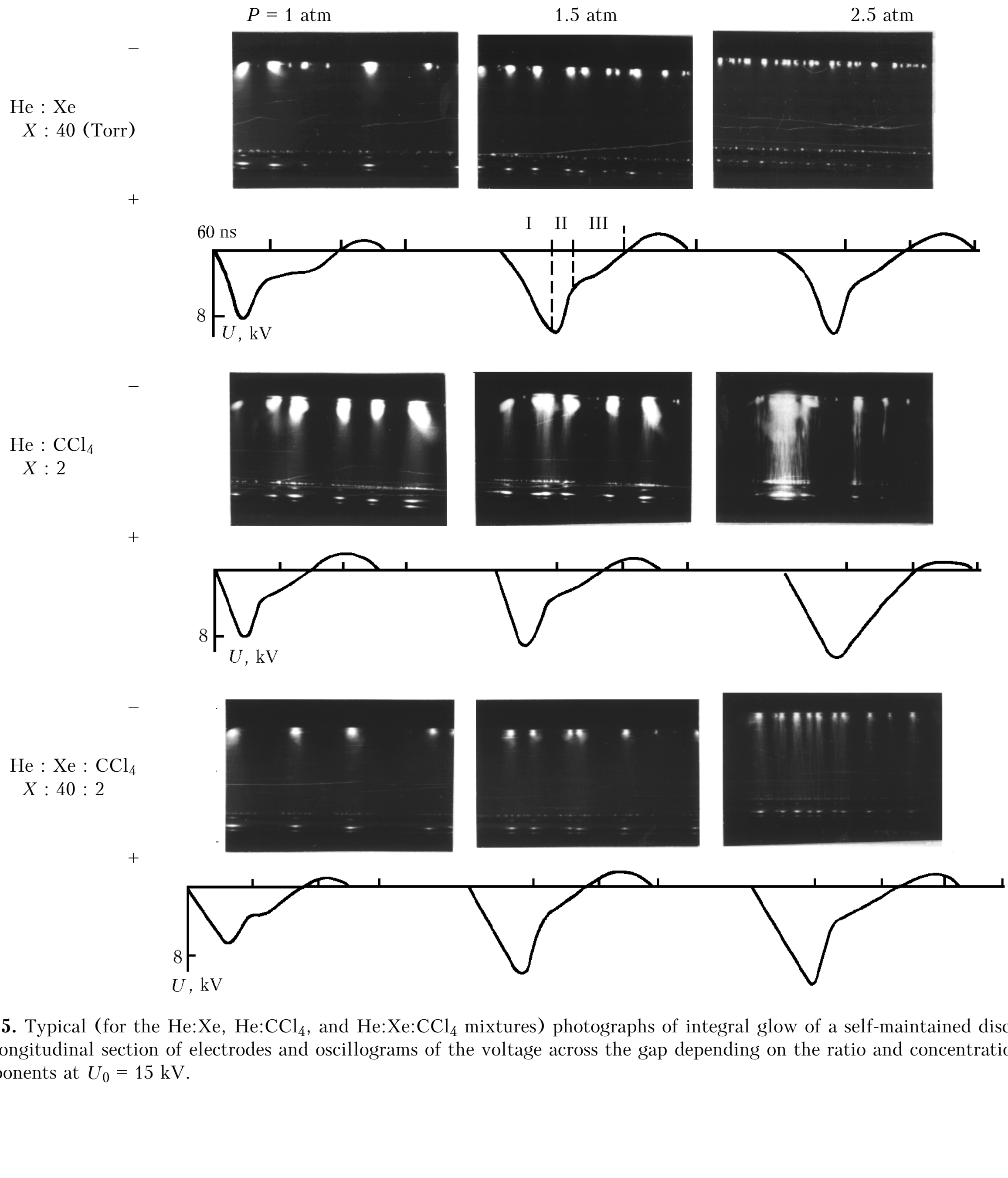


Fig. 5. Typical (for the He:Xe, He:CCl_4, and He:Xe:CCl_4 mixtures) photographs of integral glow of a self-maintained discharge in the longitudinal section of electrodes and oscillograms of the voltage across the gap depending on the ratio and concentration of gas components at U_0 = 15 kV.

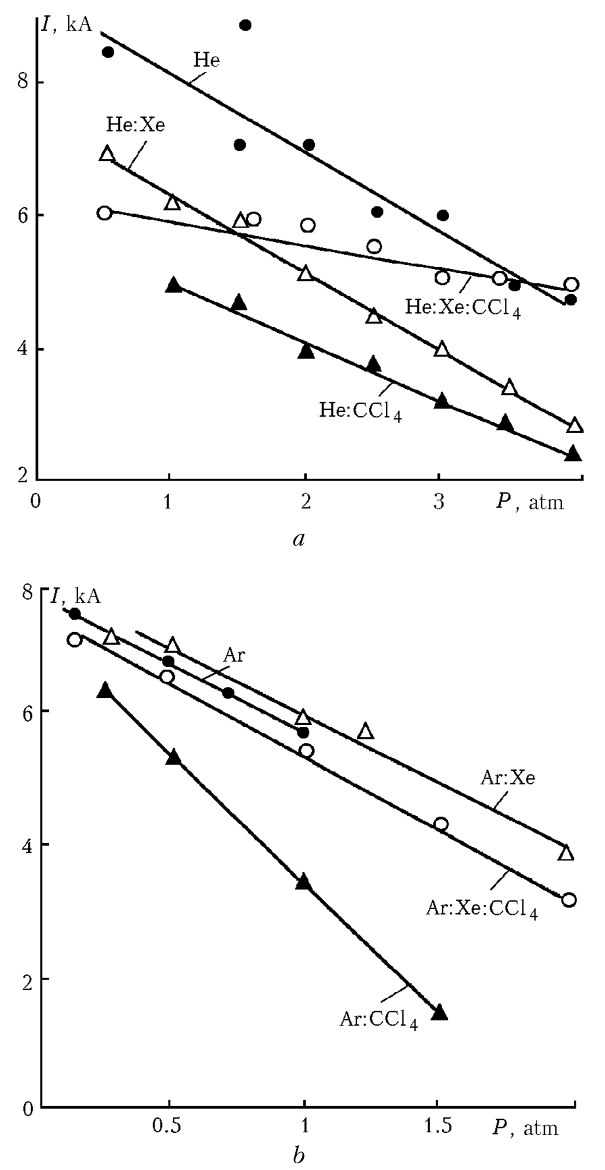


Fig. 6. Discharge current as a function of the ratio and concentration of gas components in helium (*a*) and argon (*b*) mixtures at U_0 = 15 kV.

The structure of the cathode spots in He:Xe:CCl_4 was similar to that in He:Xe. However, as the pressure increased above 2.5 atm, a number of weakly conductive filamentary channels uniformly distributed along the electrodes occurred in the gap. The 100-ns-long volume discharge was maintained up to the pressure of 4 atm at the specific energy deposition up to 200 J/(l·atm) for the Xe concentration no higher than 5% and CCl_4 concentration no higher than 0.1%. This is confirmed by the characteristics of the discharge shown in Fig. 6*a*. Besides, they allow us to assert that the homogeneity and the areas of existence of the volume discharge in helium mixtures depend on the concentration of the buffer gas He and weakly depend on the type and the operating mode of the source of UV preionization.

1.5. Discharges in two- and three-component mixtures with argon

The studies were also conducted in two- and three-component mixtures with argon as a buffer gas (Fig. 7). Comparing the discharges in pure argon and in mixtures with argon, we would like to note the following differences.

Spots of two types (on the cathode and in the space adjacent to the cathode) were observed in the discharge in the Ar:Xe mixtures. The spatial spots were separated by 2 to 3 mm from the cathode. The cathode spots in the mixtures Ar:Xe had smaller size as compared with those in pure argon, and their number increased with the growth of the pressure up to 1 atm. The spatial spots disappear at the pressure higher than 1 atm, but low-intensity diffuse channels spanning the gas discharge gap arose. The homogeneous discharge was observed up to the pressure of 2 atm.

Widening the pressure range of the steady discharge glow in Ar:Xe in comparison with Ar is caused by the fact that Xe played the role of an addition easily ionized by the UV radiation. It is well known that photoionization and photoexcitation cross sections for Xe are larger than for Ar and spectrally shifted toward longer waves.[15] The experimental confirmation of this fact can be the formation of spatial cathode spots and an increase in the discharge current in Ar:Xe as compared with that in pure Ar (Fig. 6*b*). Three characteristic stages were also observed in the oscillograms of voltage across the gap.

The cathode spots in the Ar:CCl_4 mixtures were larger and came to the anode through filamentary channels. The homogeneous discharge was observed up to the pressure of 0.5 atm at the CCl_4 concentration ≤ 0.1%. Three stages were observed in the voltage oscillograms as well.

The cathode spots in Ar:Xe:CCl_4 were similar to the spots in Ar:Xe, but the discharge was more homogeneous. As the pressure increased above 1 atm, the cathode spots ended with uniform diffuse channels joining the cathode and the plasma of the source of corona preionization similarly to the discharge in Ar described above (see Fig. 4, stage III). In the Ar:Xe:CCl_4 mixtures, the quasistationary stage of discharge was observed in oscillograms of voltage across the gap. Its duration depended on the operating mode of the corona source of preionization and on the concentration of gas components. The 100-ns-long homogeneous discharge was observed up to 2 atm at Xe concentration ≤ 5% and CCl_4 concentration ≤ 0.1%. In the volume stage of the discharge, the specific energy up to 300 J/(l·atm) was deposited into the gas. This is confirmed by the discharge characteristics shown in Fig. 6*b*. Besides, they allow us to assert that the homogeneity and the areas of existence of the volume discharge in Ar are determined mostly by the concentration of the gas components.

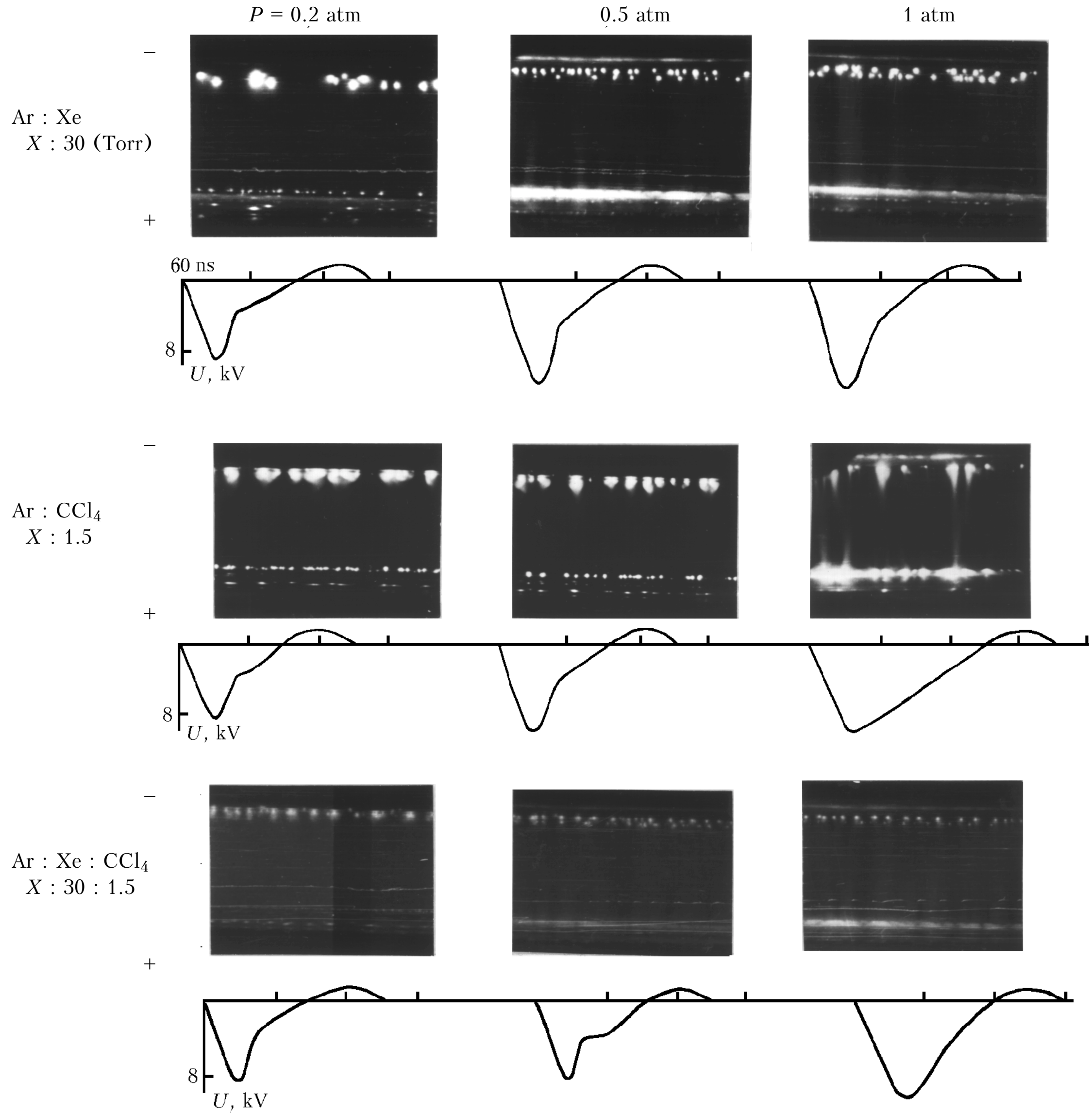


Fig. 7. Typical (for Ar:Xe, Ar:CCl_4, and Ar:Xe:CCl_4 mixtures) photographs of integral glow of a self-maintained discharge in the longitudinal section of electrodes and oscillograms of voltage across the gap depending on the ratio and concentration of gas components at U_0 = 15 kV.

At the end of the description of self-maintained high-pressure discharges for XeCl laser with the He and Ar buffer gases pumped by a single-circuit power supply with automatic corona preionization, we would like to note two their properties: (1) the existence of the quasistationary stage of voltage across the gap regardless of the type of the buffer gas and (2) formation of the new type of discharge (under conditions of the plasma electrode) characteristic of heavy inert gases or lasing gas mixtures with argon.

Based on the results obtained, we have developed a plasma electrode with the surface corona discharge (see Fig. 1*b*). It has been found that for the plasma electrode to occur, we need (1) an overvoltage gap, (2) an automatic source of corona discharge bounded by a dielectric and located nearby an electrode, (3) a heavy inert gas providing the predominant process of volume photoexcitation and photoionization of the active medium. The high efficiency of the plasma electrode for excimer lasers has been demonstrated.[16] In particular, parameters of laser radiation at the XeF and XeCl molecules with Ar as a buffer gas for the plasma electrode were 1.5 to 2 times higher than for He (Ref. 17).

2. Experimental studies of the discharge stabilization in systems with two-circuit power supply

2.1. Experimental setup

The existence of the quasistationary stage of the discharge in the case of a single-circuit power supply with automatic source of UV radiation suggests that in the case of a more complex, e.g., two-circuit, power supply the duration of the quasistationary stage can be controlled by varying the circuitry and parameters of the power supply circuits. The simplest modifications of the two-circuit power supply employ a peaking capacitor (C_p). Earlier, in Ref. 12 it was shown that long volume discharges in XeCl laser could be obtained by use of a two-circuit power supply with automatic spark UV preionization.

In this paper, we present similar studies of the discharge properties, as well as power and time parameters of the XeCl laser with the active volume $V = 2 \times 0.3 \times 20$ cm^3 and the active mixture He:Xe:CCl_4 for a two-circuit power supply with automatic corona UV preionization.[7,18] A feature of the power supply was the constant accumulative capacitance (C_a = = 20 nF) and peaking capacitance variable from 2 to 12 nF.

The necessity to vary the peaking capacitance is caused by the fact that it plays two roles: first, it decreases the rise time of the voltage across the electrodes of the laser gap and, second, it provides the given duration of the fast stage of the discharge.

2.2. Discharge properties provided by two-circuit power supply

Figure 8 shows the oscillograms of the voltage and discharge current, as well as the dependences of pulse power and output energy typical of the (He)Xe:CCl_4 mixture. These data can be generalized as follows.

The increase of the discharge voltage at a constant pressure of 2 atm and C_p = 4 nF (Fig. 8*a*) led, as should be expected, to the increase of the amplitude of the breakdown voltage at a constant rise time of the voltage across the gap. The main property of the discharge is the presence of the fast stage. Its peculiarity is the following: with the increase of the discharge voltage, the time of the postbreakdown voltage fall off across the gap became shorter, and the amplitude of the discharge current of the peaking capacitor increased, and, consequently, the fast stage of the discharge shortened. Besides, the slow increase of the current corresponding to the corona current of preionization was recorded in the beginning of the oscillograms of the discharge current of the peaking capacitor. For the corona discharge, in contrast to the main discharge, the growth of the discharge voltage affects neither amplitude nor duration of the preionization current.

The maximum laser output energy was observed at the maximum discharge voltage and the maximum discharge current. Laser pulses were up to 50 ns long. The output energy for the first 20 ns was equal to the energy for the next 30 ns. The fast stage of the discharge lasted no longer than 20 ns. This fact indicates that the total discharge current includes a component of the discharge current of the peaking capacitor.

The increase of the pressure of the gas mixture at a constant discharge voltage of 20 kV and C_p = 4 nF (Fig. 8*b*) led to the growth of both the constant of the build-up time of the breakdown voltage and its amplitude. As could be expected, the discharge current of the peaking capacitor and laser pulses behaved similarly to the case shown in Fig. 8*a*, but at the optimal pressure of the mixture. The value of the optimal pressure is connected with the parameters of the source of automatic UV preionization. Consequently, the two-circuit power supply with C_p = 4 nF and C_a = 20 nF allowed, on the one hand, optimal excitation of the gas mixture to be obtained due to optimal E/N and, on the other hand, the rate of energy deposition into the active medium to be increased due to the fast stage of the discharge. The increase of the peaking capacitance from 4 to 20 nF at the constant discharge voltage of 20 kV and the pressure of 1.5 atm (Fig. 8*c*) led to the increase of the constant of the build-up time of the breakdown voltage and its amplitude. However, the maximum output energy was observed at the peaking capacitance of 6 nF. With the further growth of C_p, the duration of the laser pulses decreased, and at C_p = 12 nF it was 20 ns. This is connected with the fact that the peaking capacitance determines some discharge characteristics, namely, the decay time of the voltage across the gap, the duration of the current of the corona discharge, and the amplitude of the discharge current. As known, the high density of the discharge current of the peaking capacitor led to the discharge contraction and, correspondingly, to shortening of the laser pulses. Within the framework of this model, at the discharge contraction the energy remained in the accumulative capacitor, i.e., in the second circuit of the power supply, runs to waste.

The role of C_p can be understood better if measuring the voltage across the capacitor U_c and plasma U_{pl}. It was determined by the method of graphic differentiation of the discharge current oscillograms.[19] Such a complicated procedure of determining U_{pl} is caused by the fact that U_{pl} cannot be measured sufficiently accurate in the fast discharge because of the high build-up rate of the discharge current.

Figure 8*d* shows the characteristics of the gas-discharge plasma and oscillograms of the laser pulses for C_p equal to 4 and 8 nF (Ref. 7). For both C_p values, we can see two characteristic stages (fast and quasistationary) in the behavior of the voltage across the plasma. With the increase of the peaking capacitance, no marked changes in the behavior of the voltage at the stage of its decay were observed, and the duration of the quasistationary stage increased significantly. Consequently, the two-circuit power supply with automatic UV preionization automatically provides for conditions necessary for formation of the long quasistationary stage in the discharge.

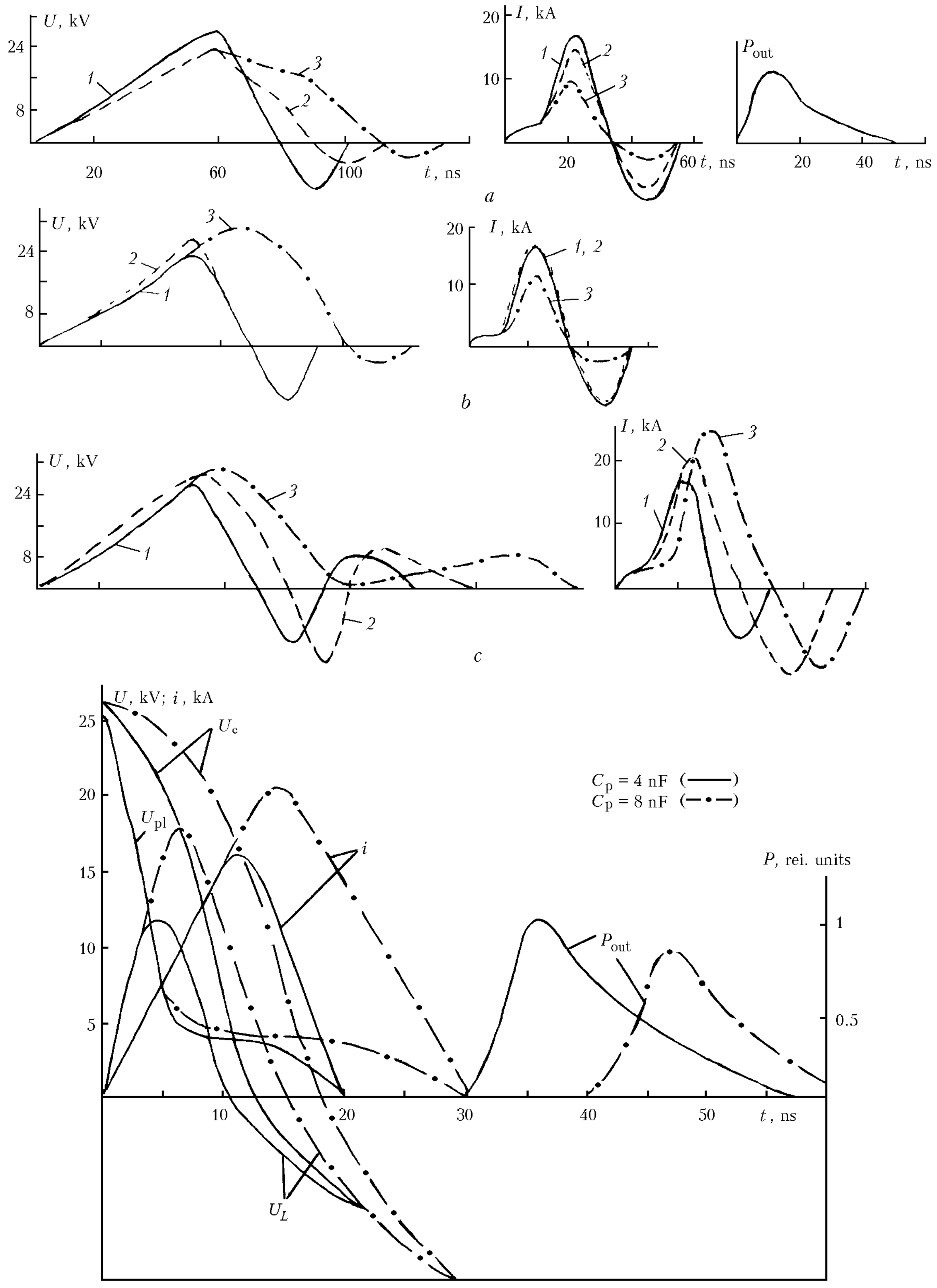


Fig. 8. Typical [for (He)Xe:CCl_4 = 10:1 mixture (2 Torr)] oscillograms of voltage across the laser gap and discharge current of the peaking capacitor, as well as dependences of the output energy and laser pulses on the discharge voltage (*a*), working pressure (*b*), peaking capacitance (*c*), and calculated characteristics of plasma (*d*) for C_a = 20 nF and the following parameters:
Fig. 8*a*: U_0 = 20 kV, 6 mJ (*1*); 16 kV, 3.6 mJ (*2*); 14 kV, 1 mJ (*3*) at P = 2 atm, C_p = 4 nF;
Fig. 8*b*: P = 1.5 atm, 3.6 mJ (*1*), 2 atm, 6 mJ (*2*), 2.5 atm, 3.2 mJ (*3*) at U_0 = 20 kV, C_p = 4 nF;
Fig. 8*c*: C_p = 4 nF, 3.6 mJ (*1*), 6 nF, 4 mJ (*2*), 12 nF, 2.6 mJ (*3*) at U_0 = 20 kV, P = 1.5 atm;
Fig. 8*d*: calculated parameters of plasma at C_p = 4 and 8 nF at U_0 = 20 kV, P = 1.5 atm.

The characteristics of the plasma (see Fig. 8*d*) confirm the experimental results of research into the dependence of the laser output energy and efficiency (η) on the peaking capacitance (Fig. 9*a*) and specific energy of radiation, as well as the dependence of η on the energy deposited into the active medium (Fig. 9*b*). This confirmation is in the following.

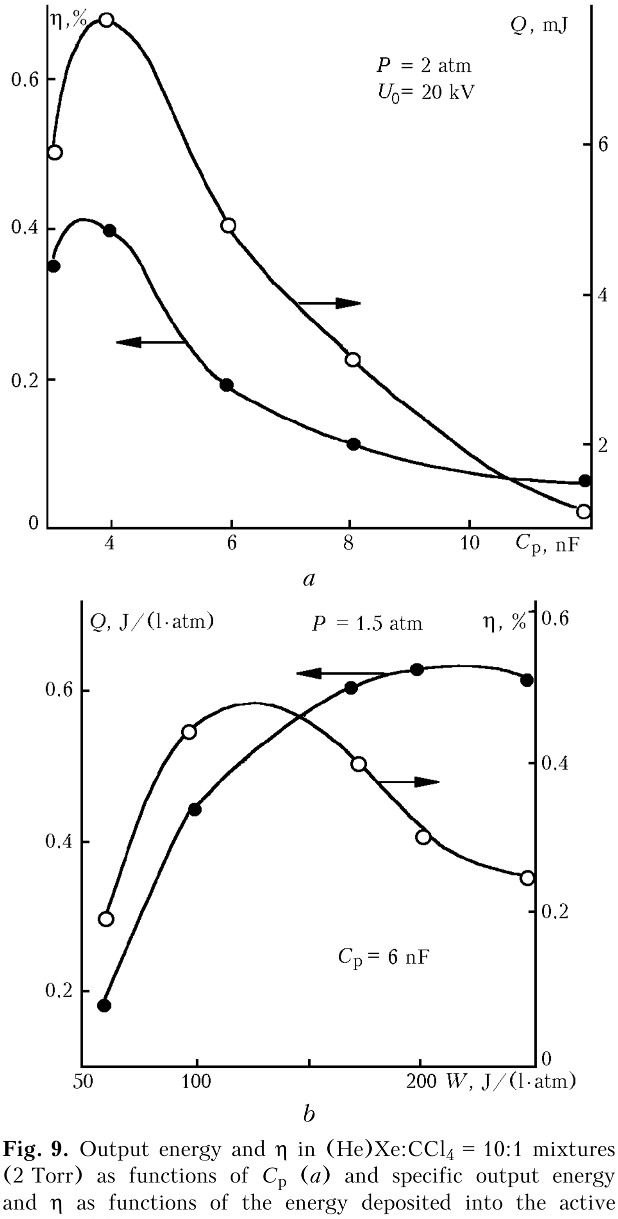


Fig. 9. Output energy and η in (He)Xe:CCl_4 = 10:1 mixtures (2 Torr) as functions of C_p (*a*) and specific output energy and η as functions of the energy deposited into the active medium (*b*) for two-circuit power supply.

The maximum output energy and η were obtained at the optimal capacitance C_p = 4 nF, although for the fast pumping mode the energy deposited into the discharge is maximum at $C_p \approx C_a$, i.e., at C_p = 20 nF. The condition of the optimal ratio between the capacitances of the power supply $C_a/C_p \geq 5$ indicated that the peaking capacitor provided the optimally high E/N ratio and formed the fast stage of the discharge. Due to UV preionization, this stage graded into the quasistationary stage with the further deposition of the main energy into the discharge from the accumulative capacitor.

To conclude this description, let us note the following properties of the discharges obtained from the two-circuit power supply with automatic corona preionization in XeCl laser:

1. The discharge consists of two stages: fast and quasistationary ones.

2. The time of transition from the fast stage to the quasistationary one depends on both the ratio between the parameters of the power supply circuits (C_a/C_p, L_a/L_p) and the density of the current in the fast stage of the discharge.

3. The quasistationary pump mode that occurs at $C_a/C_p \geq 5$ provides the highest output parameters of the XeCl laser.

Thus, according to the results obtained, the long pumping mode should be called a quasistationary mode taking into account the properties of the active medium and the characteristics of the plasma of the self-maintained discharge. Under most conditions, the kinetic processes in excimer media are quasistationary, since the characteristic times of excitation and ionization are much shorter than the duration of the pump pulses.[20] At the same time, macroscopic characteristics of self-maintained discharges (voltage across the plasma and discharge current) correspond to the generally accepted definition of quasistationarity. Recall that the state of a system is called quasistationary if the parameters, at which it is stationary, vary in time slowly. The relations among different properties of the system in this case remain the same as in the stationary case.[21]

Consequently, in the problems connected with obtaining of long XeCl laser pulses, two-circuit or, in the general case, multicircuit power supply of the gas-discharge gap is preferable. For the quasistationary pumping from a two-circuit power supply with the UV preionization to occur, the following conditions should be met: (1) $C_a/C_p \geq 5$ (in this case, the pump power in the fast stage of the discharge is much higher than in the quasistationary stage) and (2) the density of the discharge current should be lower than 200 A/cm^2 (in our case, it was achieved due to the increase of the discharge section area or the use of an active resistor connected in series with the discharge gap).

Under these conditions, we have obtained for the first time the quasistationary pump mode with plasma UV preionization and output energy of 0.5 J with pulses longer than 250 ns (Ref. 22).

Conclusion

As was noted in the Introduction, the use of the self-maintained fast discharge and corona UV preionization for pumping excimer lasers demonstrated that the output parameters of the XeCl laser are highly competitive with the output parameters of the XeF and KrF lasers (see the Table).

Table. Output parameters of XeF, KrF, and XeCl lasers with fast pumping

Working gas mixture (buffer gas He)	V, cm^3 $D \times H \times L$	U_0, kV	P_{opt}, atm	Q, mJ	$\tau_{h/2}$*, ns	η, %	References
$Xe:NF_3$ = 1:1	1.8 × 0.3 × 100	16	0.6	15	25	0.17	3
$Kr:NF_3$ = 30:1	«	12	0.7	5	25	0.1	5
$Xe:CCl_4$ = 12:1	«	16	1.8	21	12	0.23	7
$Xe:CCl_4$ = 20:1	0.9 × 0.2 × 20	14	3.4	0.36	10	–	4
$Xe:CHCl_3$ = 20:1	«	14	3.5	0.68	7	–	4
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*$\tau_{h/2}$ is the pulse duration at half-maximum.

The study of the discharge and energy parameters of the output radiation of the XeCl laser in the $He:Xe:CCl_4$ mixtures showed that the self-maintained volume discharges initiated by a two-circuit power supply with automatic corona UV preionization can provide not only fast, but also quasistationary pumping of the active medium that provides generation of long pulses. This conclusion has been confirmed in Refs. 23 and 24 that report on obtaining of up to 200-ns-long laser pulses with the practical efficiency of 1%. In more complicated power supply circuits with two independent pump sources, pulses as long as 1.4 μs were obtained with $\eta \le 1\%$ (Ref. 25). The advantages of a multicircuit power supply are illustrated by the results from Ref. 26, two of which should be mentioned. First, in that work three independent power supplies were used: (1) two-circuit source of a prior pump pulse, (2) independent source of corona UV preionization, and (3) main accumulative power supply. This allowed the experimental capabilities of this power supply circuit to be extended. Second, it was shown that if the source of UV preionization is turned on after the prior pump pulse, then the best matching between the pre-pulse and the main pump pulse is achieved. It is the best proof that preionization continues to affect the active medium once the discharge plasma is already formed.[27–29] In Ref. 26, generation of pulses as long as 340 ns with the mean output power of 505 W was reported. Thus, the studies of self-maintained discharges and energy parameters of radiation of XeCl lasers with automatic corona UV preionization and multicircuit power supply for the $Ar(He):Xe:CCl_4$ mixtures allowed the following conclusions to be drawn:

1. Corona preionization allows obtaining the quasistationary stage in high-pressure discharges, in particular, in XeCl lasers even with a single-circuit power supply.

2. Plasma created by the source of corona discharge can serve an electrode of the main discharge gap. For the plasma electrode to occur, we need an overvoltage discharge gap and an automatic source of the corona discharge bounded by a dielectric and situated nearby an electrode, as well as a heavy inert gas providing the predominant process of volume photoexcitation and photoionization of the active medium.

3. Discharges with plasma electrodes have some advantages. No instability is developed on the electrode surface. This allows higher specific energy deposition to the discharge and higher specific output energies to be obtained, in particular, in XeCl and XeF lasers.

4. The output parameters of the XeCl laser with corona preionization are highly competitive with the output parameters of the XeF and KrF lasers.

5. In the problems connected with obtaining of long XeCl laser pulses, a two-circuit or, in the general case, multicircuit power supply of the gas-discharge gap is preferable.

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