

PACS numbers: 42.55.Lt; 42.60.Lh
DOI: 10.1070/QE2009v039n04ABEH013898

A XeCl laser with a controlled radiation pulse shape

A.I. Fedorov

***Abstract*. The pump parameters of a three-contour excitation system are studied in a gas-discharge excimer XeCl laser using a Ne – Xe – HCl mixture. A computation model is developed for finding the parameters of multi-contour excitation systems. A setup incorporating a three-contour system for excitation and automatic UV preionisation is designed, which provides multipulse generation of 65-ns, 26-mJ laser pulses at the laser efficiency of 1 %. It is shown that generation of short radiation pulses of duration 7 ns and relatively long pulses of duration 65 ns in the multipulse generation regime is possible in the excitation system under study in Xe : HCl = 20 : 1 mixtures containing neon as buffer gas.**

Keywords: *excimer XeCl laser, radiation energy, UV preionisation, efficiency, buffer gas.*

1. Introduction

The possibility to control the pulse duration and amplitude of excimer lasers is important in many applications. The duration of UV pulses generated by electric-discharge excimer lasers can vary from 10 to 50 ns [1]. The use of quasi-stationary pumping provides generation of laser pulses with the duration over 100 ns [1 – 5]. Most electric-discharge excimer lasers are known to produce pulses of duration ~ 20 ns [4, 6]. It is difficult for a single laser to generate both short (of the order of a few nanoseconds) and long (of the order of a few hundreds of nanoseconds) pulses. Frequency-doubled dye lasers [7], active [1, 8] or passive [9] mode locking of excimer lasers, dye-based saturable absorbers [10] or plasma shutters [11] were used for generation of short pulses. These means of producing short UV pulses require rather complicated optical systems, which makes their application rather problematic. In paper [12], we demonstrated the possibility to increase the pulse duration of gas-discharge lasers in two-circuit power supplies by using a quasi-stationary pump regime stabilised by UV radiation from an additional preionisation source.

A.I. Fedorov V.E. Zuev Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences, pl. Akad. Zueva 1., 634021 Tomsk, Russia; e-mail: fedorov@asd.iao.ru

Received 16 May 2008; revision received 24 November 2008
Kvantovaya Elektronika **39** (4) 313 – 316 (2009)
Translated by M.V. Politov

The aim of this paper is to design a prototype of a repetitively-pulsed XeCl laser that features a three-contour excitation system providing spark UV preionisation, and systems for precise detection of current and voltage pulses in the discharge circuits and discharge-gap plasma, as well as to select a computation model for a multi-contour excitation system which permits us to calculate the oscillograms of current and voltage pulses in the pump circuits, the duration and shape of laser pulses for different compositions of the laser gas mixtures.

2. Experimental

Energy, amplitude and time characteristics of voltage, current and laser output pulses were measured in a nanosecond range in the experiments. Earlier, the particularities of current and voltage measurements in the discharge circuits of excimer lasers were considered in paper [13] by using current shunts and voltage dividers based on resistive elements. The amplitude and time errors introduced by these elements in the measurements depended on the voltage applied to them, the presence of a noticeable inductive component and on the capacitive effect of the element shielding. To decrease these errors, we designed low-inductance shunts using a high-resistance foil and improved the construction of the shielding for the voltage dividers. All these components and also elements of the signal transmission and attenuation channels were tested in high-current and high-voltage working conditions using simple testing setups. An IMO-2N calorimeter was used to measure the radiation energy and a coaxial FEK-22SPU photocell was employed to detect the pulse shape. A S8-14 oscilloscope was used to measure amplitude and time characteristics.

Figure 1 shows the equivalent electric circuit of a laser with precise current and voltage detection in the contour and discharge gap. The circuit consists of three capacitive excitation contours, in which C_1 is the storage capacitor, C_2 is the peaking capacitor, C_3 is the capacitor of the automatic spark UV preionisation contour. Our primary goal is to find the optimal parameters of the excitation contours which provide, on the one hand, the efficient energy transfer from the storage capacitor C_1 to the peaking capacitor C_2 and the capacitor C_3 of the spark UV preionisation contour, and, on the other hand, the possibility to determine the effect of these parameter on the laser pulse duration. The distance between the electrodes of the discharge chamber varied from 1 to 2 cm. The length of the working segment of the electrodes was 20 cm. Determined from the light spot diameter, the discharge width was 0.5 cm. The automatic UV preionisation was realised along one of the electrodes by placing two rows of spark gaps of 10–15 sparks each. The capacitor C_1 was charged by the KVI-3 capacitors with the total capacitance of up to 12 nF. The capacitor C_2 was charged by the KVI-3 and KVI-1 capacitors with the total capacitance from 0.6 to 4 nF, the capacitor C_3 was charged by the KVI-1 capacitors with the total capacitance up to 0.6 nF. A TGI-1000/25 thyratron with a saturable choke was used as a switch S. As the laser operated in a repetitively pulsed regime, the current leads of the laser chamber had a high inductance ($L_2 = 20 - 40$ nH). Dielectric mirrors with the reflection coefficients 98 % and 33 % were employed as the resonator mirrors.

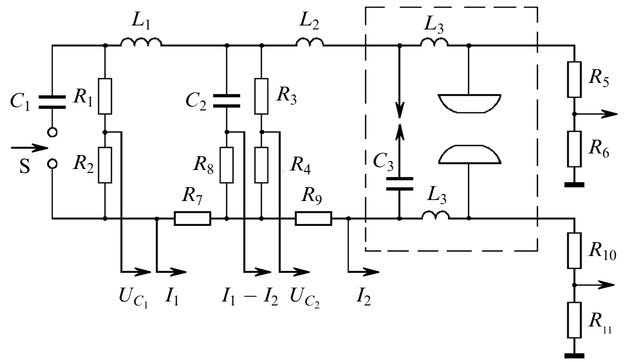

Figure 1. Equivalent electric circuit of a laser with precise detection of voltage and current in the discharge contours: C_1 is the storage capacitor, C_2 is the peaking capacitor, C_3 is the capacitor of the UV preionisation contour, L_1, L_2, L_3 are the inductance of the pump circuits, I_1, I_2 are the discharge currents, S is the switch.

3. Experimental results and discussion

The Runge–Kutta method for a system of first-order differential equations was used to calculate all current and voltage oscillograms. The equations for a three-contour pump system can be written in the form:

$$\frac{dU_{C_1}}{dt} = -\frac{1}{C_1} I_1, \tag{1}$$

$$\frac{dU_{C_2}}{dt} = \frac{1}{C_2}(I_1 - I_2), \tag{2}$$

$$\frac{dI_1}{dt} = \frac{1}{L_1}(U_{C_1} - U_{C_2} - U_c), \tag{3}$$

$$\frac{dU_{C_3}}{dt} = \frac{1}{C_3}(I_2 - I_3), \tag{4}$$

$$\frac{dI_2}{dt} = \frac{1}{L_2}(U_{C_2} - U_{C_3} - U_{UV}), \tag{5}$$

$$\frac{dI_3}{dt} = \frac{1}{L_3}(U_{C_3} + U_{UV} - U_d), \tag{6}$$

where U_{UV}, U_c, U_d are breakdown voltages of the sparks and the switch, and the voltage across the main gap, respectively. At first, we solved equations (1)–(3), then (after the breakdown voltage of sparks, and then the breakdown voltage of the plasma of the main discharge were achieved) we additionally calculated equations (4), (5), (6), etc. Consideration of various computational models for discharge gaps showed that the best agreement with real oscillograms is provided when we use the sparks and main discharge models featuring a gradually decreasing voltage which is independent of the current in the gap. It turned out that the model of the switch (thyratron) should be supplemented with an active resistance of 0.15 Ω. In calculations we used the quantities of the combustion voltage, the breakdown voltage of the spark gaps and inductance from the results of the experiments. The computation method is given in detail in [13]. The difference between calculated oscillograms (except for the oscillograms of the voltage across the plasma of the main discharge) and experimental ones did not exceed 15 %.

We carried out preliminary investigations of output parameters of a XeCl laser operating on Xe and HCl mixtures containing helium, argon and neon as buffer gases. The experiments showed that the pulse duration can be varied from 7 to 65 ns by appropriately choosing the quantity of the peaking capacitor, the interelectrode distance and buffer gas. A mulipulse generation regime was observed only when argon and neon were used as buffer gases and the interelectrode distance was no greater than 1.5 cm. When we used argon as a buffer gas at the optimal pressure of 0.6 atm, the laser output energy was approximately three times smaller than that in the laser with a neon buffer gas. This is explained by the fact that the spark preionisation for argon is less efficient. In the case of helium, the width of the discharge volume was one and a half times smaller than in the case of neon. With helium being used as a buffer gas, the pulse duration did not exceed 20 ns and the laser output energy was two times less than that with neon. That is why neon was used as buffer gas in the main experiments. The lifetime of neon-based mixtures was 2×10^6 pulses. The analysis of the voltage and current oscillograms in discharge contours allowed us to draw a conclusion that the modulation of the laser output is caused by the corresponding modulation of the volume discharge current. Lasing stopped when the discharge current changed its direction.

Figure 2 presents the voltage oscillograms for the capacitors C_1, C_2 and the discharge gap U_d, and oscillograms of the discharge currents I_1 and I_2, and the laser output pulse for the parameters of the excitation system: $C_1 = 12$ nF, $C_2 = 2.5$ nF, $C_3 = 0.6$ nF, the Ne:Xe:HCl = 1752:20:1 gas mixture at the pressure of 3.5 atm and the charging voltage of 25 kV. The modulation of the discharge current I_2 is explained by the multiple dosed transfer of a part of the energy from the storage capacitor C_1 to the discharge via the peaking capacitor C_2. The transfer is possible only for particular relations between the values of capacitors and inductances of pump circuits. The process was as follows: charged from the storage capacitor, the peaking capacitor was discharged through the main gap. The voltage across the peaking capacitor changed its polarity, which resulted in its additional recharge of the storage capacitor. If inductances L_2 and L_3 are large enough to prevent the discharge current from falling to zero, the peaking capacitor, after recharging, was discharged through the still burning volume discharge again, bringing about an

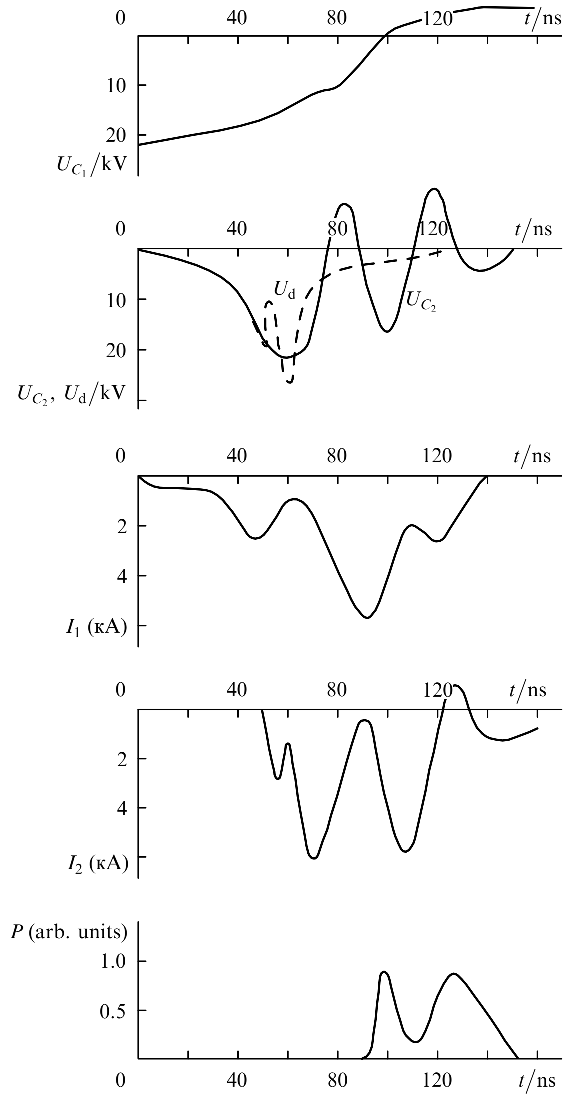

Figure 2. Oscillograms of the voltage across the capacitors C_1, C_2 and the voltage across the discharge gap U_d, as well as discharge currents I_1, I_2 and the output laser pulse for a working gas mixture Ne:Xe:HCl = 1752:20:1 at the pressure 3.5 atm, charging voltage 25 kV, $C_1 = 12$ nF, $C_2 = 2.5$ nF, and $C_3 = 0.6$ nF.

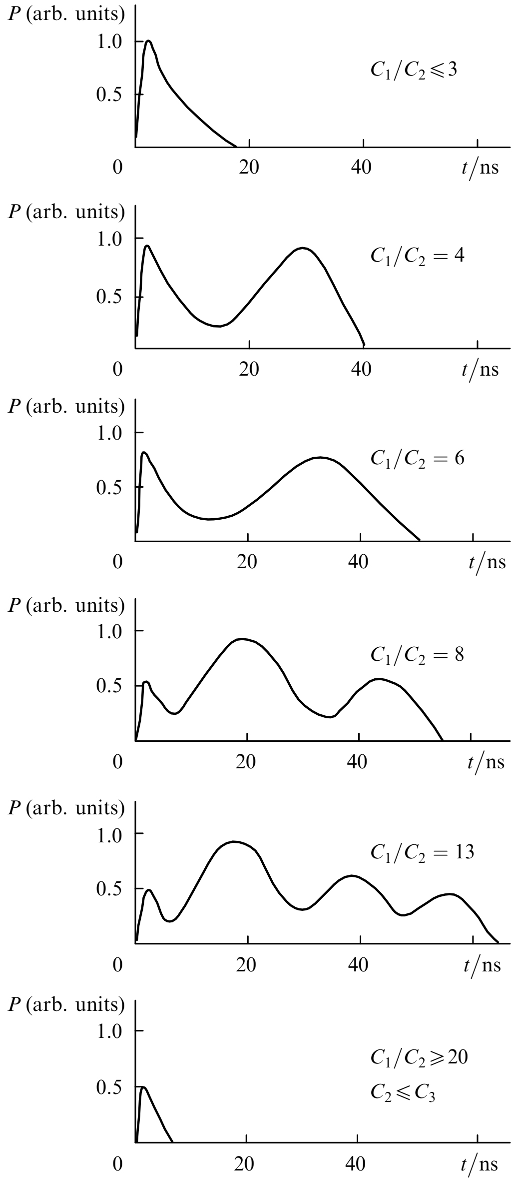

Figure 3. Output pulse oscillograms for a laser operating on a Ne:Xe:HCl = 1752:20:1 gas mixture at a pressure of 3.5 atm, charging voltage of 25 kV, $C_1 = 12$ nF, $C_3 = 0.6$ nF and different values of the peaking capacitor C_2.

additional current pulse. In our case, the laser output pulse had two maxima, which corresponded to the pulse of the discharge current through the main gap.

Figure 3 presents the oscillograms of output pulses of the laser operating on the Ne:Xe:HCl = 1752:20:1 gas mixture (3.5 atm) for different values of the peaking capacitor. In this case, the values of the storage capacitor and the UV preionisation capacitor did not change and were $C_1 = 12$ nF and $C_3 = 0.6$ nF. When the ratio of the capacitors was $C_1/C_2 \leqslant 3$, the fast-pump regime was observed with the output pulse duration of about 20 ns (measured across the pulse bottom). When the charging voltage was 20 kV, the output pulse energy was 12 mJ, and the practical laser efficiency was 0.5 %. We defined the practical laser efficiency as the ratio of the output energy to the energy stored in the storage capacitor of the excitation system.

When the ratio was $C_1/C_2 = 4$, the second maximum appeared in the output pulse and the total pulse duration increased to 40 ns. The maximum laser output energy was 23 mJ, and the laser efficiency was 0.9 % for the 2.5-J energy stored in the storage capacitor. In this case, the energy loss was 0.55 J in the thyratron, 0.15 J in the spark gaps and 1.35 J in the active medium; the energy, left in the excitation system elements immediately after the termination of the volume phase of the discharge, was equal to 0.45 J. When the quantities of the peaking capacitance were varied, the energy loss in the elements of the excitation system hardly changed. When the ratios were $C_1/C_2 = 6$ and 8, the laser output energy was 24 mJ and the laser efficiency was 0.9 %. In this case, the total pulse duration was increased, resulting in a simultaneous decrease in the amplitude of the first maximum and the appearance of the third maximum. The maximum pulse duration (65 ns) was observed when $C_1/C_2 = 13$ and the maximum pulse energy was 26 mJ and the laser efficiency was 1 %. In this case, the optimal regime of mulipulse lasing was realised. When ratio C_1/C_2 was further increased, the pulse duration started decreasing and so did the pulse energy and the laser efficiency. With $C_1/C_2 \geqslant 20$, we observed only short laser pulses whose duration was about 7 ns and the energy was 5 mJ, the efficiency being 0.2 %. In this case, the value of the peaking capacitor was less than that of the spark preionisation capacitor ($C_2 \leqslant C_3$), while the excitation system worked as a two-contour system and the storage capacitor did not play an important role.

Thus, the duration and shape of output laser pulses and, hence, the laser efficiency could vary with the increasing the ratio C_1/C_2. The decrease in the value of the peaking capacitor C_2 resulted in the decrease in the output energy in the first pulse maximum and in its increase in the following pulse maxima. This behaviour of output pulses is due to the discharge-current modulation caused by variations in the capacitance of the peaking capacitor.

4. Conclusions

We have developed a computational model for multi-contour excitation systems of XeCl lasers. It has allowed us to calculate current and voltage oscillograms for all points of the electrical excitation system with an error of 10 % – 15 %. We have designed a setup with a three-contour excitation system and automatic UV preionisation system allowing realisation of a mulipulse regime of generation with the pulse duration of 65 ns, the pulse energy of 26 mJ and the laser efficiency of 1 %. The duration and the shape of output pulses can be varied by modulating the discharge current with insignificant changes in the excitation system parameters. We have shown that in $Xe:HCl = 20:1$ mixtures with neon as a buffer gas, the excitation system under study provides multipulse generation of both short (7 ns) and relatively long (65 ns) laser pulses.

References

1. Grasyuk A.Z., Efimovskii S.V., Zhigalkin A.K., et al. *Kvantovaya Elektron.*, **17** (1), 35 (1990) [*Sov. J. Quantum Electron.*, **20** (1), 27 (1990)].
2. Bychkov Yu.I., Mel'chenko S.V., Mesyats G.A., et al. *Kvantovaya Elektron.*, **9** (12), 2423 (1982) [*Sov. J. Quantum Electron.*, **12** (12), 1581 (1982)].
3. Taylor R.S., Leopold K.E. *J. Appl. Phys.*, **65**, 22 (1989).
4. Atezhev V.V., Bukreev V.S., Vartopetov S.K., et al. *Kvantovaya Elektron.*, **18** (5), 560 (1991) [*Sov. J. Quantum Electron.*, **21** (5), 507 (1991)].
5. Fedorov A.I. *Opt. Atmos. Okean*, **17** (2-3), 183 (2004).
6. Razhev A.M., Shchedrin A.I., Kalyuzhnaya A.G., et al. *Kvantovaya Elektron.*, **34** (10), 901 (2004) [*Quantum Electron.*, **34** (10), 901 (2004)].
7. Maeda M., Mizunami T., Stao A., et al. *Appl. Phys. Lett.*, **36**, 636 (1980).
8. Chistensen C.P., Braverman L.W., Steier W.H., et al. *Appl. Phys. Lett.*, **29**, 424 (1976).
9. Watanabe S., Watanabe W., Endoh A. *Appl. Phys. Lett.*, **43**, 533 (1983).
10. Warghese T. *Appl. Phys. Lett.*, **43**, 684 (1983).
11. Panchenko A.N., Tarasenko V.F. *Fiz. Plazmy*, **13** (4), 497 (1987).
12. Fedorov A.I. *Pis'ma Zh. Tekh. Fiz.*, **27** (24), 52 (2001).
13. Fedorov A.I. *Avtoref. Doct. Diss.* (Novosibirsk, 2002).