# 50 W Efficient Discharge XeCl Laser

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**Abstract – The results of experimental research of discharge pulse-repetition XeCl laser model EL-500–100 with output energy of 500 mJ and repetition rate up to 100 Hz are presented. The maximal total laser efficiency of 2.6%, specific output energy from the active medium of 1.36 J/l · atm and laser beam intensity of 7.5 MW/cm$^2$ have been obtained.**

## 1. Introduction

Presently the discharge excimer lasers are widely used in scientific researches and technological processes. It is known, that at interaction of radiation with substance, in most cases, the determining factor of influence is the high density of energy and power of a laser beam on a surface. Therefore, the problem of specific output energy increase from the active medium of the laser and, accordingly, its radiation intensity is relevant for the present moment.

There are some publications devoted to research of radiation parameters of discharge XeCl lasers with high pump power. In work [1] the results of the laser research with pump power of 45 MW/cm$^3$ and 14 kA/cm$^2$ discharge current density are described, thus the pump power efficiency of 0.8%, specific output energy ~ 2.4 J/l · atm, radiation intensity of 4.8 MW/cm$^2$ were achieved. In work [2] the conditions of the discharge burning have been realized at pump power density of 3.77 MW/cm$^3$, in this case the laser efficiency reached 2.9%, specific output energy – 0.6 J/l · atm, and radiation intensity – 6.5 MW/cm$^2$. With change of mix pressure from 4 up to 6 atm and charging voltage from 18 up to 36 kV the laser efficiency was reduced up to 1.8%, but specific laser energy reached ~ 1 J/l · atm, and radiation intensity – 15.7 MW/cm$^2$. In work [3] the opportunity of the discharge burning consisting of set diffusion channels at average pump power of 10 MW/cm$^3$ and average current density of 5 kA/cm$^2$ has been realized, the laser efficiency with such active volume has made 1.2%, specific output energy ~ 3.9 J/l · atm, radiation intensity of 14.9 MW/cm$^2$.

In the papers submitted above the experimental breadboard, models of lasers worked in alone pulse mode are described. In such lasers, it is easier to provide a minimal inductance of electric pump circuits. For the lasers working in a pulse-periodic mode this inductance increases as a rule. It is connected to increase of the discharge contour dimensions at the realization of gas mix blowing and problems solution of electric insulation. Increase of a pump circuit inductance not only worsens the conditions of discharge formation but also reduces an overall laser efficiency due to a mismatch of discharge resistance and contour wave resistance.

At HCEI of Siberian Branch of the Russian Academy Sciences, Tomsk, Russia have been developed XeCl lasers of series EL with pulse energy of up to 350 mJ and repetition rate of up to 50 Hz [4, 5].

Fig. 1. Outward appearance arrangement of EL-500-100

This paper presents the results of experimental research of discharge pulse-repetition XeCl laser model EL-500-100 with output energy of 500 mJ and repetition rate of up to 100 Hz (Fig. 1).

## 2. Experimental equipment

The typical charge–transfer electric circuit was used for laser pumping (Fig. 2). The storage capacity $C_1$ = 107 nF (TDK UHV-6A, 2700 pF & 30 kV capacitors) is charged from constant-voltage source up to $U_0$ = 24 kV.

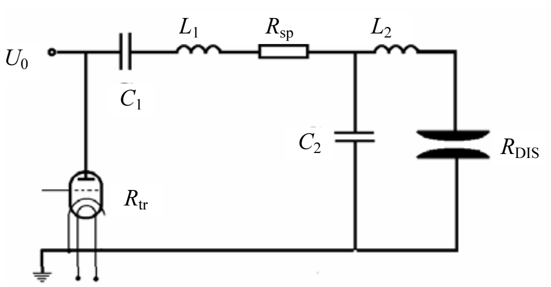


Fig. 2. Schematic diagram of excitation circuit. $C_1$ = 107 nF; $C_2$ = 72 nF; $L_1$ = 150 nH; $L_2$ = 4 nH, $R_{sp}$ – sparks resistance; $R_{DIS}$ – discharge plasma resistance; $R_{tr}$ – thyratron resistance

The thyratron of TPI3-10k/25 is used as a switch. Inductance of the first circuit $L_1$ = 150 nH was selected as optimal proceeding from two conditions:

operation reliability of thyratron and obtain of maximum radiation energy. The discharge capacity of the second circuit $C_2$ = 72 nF (TDK UHV-6A, 2700 pF & 30 kV capacitors) is pulsed charged and then it discharges providing pumping of active medium. Assembling of the laser chamber and peaking capacitors allowed reaching inductance in the discharge second circuit being equal 4 nH.

The discharge electrodes had length of 65 cm. Inter-electrode distance was 2.5 cm. Discharge effective width was 0.7–0.9 cm. Gas operating mixture Ne/Xe/HCl = 800/8/1 was used in experiments with total pressure of 3.8 bar. The length of resonator was 100 cm, reflection mirrors were $R_1 = 0.95$ and $R_2 = 0.07$.

Measurements of the laser radiation energy and laser pulse in the experiment carried out by means of the calorimeter Gentec-E and FEK22-SPU, accordingly. Electric pulses registered by means of the oscilloscope TDS-3014.

## 3. Results and discussion

Measured temporal evolutions of capacitor $C_2$ voltage, capacitors current, as well as lasing power and specific pump power are shown in Fig. 3.

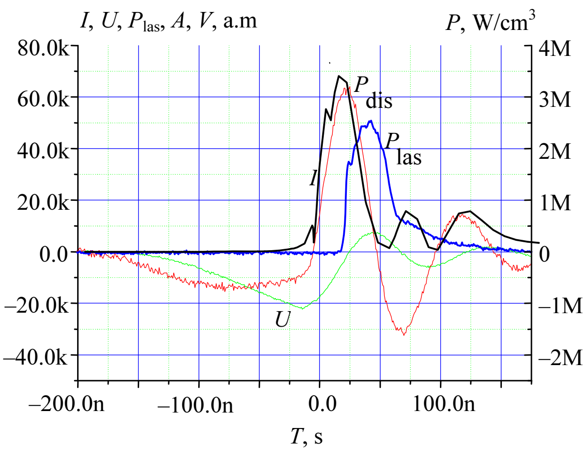


Fig. 3. Experimental temporal evolutions of capacitor $C_2$ voltage ($U$), current ($I$) and lasing power ($P_{las}$), calculated specific pump power ($P_{dis}$)

The experimental dependences of laser radiation energy and total laser efficiency versus charging voltage are shown in Fig. 4. Total laser efficiency was determined as the relation of laser radiation energy to the storage energy in initial $C_1$ capacity. The maximal efficiency was 2.6% at 18 kV, at the further increase of charging voltage the laser efficiency was reduced and at 25 kV was 1.7%.

The calculated dependences of time behavior of pump power for following conditions: mix Ne/Xe/HCl = 800/8/1, pressure $P$ = 3.8 atm, active volume – 130 cm$^3$, 24 kV charging voltage, maximal specific pump power – 3.3 MW/cm$^3$ are shown in Fig. 3. In a range of charging voltage from 24 up to 18 kV the specific pump power changes insignificantly from 3.3 up to 3 MW/cm$^3$ due to narrowing discharge width. At the further charging voltage reduction up to 15 kV the specific pump power was ~ 2.6 MW/cm$^3$.

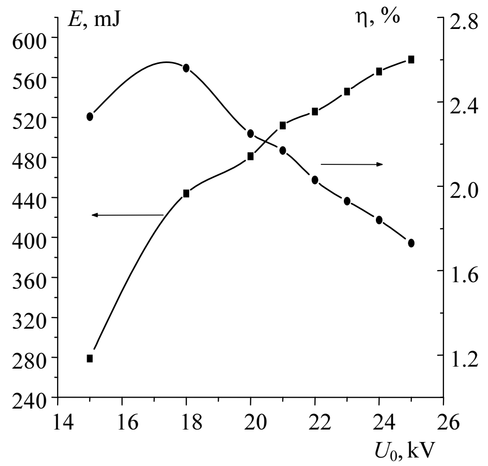


Fig. 4. Experimental (▪) laser energy, total laser efficiency (•) versus charging voltage

The threshold of generation at such range of pump power was reached through ~ 25 nanoseconds after the beginning of a discharge current. At the maximal power of generation of 14.5 MW pulse duration (FWHM) was 36 nanoseconds, a target intensity of radiation reached value of 7.5 MW/cm$^2$. At 24 kV laser efficiency determined as the relation of the maximal powers of generation and pump was 3.5%.

With the purpose of the reason definition of a total laser efficiency reduction with charging voltage growth the efficiency researches of transfer of originally storage energy to discharge energy and the discharge energy to laser radiation energy have been carried out. The dependences of intrinsic laser efficiency (concerning the energy deposited in the active medium) (*1*) and efficiency of transfer of the storage in $C_1$ energy in plasma of the gas discharge (*2*) versus charging voltage are shown in Fig. 5. The given

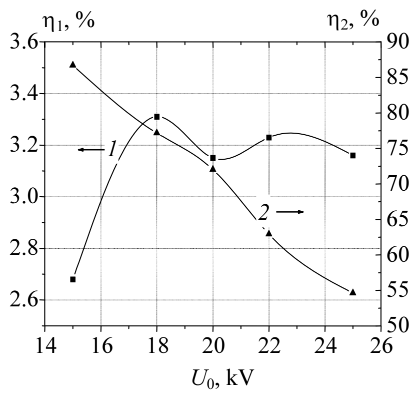


Fig. 5. Intrinsic laser efficiency (*1*) and efficiency of transfer of the storage in $C_1$ energy into plasma of the gas discharge (*2*) versus charging voltage

dependences have been received as a result of calculation of the electric pump circuit. The variable of discharge resistance was selected on coincidence of volt-ampere characteristics models with experimental results.

From the resulted dependences, it is visible, that a principal cause of total efficiency reduction of the laser is decrease of efficiency of energy transfer from capacity $C_1$ in $C_2$. Decrease of intrinsic efficiency at charging voltage less than 18 kV is caused by low level of specific pump power. In an interval of specific pump power from 3 up to 3.3 MW/cm$^3$ at average density of a current of 1.2–1.4 kA/cm$^2$ the intrinsic efficiency is kept at a level of 3.2%.

On the basis of the analysis of the resulted dependences, it is possible to assume, that the active medium has potential possibility as on more full use of molecules HCl and increase of saturation of amplification factor. Accordingly, it is possible to expect, that the further increase of specific pump power more than 3.4 MW/cm$^3$ at constant pulse duration will permit to increase the radiation energy at rather high intrinsic efficiency. However, in this case the difficulties of uniform volume discharge realization grow. As at such pump levels the macro or micro-heterogeneity inevitably arise in discharge [3]. The kind of heterogeneity is determined mainly by concentration of halogen in a laser mixture. In our experiments at the percentage of halogen in a mixture less then 0.1% (ratio of Ne/HCl > 1000/1) the micro-heterogeneities were arose. While at the percentage of halogen in mixture more than 0.15% (ratio of Ne/HCl < 700/1) the macro-heterogeneities were grown. Thus, for more full use of active medium opportunities in case of pump power increase it will be necessary to select very carefully an optimum laser mixture composition and to struggle for realization of uniform discharge.

## 4. Conclusion

XeCl laser with output energy of up to 0.59 J, the pulse duration (FWHM) of 36 ns and 100 Hz pulse repetition rate has been developed. The maximal total laser efficiency of 2.6%, specific output energy from the active medium of 1.36 J/l · atm and laser beam intensity of 7.5 MW/cm$^2$ have been achieved. It is shown, that at duration of a pump pulse of 30 ns increasing of specific pump from 2.6 MW/cm$^3$ up to 3.2 ± 2 MW/cm$^3$ leads to growth of an intrinsic efficiency with 2.7 up to 3.2%. On the basis of the received results analysis it is draw a conclusion about an opportunity of energy parameters increase of the developed laser.

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