# A XeCl LOW–PRESSURE LONGITUDINAL–DISCHARGE LASER

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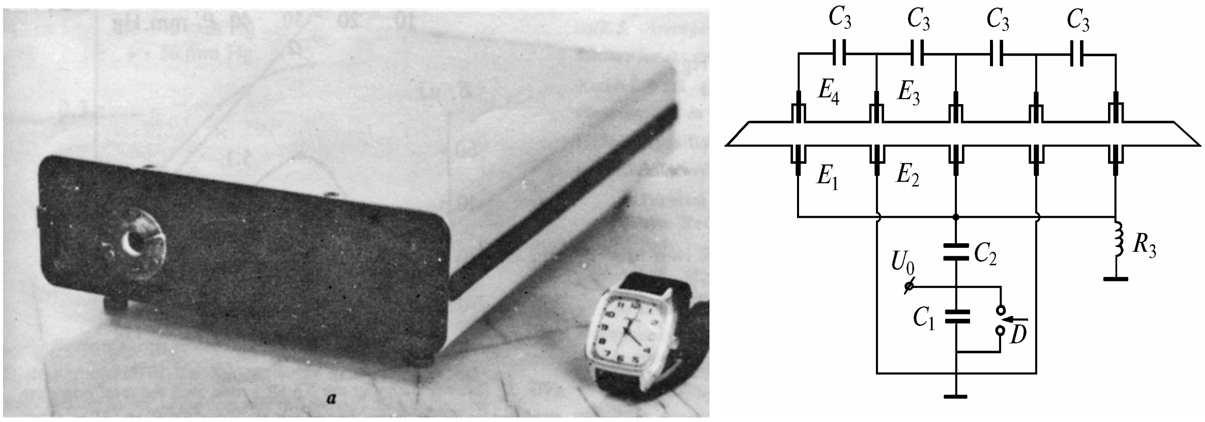
*A* XeCl *longitudinal–discharge laser is analyzed which operates at low pressure with UV preionization in different buffer gases (*He, Ne, *and* Ar*). Its output energy reaches* 0.1 mJ *at a pulse length of* 5 ns *and a total pressure of the gas mixture of* 45 mm Hg. *The* XeCl *laser has also operated without buffer gas, at* $E/P$ = 100 V/(cm·mm Hg).

To pump energy in miniature excimer lasers, the transverse discharge[1,2] is most commonly used, although the longitudinal discharge features certain merits as well. Among them are the simplicity of the emitter design, the circular cross section of the emitted beam, and its high homogeneity resulting in small divergence of the beam.[3] The possibility of using the longitudinal discharge to pump excimer molecules was first demonstrated in Ref. 4. The disadvantages of such a pumping system were poor characteristics of radiation at operating voltages exceeding 100 kV. The authors of Ref. 5 demonstrated the possibility of using the longitudinal discharge with corona preionization arising from an additional foil–coated electrode. Such systems were referred to as capacity–initiated longitudinal–discharge systems. They allowed one to improve substantially the energy parameters of emission at lower charging voltages of 30–60 kV. Thus lasing with energy of 0.317 mJ and $\tau$ = 35 ns in XeCl* was obtained by the authors of Ref. 6 at an operating voltage of 36 kV, a pressure of 520 mm Hg, and an active discharge length of 35 cm. In addition, in Ref. 7 lasing was obtained in KrF* at 300 mm Hg without any buffer gas. Longitudinal pumping system was further improved by the authors of Ref. 8, who applied an additional spark source of preionization. They obtained an energy of 0.1 mJ at $\tau$ = 15 ns and a pressure of 1.5 atm. The active discharge was 26 cm long at 40 kV discharging voltage.

This article presents the results of investigation of the efficiency of a low–pressure XeCl laser with additional preionization source as functions of various gaseous components.

Figure 1 *a* shows the general view of a miniature laser. Fig. 1 *b* illustrates the circuit diagram of power supply unit of this laser. Quartz tubes with inner diameters of 4 and 5 mm were used. Four lasing gaps with longitudinal initiation of a discharge were employed, with individual gap being 4 cm long. Five pairs of steel electrodes were used, so that the discharge channel was 16 cm long to form an active volume of 1.6 cm.[3] A cavity was formed by an aluminium reflecting mirror and a plane–parallel quartz plate. The pumping scheme followed that by Blumlein. The capacities $C_1$ and $C_2$ varied from 4 to 9 nF. The capacity $C_3$ was used as a peaker and a source of preionization of the laser channel. The total capacity $C_3$ varied from 0.6 to 1.32 nF. The RU–62 commercial discharger was used for a commutator, so that the initiation scheme was simplified and better parameters of lasing were obtained as compared to thyratron.[9] On operation of the discharger $D$ the voltage across the capacity $C_1$ inverted, and rapidly increased high–voltage pulse was applied to pairs of electrodes $E_1$–$E_4$ and $E_2$–$E_3$ across the peaking capacity $C_3$.




*a* *b*

*FIG. 1. A miniature* XeCl *laser: a) general view and b) circuit diagram of a power supply unit of the laser.*

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After the breakdown of gaps resulting in ionization of a gas, preionization discharges simultaneously charged the peaking capacity $C_3$. After it was charged to breakdown voltage, the principal longitudinal discharge occurred along the tube axis between the electrodes $E_3$ and $E_4$. Under appropriate conditions a discharge was also observed between the electrodes $E_1$ and $E_2$. Hence all the four longitudinal gaps operated simultaneously. In deciding on the operating mode, one may select between the spark and the corona preionization. Experiments made use of the gas mixtures of He (Ne, Ar):Xe:HCl. The parameters of laser radiation were recorded using the IMO–2N calorimeter, the FEK–22 SPUM photodiode, and the S8–14 oscillograph.

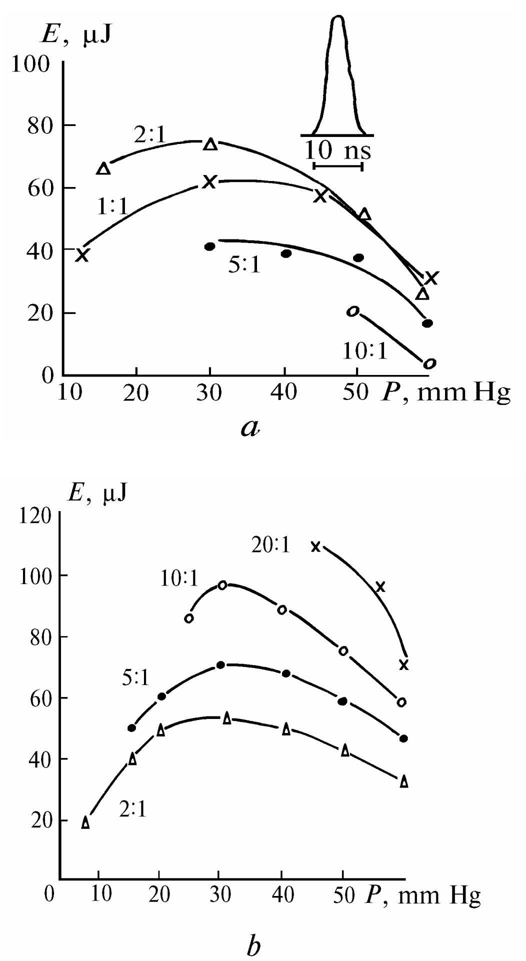


*FIG. 2. Radiant energy vs the* Xe:HCl *ratio and the total operating pressure for buffer gas* He *at* $U_0$ = 12 kV *and the* HCl *concentration of* 4 *(a)* and 2 *(b)* mm Hg. *Generated pulse of the* XeCl *laser (a).*

Figure 2 *a* shows the pulse generated by a XeCl laser with duration at half maximum of 5 ns. In addition, the dependences are shown of radiant energy on the Xe:HCl = N:1 ratio and on the total operating pressure of the gas mixture at the constant concentration of HCl. As a buffer gas, we used He. The concentration of Xe increasing, the radiant energy decreases. An optimal ratio is Xe:HCl = 2:1. On the low–pressure side, experimental results have been obtained only for the content of the fundamental components, i.e., of Xe and HCl. The content of He increasing, the radiant energy decreases.

Figure 2 *b* shows the analogous dependencies for concentration of HCl of 2 mm Hg. In this case as Xe:HCl ratio increases, the radiant energy sharply increases. As before, increasing the content of the buffer gas He results in lower radiant energies. The optimal ratio of the two components is Xe:HCl = 20:1. The maximum radiant energy reaches 110 μJ in mixtures practically free of buffer gas He, while the peak power is 20 kW.

We note that weak lasing was earlier observed in the transverse discharge in mixtures Xe:$CCl_4$ = 400:1 at pressures 0.1–0.6 atm (see Ref. 10). Hence it follows that a significant role is played by the concentration of HCl in the gas mixture when we make use of the longitudinal discharge and powerful source of preionization, while the resistance of plasma is primarily determined by the values of concentration of Xe and HCl. The sharp difference found between Xe:HCl ratios which are optimal for low and high concentration of HCl is apparently associated with the mechanism of formation of XeCl* molecules (Fig. 5 *b*). It follows from Figs. 2 *a* and *b* that the optimal pressure of working mixtures is about 30 mm Hg.

Figure 3 *a* shows the dependencies of radiant energy on the ratio Xe:HCl = N:1 and on the total pressure of gas mixture containing the buffer gas. At higher values of concentration of HCl the discharge became less homogeneous. The optimal ratio was Xe:HCl = 5:1 while the pressure of the mixture was 30 mm Hg. The maximum energy of emission was 70 μJ/pulse. When we made use of Ar, sharper optima in operating pressure were found.

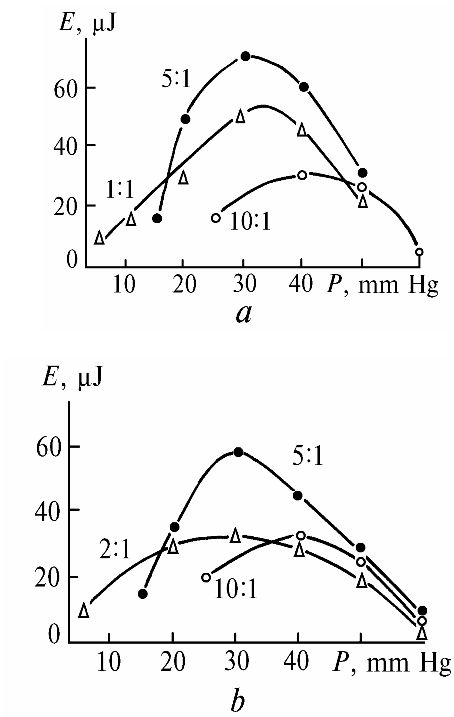


*FIG. 3. Radiant energy vs the* Xe:HCl *ratio and the total operating pressure for buffer gases* Ar *(a) and* Ne *(b) at* $U_0$ = 12 kV *and* HCl *concentration of* 2 mm Hg.

Figure 3 *b* gives such dependencies of the emitted energy in mixtures containing Ne for a buffer gas. The optimal Xe:HCl ratio was 5:1, while the pressure of the mixture was 30 mm Hg. The maximum energy of emission was 60 μJ/pulse.

Thus better performance characteristics are achieved in a longitudinal discharge with an additional power supply unit when He is used for a buffer gas or without buffer gas. Such results are apparently explained by high values of $E/P$ ($E/P$ = 100 V/(cm·mm Hg)), at which buffer gas is not as important as in lasers with transverse pumping.[11,12] Figure 4 *a* shows the dependencies of radiant energy in mixtures with He for a buffer gas on the Xe:HCl ratio and on the concentration of HCl. The content of Xe increasing, the radiant energy increases too, while an optimum is found for HCl at a pressure of 3 mm Hg, in analogy with the case of the transverse discharge.[11] When lowering the HCl concentration, the radiant energy decreases as HCl in the active volume burns away at low operating pressures and high values of $E/P$. At high values of concentration of HCl, contraction of the discharge was observed. Experimental data confirm a rigid relation between the wave resistance of the discharge plasma and the power source, see Fig. 4 *b*. These are the dependences of the average radiant power at $f$ = 5 Hz, with He for a buffer gas, on the energy input to a discharge (that is, on the charging voltage) and on the total pressure of the mixture (on the resistance of the discharge plasma). We note that the charging voltage increasing, the output radiation power linearly increases and reaches 0.47 mW. In addition, the total pressure of the mixture increasing, the output radiation power decreases regardless of the buffer gas (Fig. 5 *a*). The maximum average output power is reached for He as a buffer gas, with the optimal operating pressure being 30 mm Hg. Figure 5 *b* shows the dependencies of radiant energy on the concentration of Xe in the mixture Xe:HCl:He = $N$ :1:1 for HCl concentration of 2 and 4 mm Hg at $U_0$ = 12 kV. At low values of concentration the role of the buffer gas is apparently played by Xe.

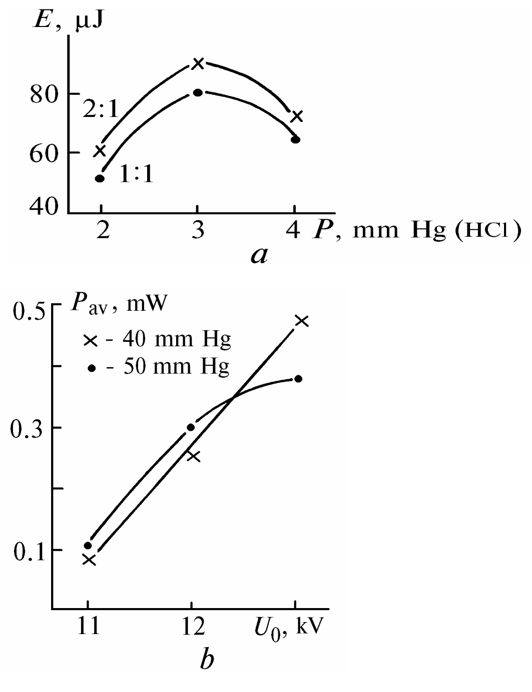


*FIG. 4. Radiant energy vs the concentration of* HCl *(*He *as a buffer gas) as a function of the* Xe:HCl *ratio at* $U_0$ = 12 kV *(a), and average radiant power vs the charging voltage and the total pressure of the mixture at* $f$ = 5 Hz, Xe:HCl = 5:1 *(*2 mm Hg*) (b).*

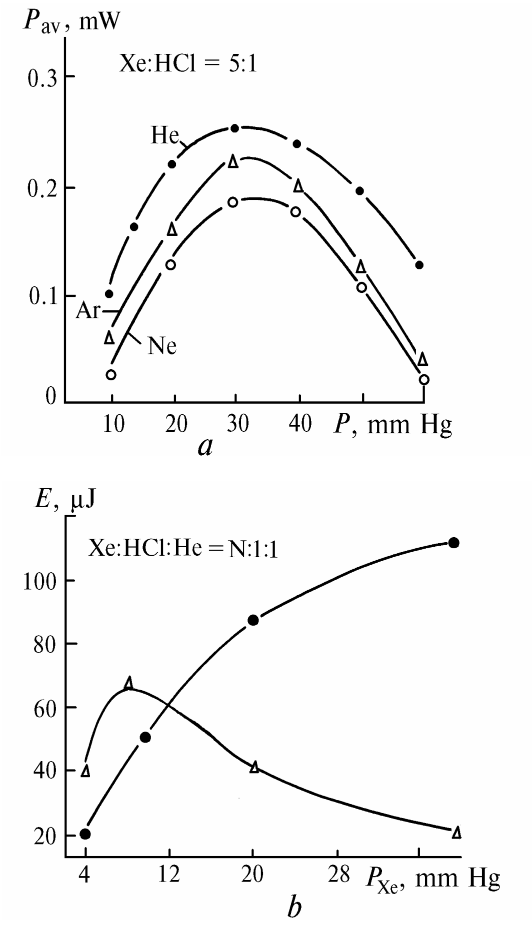


*FIG. 5. Average radiant power vs the total operating pressure of the mixture for* Ar, Ne, *and* He *as buffer gases at* $f$ = 3 Hz, $U_0$ = 12 kV, Xe:HCl = 5:1 *(*2 mm Hg*) (a), and the radiant energy vs* Xe *concentration in the* Xe:HCl:He = $N$ :1:1 *mixtures at* $U_0$ = 12 kV, HCl = 2 *(filled circles) and* 4 mm Hg *(triangles) (b).*

We note in conclusion the principal results of our study.

1. The XeCl low–pressure laser has been investigated with He, Ne, and Ar used for buffer gases. Better parameters of radiation are found for He.

2. Lasing has been achieved in XeCl* with the use of the longitudinal discharge without buffer gas at $E/P$ = 100 V/(cm·mm Hg).

3. Our experiments indicate a possibility of developing an efficient miniature excimer low–pressure lasers with UV preionization operating at low charging voltages of 10–13 kV.

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