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Efficient long-pulse XeCl laser with a prepulse formed by an inductive energy storage device

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Abstract. An efficient electric-discharge XeCl laser is developed, which is pumped by a self-sustained discharge with a prepulse formed by a generator with an inductive energy storage device and a semiconductor current interrupter on a basis of semiconductor opening switch (SOS) diodes. An output energy up to 800 mJ, a pulse length up to 450 ns, and a total laser efficiency of 2.2% were attained by using spark UV preionisation.

1. Introduction

The development of efficient electric-discharge exciplex lasers with long radiation pulses involves the solution of two problems. The first is the formation and maintenance of a homogeneous volume discharge in gas mixtures containing electronegative halogen molecules. The second problem is related to the necessity of increasing the efficiency of energy transfer from a storage device to a plasma of this volume discharge. With self-sustained discharge pumping, long radiation pulses in a XeCl laser were first realised in a laser employing x-ray preionisation and with the main energy storage device in the form of a pulse forming line [1]. The output energy in the long-pulse mode ($\sim$200 ns) was in the range 1 – 3 J with the use of different buffer gases.

To ensure the total energy transfer from the storage device to the gas-discharge load during the laser pulse and to attain a high radiation efficiency of electric-discharge exciplex lasers, a two-generator scheme should be used [2]. A high-voltage generator with low energy storage produces the volume discharge while the second generator provides the pumping from the main capacitor in the matched mode. In Ref. [2], a laser efficiency of 4.2%, an output energy of 4.2 J, and a radiation-pulse length of 200 ns were obtained.

We obtained laser-pulse lengths up to 1 μs in an electric-discharge XeCl laser in 1984 [3, 4]. A nonsteady-state pumping mode was proposed to solve the problem of discharge stability. Moreover, this mode, which involves specific build-up and decay rates of the discharge current [4, 5], made it possible to lengthen the radiation pulse of an XeF electric-discharge laser to $\sim$400 ns and to extend the spontaneous radiation pulse in the working mixture of the KrCl laser to $\sim$500 ns.

The two-generator scheme for pumping long-pulse XeCl lasers was most successfully used in Ref. [6], where pulse forming lines of ceramic capacitors, a magnetic switch, and the preionisation induced by a corona discharge through a mesh electrode were employed. A laser pulse length of 1.5 μs was obtained for an energy of 100 mJ and an efficiency of 0.44%; and a pulse length $\sim$800 ns was obtained for an energy of 500 mJ and an efficiency $\sim$2% (relative to the energy stored in the strip line). In addition, when the strip line was replaced by two 0.25 μF capacitors, the laser pulse length was $\sim$500 ns for an energy of 600 mJ and an efficiency of 1.3%.

The aim of this work is to develop an efficient long-pulse XeCl laser with a spark preionisation featuring high reliability and a long life expectancy. The laser is pumped by a double discharge with a prepulse formed by a generator with an inductive energy storage device. Earlier [7, 8] we used this method of forming a prepulse to pump a CO_2 laser, wherein the resistance of a discharge plasma was significantly higher than in a XeCl laser.

2. Experimental

The design of a long-pulse XeCl laser is shown in Fig. 1. The laser electrodes were located in a cylindrical chamber separated from the pump generator by a plastic insulator. The active laser volume was $V = 2.5\ \text{cm} \times 4\ \text{cm} \times 80\ \text{cm} = 800\ \text{cm}^3$ for an interelectrode gap $d = 4$ cm. The preionisation was achieved by the radiation of 72 spark gaps evenly distributed on either side of the cathode. The pump generator consisted of a storage and a peaking capacitance assembled of KVI capacitors. Their capacitances were 240 and 2.4 nF, respectively. The storage capacitor was charged to a voltage $U_0 \simeq 2U_s = 15 - 18$ kV, where U_s is the voltage during the quasi-stationary phase of the discharge. Ten special-purpose semiconductor opening switch (SOS) diodes placed in parallel with the peaking capacitors were used as a semiconductor current interrupter. The break current of this SOS diode is as high as 2 kA, the response time is 10 – 20 ns, and the pulse repetition rate amounts to 1 kHz with oil cooling. To run the diodes as current interrupters, a current of 100 – 500 A was passed through them in the forward direction for 500 ns. A capacitor with $C_1 = 14$ nF was used for this purpose. The inductance of the C_1 capacitor circuit was 1.8 μH. The minimum energy required to control the diodes did not exceed 5% of the energy stored in the C_0 storage device. After triggering the D_1 gap, the reverse current from the C_0 storage device began to flow through the diodes and broke $\sim$ 100 ns later, upon attaining the critical value [9]. At the instant of current break by the SOS diodes, across the laser gap there appeared a voltage pulse with an amplitude $U = L\mathrm{d}I/\mathrm{d}t \sim 50$ kV

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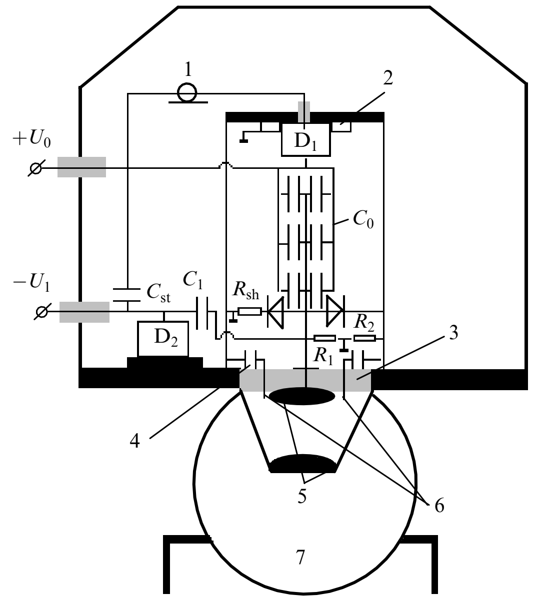

Figure 1. Schematic diagram of the XeCl laser with a prepulse formed by an inductive energy storage and SOS diodes: (C_0) storage capacitors; ($C_1 = 14$ nF) the capacitor for pumping the SOS diodes in the forward direction; (D_1, D_2) spark gaps; ($C_{st} = 1.5$ nF) switching capacitance; (R_1, R_2) voltage divider; (R_{sh}) current shunt; (1) delay line for triggering D_1; (2) Rogowski loop; (3) insulator; (4) peaking capacitors; (5) electrodes; (6) preionisation spark gaps; (7) laser chamber.

(where $L = 0.11$ μH is the inductance of the discharge circuit of the C_0 storage device) which formed the volume discharge. The C_0 storage device next discharged into the gas-discharge load in a nearly matched mode. Note that the SOS diodes can be placed both in parallel and in series to obtain the required break current and the prepulse amplitude. In this case, the triggering of the diodes is synchronized automatically.

The laser resonator was formed by a totally reflecting (100%) mirror and mirrors with dielectric coatings with a reflectivity in the range 20% – 70% at $\lambda = 308$ nm.

We measured the amplitude – time characteristics of voltage, current, and laser radiation pulses. An IMO-2N calorimeter was employed to measure the radiation energy. The shape of the radiation pulses was determined with a coaxial FEK-22SPU photocell. The pulses of the discharge current, the current through the SOS diodes, and the voltage across the laser discharge gap were recorded by using a Rogowski loop, an ohmic shunt, and a voltage divider. An S8-14 oscilloscope was employed to measure the parameters of the electric pulses.

3. Experimental results and discussion

Mixtures with the neon buffer gas at pressures 1 – 3.5 bar were used in experiments. A maximum output energy was attained for the ratio Xe : HCl = 10 : 1 and a partial pressure of hydrogen chloride of 1.5 Torr. The increase in the content of HCl resulted in a quick discharge contraction and reduced the length of the radiation pulse.

Fig. 2 shows the oscilloscope traces of the pulses of the voltage across the discharge gap, the discharge current, and the output laser power. The inductive energy storage device provided a fast build-up of the voltage across the laser gap, with the pulse rise time ~50 – 80 ns. The rates of rise of the voltage pulses and their amplitudes were proportional to the forward current (to the charging voltage U_1 of the C_1 capacitor). In particular, as U_1 increased from 10 to 30 kV, the breakdown voltage increased from 30 to 36 kV, while the rise time decreased from 80 to 50 ns. The increase in U_1 caused the increase in break current. As this takes place, a progressively larger fraction of the energy accumulated in the C_0 storage device is used in the formation of the prepulse. On the one hand, this improves the conditions for the discharge formation and augments its stability, but on the other hand, the energy deposition from the main C_0 storage device is reduced.

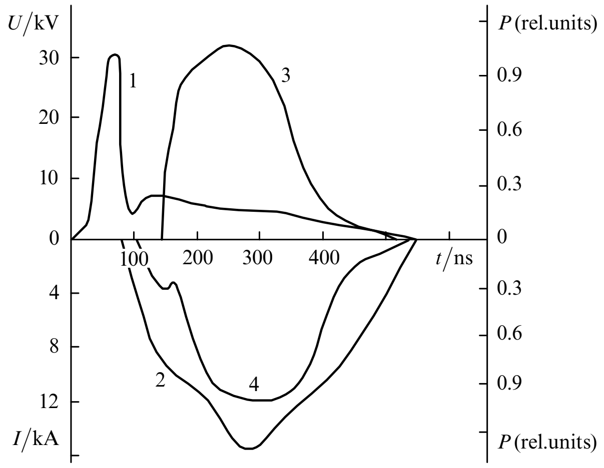

Figure 2. Oscilloscope traces of the voltage across the discharge gap (1), the discharge current (2), and the power of laser radiation (3, 4). The gas mixture was Ne : Xe : HCl = 3 bar : 12 : 1.5 Torr, $U_0 = 16$ kV, $U_1 = 15$ kV, and the reflectivity of the output mirror was 20% (3) and 70% (4).

Maximum energy and length of the laser pulse were obtained for $U_1 = 15$ kV. The length of the laser pulse at half maximum (FWHM) was 210 ns, and its total length was ~400 ns. Lasing continued throughout the excitation pulse. This means that the discharge formed by the inductive energy storage device is homogeneous. When the Q factor of the resonator was increased, the output pulse started earlier and its duration increased.

In our experiments, the charging voltage of the storage capacitor was varied from 15 to 18 kV. This is somewhat higher than the $2U_s$ for the gas mixture in use. However, under optimal conditions, approximately 10% of the energy accumulated in the C_0 storage device is utilised to form the discharge. For this reason the voltage across C_0 lowers by the time of breakdown of the laser gap, and the storage capacitor discharges in the regime close to the matched regime. It is significant that the current of the storage device flows, during the second half-period, through the SOS diodes rather than through the discharge gap. This precludes the formation of channels after change of polarity of the discharge current and reduces erosion of the electrodes.

Fig. 3 shows dependences of the output energy and the total laser efficiency on the charging voltage of the storage capacitor. As the charging voltage increases, the output energy also increases, to as high as 800 mJ. The laser efficiency reached a maximum of 2.2% for $U_0 = 16$ kV and then decreased because of the decrease in the efficiency of energy transfer from the C_0 storage device. Note that the specific pump power was below 100 kW cm^{-3} in our

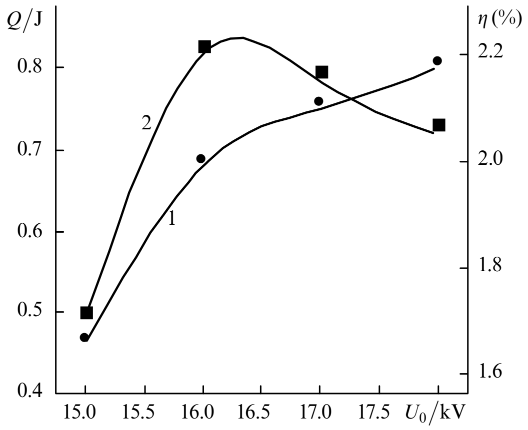

Figure 3. Output energy (1) and total laser efficiency (2) as functions of the charging voltage U_0 of the storage capacitor. The gas mixture was Ne:Xe:HCl = 3:12:1.5 Torr, U_1 = 15 kV, and the reflectivity of the output mirror was 20%.

experiments and therefore the laser efficiency would be expected to improve with increasing specific pump power.

4. Conclusions

We have developed an efficient electric-discharge XeCl laser pumped by a double discharge, wherein the prepulse is formed by a generator with an inductive energy storage device and a semiconductor current interrupter made on a basis of SOS diodes. An output energy up to 800 mJ, a pulse length up to 450 ns, and a total laser efficiency of 2.2% were obtained. These parameters were obtained using a reliable illumination from a spark. The elaborated inductive generator can also be applied to pump large-aperture and repetitively pulsed exciplex lasers.

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