IR LASERS WITH ACTIVE MEDIA BASED ON EXTENDED OPEN INHOMOGENEOUS ELECTRICAL DISCHARGES IN NOBLE GASES

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Some results of an experimental study of the effect of discharge circuit parameters and the operative gas mixture composition and pressure on the output pulse duration of a XeCl *laser generation pulse* (λ = 308 nm) *are presented. Pulses of full duration* τ ~ 500 ns *and energy* Q ~ 0.35 J *and* τ ~ 300 ns *and* Q ~ 0.6 J *have been obtained with a modified laser of the LIDA–T type.*

INTRODUCTION

A radiation pulse of duration ~ 1 μs produced by an electric–discharge–pumped exciplex rare–gas–halide laser was first obtained at λ = 308 nm due to a non–steady–state mode of pumping.[1–2] This mode is discussed at length in Ref. 3. An increase in output pulse duration for the comparatively simple electric-discharge lasers makes it possible to widen their application in laser sounding of the atmosphere as well. It has therefore become necessary to solve a number of scientific and engineering problems. That is why much attention has been and is given to this question.[4–7]

In the present paper the results of an experimental investigation into the effect of the discharge circuit parameters and the active medium composition on the XeCl laser pulse duration are discussed.

EXPERIMENTAL RESULTS AND TECHNIQUES

The experiments were conducted using a modernized standard LIDA–T laser, Ref. 8. In place of a symmetric Blumlein configuration,[9] a double-circuit pumping scheme was used. The capacitance of the storage capacitor, C_o, was 120 nF and that of the peaking one, C_p, was varied from 1.65 to 13.3 nF. The inductance of the discharge circuit with the peaking capacitor was L_p ~ 12 nH and that of the storage capacitor circuit, L_0, was varied and amounted to 107, 190, and 220 nH. In the standard LIDA-T laser L_o was 15 nH. The operation of the LIDA–type lasers with a Blumlein configuration and a double-circuit configuration is described in detail elsewhere.[9,10] In the LIDA lasers preionization was accomplished with UV emission through a grid in a potential or grounded electrode; the second electrode was made solid. Three constructions of the preionization system have been previously tested.

1) Preionization was provided by a space discharge developing between a grid electrode and an auxiliary dielectric-covered electrode to which, through the main switch, a capacitor with C_1 = 3.6 nF that was charged to the voltage of the main storage capacitor was discharged.

2) Preionization was produced by a dielectric surface discharge[11] powered from the same capacitor C_1 = 3.6= nF. In a number of experiments a capacitor C_2= 1.8 nF was additionally connected in parallel with the switch (the Blumlein circuit) to increase the preionization rate. The preionization discharge width in constructions *1* and *2* was 20 and 14 mm, respectively.

3) Preionization was obtained from a set of spark gaps placed behind the grid electrode and 1.6 cm apart. The spark gaps were run off the main storage capacitor during the charging of the peaking capacitors. The best results were obtained for the preionization by the radiation of a surface discharge.

The active length was 60 cm for all of the lasers, the electrode separation could be varied from 3 to 3.5 cm, and the discharge width was determined by the active medium composition and pressure as well as by the discharge voltage. Operating gas mixtures comprising Ne(He, Ar)–Xe(Kr)–HCl were prepared directly in the laser chamber. The radiation energy was measured with a calorimeter of the IMO–2N or IKT–1M type with the sapphire window removed. The radiation pulse waveform was recorded with a photodiode of the FEK–22 type a signal from which was supplied to an oscillograph of the 6LOR type.

RESULTS AND DISCUSSION

Depicted in Fig. 1 are oscillograms of lasing pulses at λ = 222 and 308 nm and given in Fig. 2 are the radiation energy and efficiency as a function of charge voltage U_0 for optimized lasing conditions in mixtures with neon and helium buffer gas in a standard Blumlein-circuit-pumped LIDA–T laser.

For λ = 222 nm, the maximum energy, efficiency, and radiation pulse duration (Q = 0.65 J, η = 0.65%, and τ = 80 ns) are realized with neon buffer gas mixtures intensely irradiated from a surface discharge produced with a Blumlein circuit. The connection of the capacitor C_1 alone to the plasma sheet (what decreased the irradiation intensity) resulted in a 30% decrease in output energy at λ = 222 nm for Ne–containing mixtures. In this case a space discharge was failed to be initiated in He–containing mixtures and laser action at λ = 222 nm was not obtained. The radiation energy at λ = 222 nm substantially decreased as well with increasing the discharge width (decreasing the pumping power) with its homogeneity retained. Thus, for a 20–mm wide discharge in a Ne–Kr–HCl mixture (preionization system *1*) a 2.5–fold decrease in radiation energy was observed as compared with that obtained for a 1.4–cm wide discharge (preionization system *2*) with the energy consumed for preionization being the same. With the irradiation slit width 14 mm (preionization system *1*) which provided lower preionization electron density, the operational characteristics of the KrCl laser deteriorated. The full duration of the radiation pulse in Ne buffer gas mixtures reached 80 ns and was shorter for the operation with the He buffer gas or (and) with a decrease in charge voltage (Fig. 1*a, b*). In our experiments with Ar buffer gas mixtures and preionization produced using spark gaps the lasing threshold was not attained because of discharge constriction.

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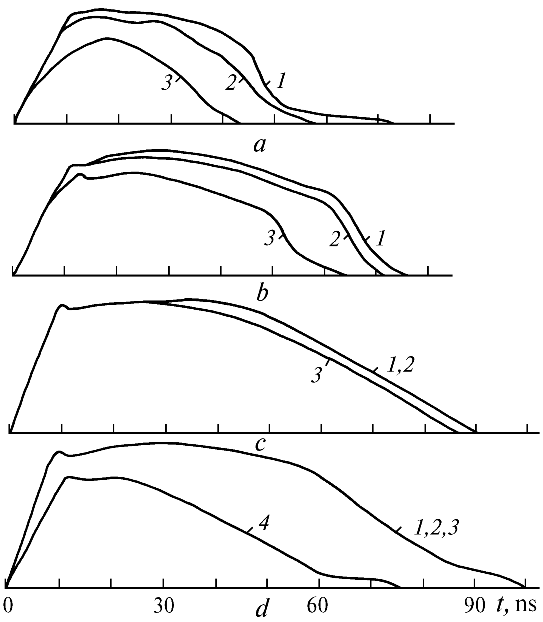

FIG. 1. Oscillograms of output pulses from the LIDA–T laser with a 3.5 cm *electrode separation and surface discharge irradiation using* C_1 *and* C_2*:*
a) He:KrHCl = 2.75 atm: 125 Torr: 3 Torr,
b) Ne:KrHCl = 5 atm: 125 Torr: 3 Torr,
c) He:Xe:HCl = 3 atm: 30 Torr: 3 Torr,
d) Ne:Xe:HCl = 5 atm: 30 Torr: 3 Torr,
U_o = 40 *(1)*, 35 *(2)*, 30 *(3)*, *and* 25 *(4)* kV.

Maximum output energies at λ = 308 nm were obtained in a wide range of experimental conditions in contrast to the lasing at λ = 222 nm. In this case the radiation energies and efficiencies (Q = 1.3 J and η = 1.3%) were the same for preionization systems *1* and *2*, with a decreased discharge width (increased pumping power) one must use mixtures with large xenon and HCl contents. The radiation pulse duration at λ = 308 nm changed slightly under optimal conditions when neon was replaced with helium and the charge voltage was decreased. As seen in Fig. 1*c*, *d*, the radiation pulse duration reduced only for minimum U_0.

To achieve maximum output pulse durations it is more useful to employ a double-circuit configuration with a comparatively large storage capacitance C_0 and small peaking one C_p, $C_o \gtrsim 40\ C_p$. The pumping pulse duration and, correspondingly, radiation pulse duration can be increased by increasing the inductance of the discharge circuit.

Figures 3, 4, and 5 represent lasing characteristics at λ = 308 nm obtained with increasing the discharge circuit inductance, varying the peaking capacitance, and with a constant storage capacitor capacitance C_0 = 120 nF (with irradiation from a plasma sheet without an auxiliary capacitor). These experiments were conducted only at λ = 308 nm, since at λ = 222 nm the lasing threshold was not achieved because the demand for higher pump powers was not fulfilled.

As seen in Fig. 3, maximum radiation energies and efficiencies were obtained at L_o = 107 nH, i.e., when it was a minimum for the two-circuit configuration with the capacitors used. The output pulse duration in this case did not exceed 300 ns and was approximately equal to the first half-period of the pump current. The pump pulse duration increased to ~ 500 ns by increasing L_o. The radiation pulse duration therewith increased to ~ 500 ns (Fig. 4*b* and Fig. 5*a*), while the radiation energy and **the** efficiency did not increase (Fig. 3, curve *4)*. To obtain long pulses with optimized mixtures, the xenon content should be decreased by a factor of two with the HCl halogen–carrier content remained unchanged. The operating pressure had to be restricted as well, since the radiation power density distribution over the output beam cross section became uneven at pressures higher than 3.5 atm. Replacement of the Ne buffer gas with helium resulted in a significant decrease in radiation pulse duration and energy. A variation of the peaking capacitor capacitance affected strongly the radiation pulse waveform (Figs. 4 and 5). To attain maximum laser pulse durations, the capacitance C_p must be chosen comparatively small. It should also be noted that the radiation pulse modulation depends on the ratio between C_0, L_0, and C_p, L_p which determine pump powers with their periods. Thus, in Fig. 4*b* the laser pulse modulation due to pumping by means of the peaking capacitor is more pronounced as compared to that shown on the oscillogram in Fig. 4*a* and obtained with the same C_p only owing to the decrease in the pump power from C_0 with increase of L_0. The radiation energy thus obtained for the mode depicted in Fig. 4*a* is about 2 times higher, and the radiation pulse modulation is correspondingly less noticeable.

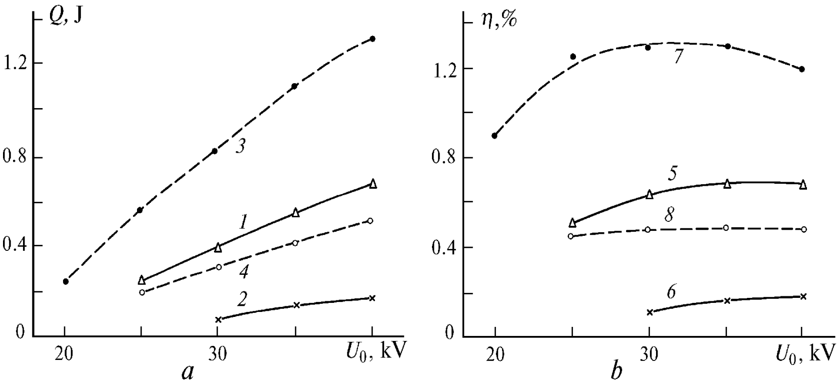

FIG. 2. The output energy and efficiency as a function of the charge voltage obtained with the LIDA–T laser with a 3.5 cm *electrode separation at* λ = 222 *(1, 2, 5, 6) and* 308 nm *(3, 4, 7, 8). 1, 5)* Ne : Kr : HCl = 5 atm : 125 Torr : 3 Torr, *preionization system 2 with* C_1 *and* C_2. *2, 6)* He : Kr : HC1 = 2.75 atm : 125 Torr : 3 Torr, *preionization system 2 with* C_1 *and* C_2. *3, 7)* Ne : Xe : HC1 = 4.5 atm : 27 Torr : *25* Torr, *preionization system 1, and 4, 8)* He : Xe : HC1 = 2.85 atm: 18 Torr : 2 Torr, *preionization system 2.*

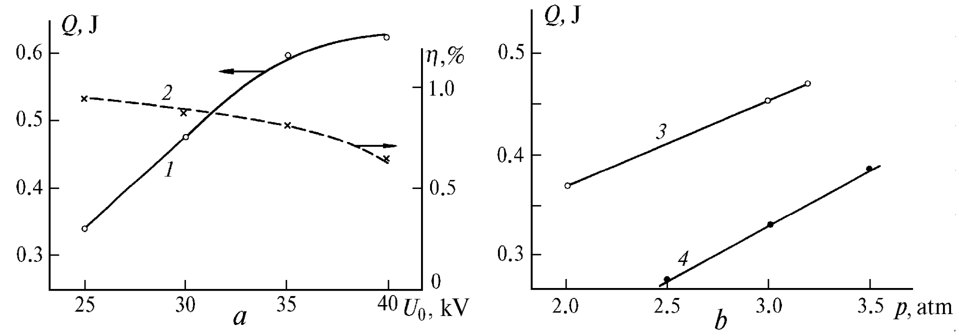

FIG. 3. The radiation energy (1) and efficiency (2) as a function of charge voltage (a) and the radiation energy as a function of mixture pressure (b) at charge voltage 30 *(3) and* 40 kV *(4). 1, 2, 3) discharge circuit inductance* L_0 = 10 nH, *4)* L_0 = 220 nH. C_0 = 120 nF, C_1 = 3.3 nF.

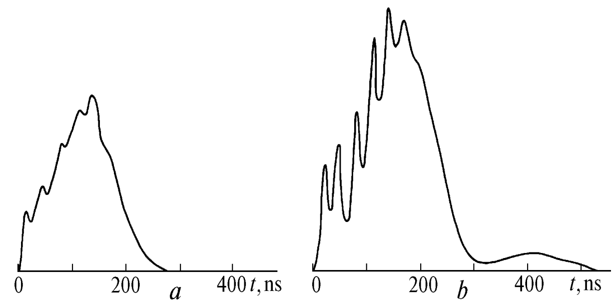

FIG. 4. Oscillograms of lasing pulses produced at U_0 = 40 kV, C_0 = 120 nF, C_1 = 3.3 nF *with a mixture of* Ne : Xe : HCl = 2.5 atm : 12 Torr : 3 Torr. L_0 *= 107 (a) and* 190 *nH (b).*

The decrease in radiation energy and lasing efficiency in going to long pulses in standard systems is accounted for by the following points:

1. First, the increase of discharge circuit inductance results in an impedance mismatching between the pumping generator and the gas–discharge plasma.

2. Second, the mixtures used to produce long pulses provide an extra mismatching between the gas–discharge plasma impedance and the wave impedance of the pumping generator, which is caused by the lower operating pressure and the smaller xenon and HCl contents.

3. Third, in some cases the radiation pulse duration can be affected by "burning–out" of HCl molecules. This may be the reason for the decrease in radiation power (Fig. 4*b*) in 200 ns after the onset of laser action.

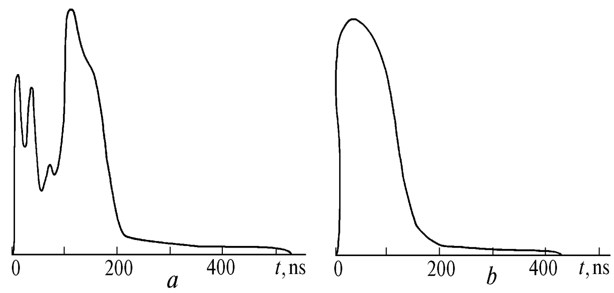

FIG. 5. Oscillograms of lasing pulses produced at U_0 = 40 kV, C_0 = 120 nF, L_0 = 220 nH *with a mixture c* Ne : Xe : HCl = 3.5 atm: 15 Torr : 3 Torr. C_1 = 7.3 *(a) an* 13.3 nF *(b).*

4. Fourth, the laser efficiency and the radiation pulse duration can also be affected by discharge constriction. However, even through these limitations exist, we were able to obtain comparatively long durations and radiation energies at λ = 308 nm.

We believe that complex systems with two pumping generators[12] or with current interrupters and inductive energy stores must be used to achieve maximum lasing efficiencies when producing long pulses with the use of electric-discharge lasers.

CONCLUSION

The effect of the discharge circuit parameters, the preionization system, the active medium pressure, and composition on the XeCl laser (X = 308 nm) pulse duration has been studied. The modernized LIDA–T laser generated radiation pulses with full duration τ ~ 500 ns and energy Q ~ 0.35 J as well as τ ~ 300 ns and Q ~ 0.6 J. When the LIDA–T laser pumped from a symmetric Blumlein circuit was used we obtained at λ = 308 nm Q equal to about 1.3 J with τ ~ 100 ns and for a Ne–Kr–HCl mixture at λ = 222 nm Q ~ 0.65 J with τ ~ 80 ns. The lasing efficiency was 1, 3, and 0.65%, respectively.

Relying on these experiments we concluded that the developed long–pulse laser can obtain practical use in laser sounding of the atmosphere, in designing laser systems capable of producing small–divergence radiation beams, as well as in other areas of science and technology.

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