A XeCl LASER WITH SPARK PREIONIZATION

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Received January 27, 1989

It is shown that quasi-stationary regimes for pumping and pulse generation of a XeCl laser can be obtained with inductive-spark discharge stabilization and a current density of about 0.2 kA/cm^2.

As is well known, excimer lasers are the most powerful sources of coherent UV radiation. A further increase of the brightness of the laser emission line and a decrease of the beam divergence can be achieved by improving the homogeneity of the laser pulses and increasing their duration. This, in turn, should increase the utility of these lasers for nonlinear optics, high resolution spectroscopy, and for remote sensing of the atmosphere.[1–3]

The simplest and most reliable way of pumping XeCl lasers is to use a capacitive double-circuit arrangement of excitation supported by an automatic UV-preionization source.[4] In this study for preionization we used spark and corona discharges as well as a plasma cathode.[5] As is shown in Ref. 6, spark discharge preionization enables one to obtain laser pulses about 100 mJ in energy with durations longer than 100 ns. The authors of this paper used in their experiments resistance stabilization of the discharge in their experiments. The low energy output obtained in this case is explained by ohmic losses, which restrict the amount of energy which can be pumped into the gas mixture and by the low intensity of the spark-discharge preionization since the spark was too far from the laser discharge gap. Because of the low intensity of preionization the quasi-stationary regime of laser generation was not obtained. The quasi-stationary regime was then realized[7] with the use of plasma preionization, and laser pulses of about 0.5 J in energy with durations exceeding 250 ns were obtained. In some studies x-ray sources[8–9] or an additional excimer laser[10] were used to achieve more efficient preionization. It is worth noting that further improvements in the creation of a quasi-stationary regime for pumping the XeCl laser have been reported which were achieved by using two independent excitation circuits.[11] In this case one of the pumping circuits operated in the fast-pumping regime while the other operated in the long-pulse regime. This arrangement enabled the authors of Ref. 11 to obtain an efficiency of about 4% of the pumped energy. This same regime[12] was also been used with a KrF laser as the preionization source, and a magnetic element was used to maintain a constant electric field component on one of discharge gap electrodes. These improvements made it possible to obtain very long laser pulses of about 1.5-μs duration.

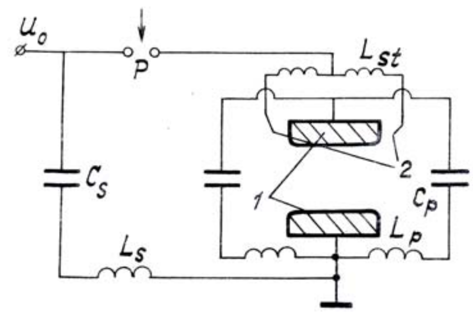

FIG. 1a. Electrical circuit of the experimental device: 1 — the main electrodes; 2 — the spark gaps; C_s is the storage capacitor; C_p is the peaking capacitor; P is the controllable discharge tube; L_s and L_p are the inductive coils of the storage and peaking circuitry; L_{st} is the stabilizing inductive coil.

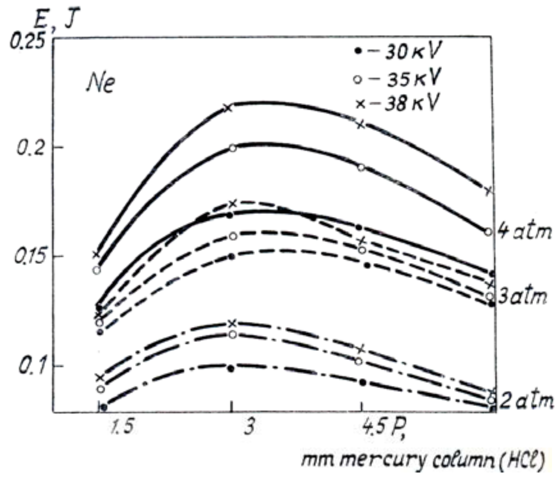

FIG. 1b. Dependence of the laser pulse energy on the HCl content of the mixture with Ne buffer gas at different pressures and charging voltages at C_s = 60 nF and C_p = 10 nF.

In this paper we report the results of investigations into the possibility of increasing the output energy and pulse duration and shaping the radiation pulse of a XeCl laser using a simple dual-circuit excitation scheme with automatic spark-discharge preionization. In our experiments we used inductive-spark stabilization of the discharge in conjunction with optimal selection of the pumping circuit parameters, the current density, and the gas mixture composition.

An electric circuit diagram of the experimental device is shown in Fig. 1a. The storage capacitor bank C_s was assembled from K15-10 low-inductance ceramic capacitors. The advantage of such a construction over a pulse-shaping line is the ease with which it can be varied in the search for an optimal regime of laser operation.[13] In particular, the low-inductance ceramic capacitor provides for a higher output energy of the laser radiation. The inductance of the energy storage circuit was L_s = 50 nH, The peaking capacitor C_p, assembled from K15-4 ceramic capacitors, was connected to one or both ends of the discharge gap. This allowed us to obtain a minimum inductance of L_p = 5 nH of the peaking circuit. Near one of the gap electrodes there were one or two rows of 40 parallel points which together with this electrode formed the spark-discharge gap, which was 2 mm in width. In contrast with known schemes, we introduced a stabilizing inductive coil with an inductance of L_{st} = 3 nH into the electric circuit of each spark-discharge gap. The electrode was 70 cm in length and its width could be varied from 0.5 to 2 cm. The 2.5 cm gap between the electrodes was kept constant. The laser cavity was formed by two mirrors with reflectivities of about 0.98 and 0.07% at λ = 308 nm. The storage capacitor was charged by a constant-voltage (40 kV) power supply and was then unloaded onto the peaking capacitor, the spark-discharge gaps, and the active gas mixture through the controllable discharge tube (DT). The discharge current density and the resistance of the gas discharge plasma could be varied by changing the electrode width and peaking capacitance. The experiments were conducted with the gaseous mixtures Ne(He): Xe: HCl.

Experimental and theoretical investigations[4,14–15] of the influence of the gaseous mixture components on the discharge parameters and the energy of the output laser radiation have shown that the laser pulse duration depends on the excitation power density and the Xe and HCl concentrations. Thus, a decrease of the HCl concentration results in an increase of the pulse duration but at the expense of a significant drop in the laser radiation energy. This was explained by the burnout of HCl at HCl partial pressures below 1 mm Hg.

In our experiments we have studied the influence of such parameters as HCl partial pressure, charging voltage, and total pressure of the gas mixture, including the buffer gas He for the mixing ratio Xe: HCl = 10:1, on the laser pulse energy. Some results of these experiments are presented in Fig. 1b. The optimal partial pressure of HCl is about 3 mm Hg and depends on neither the total pressure of the gas mixture nor the energy pumped into the electric discharge. Evidently, the optimal content of HCl Is determined mainly by the kinetics of the production of the excimer molecules under the given pumping conditions.

It should be noted that strict requirements are usually imposed only on the amplitude and rise time of the discharge current in self-maintained volume discharges, in mixtures of rare gases and halogens which are typical of the fast-pumping regime. However, stricter requirements must be imposed on the discharge current density[15–16] for increased duration of the pumping and laser pulses. In our experiments we were able to vary the discharge current density from 0.2 to 0.8 kA/cm^2 by varying the width of electrodes. The dependence of the energy and shape of the output pulse on the pressure, the charging voltage, and the buffer gas (either He or Ne) for C_s = 60 nF, C_p = 10 nF (a) and C_p = 20 nF (b) are presented in Fig. 2. The width of the electrodes was 1 cm and the preionizatlon was initiated with only one row of spark points. The discharge current density was J_{Ne} = 0.2 kA/cm^2 for Ne and J_{He} = 0.35 kA/cm^2 for He.

The quasi-stationary regime for laser pulse generation was observed in case (a) with Ne as the buffer gas. Pulse duration was about 150 ns and was restricted by the value of the storage capacitance.[4] The pulse shape varied, depending on the energy pumped into the discharge in the quasi-stationary stage. Note that this regime of laser operation was maintained at high pressures, i. e., when the gas discharge plasma was better matched with the power supply. When the buffer gas was He, only the fast pumping regime was observed. When two rows of spark-preionization points were used, there was an increase in the output energy by almost a factor of two. This is well illustrated by the dashed curve in Fig. 2a obtained at U_0 = 38 kV in the gas mixture with He as the buffer gas. In case (b) with a larger peaking capacitance there was a growth in the discharge current, and the energy pumped into the discharge during the fast stage also increased. It is characteristic of this case that neither the buffer gas nor the energy pumped into the discharge influenced the pulse shape. One of the basic conditions for realizing quasi-stationary laser generation is a proper choice of the discharge circuitry parameters. Also of interest is the fact that with a decrease in the Xe content, i.e., at Xe: HCl = 5:1, the optimum partial pressure of HCl is Increased up to 6 mm Hg (Fig. 2b), which results in an increase of the laser pulse energy at high pressures.

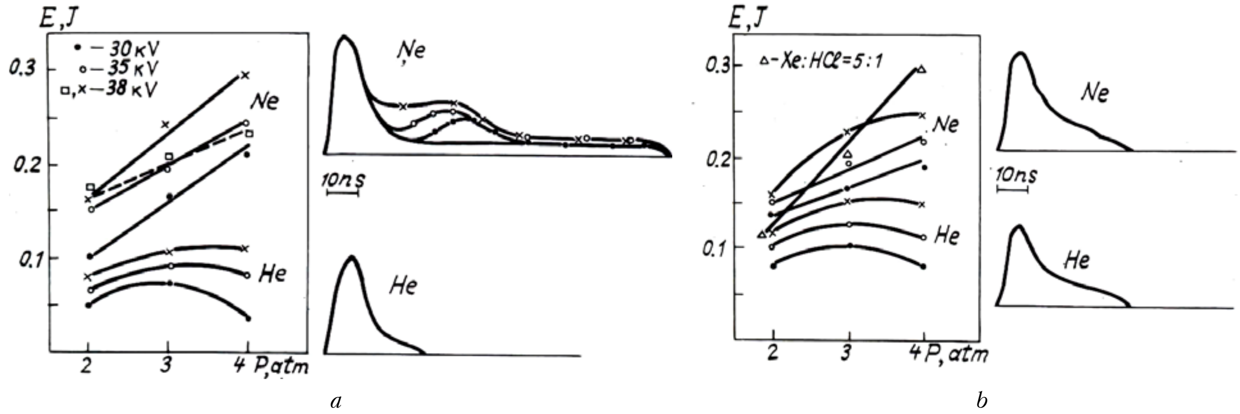

FIG. 2. Dependence of energy and shape of the laser pulse on pressure of the gas mixture, charging voltage, and buffer gas (either He or Ne) for $C_s = 60$ nF, $C_p = 10$ nF (a), and $C_p = 20$ nF (b).

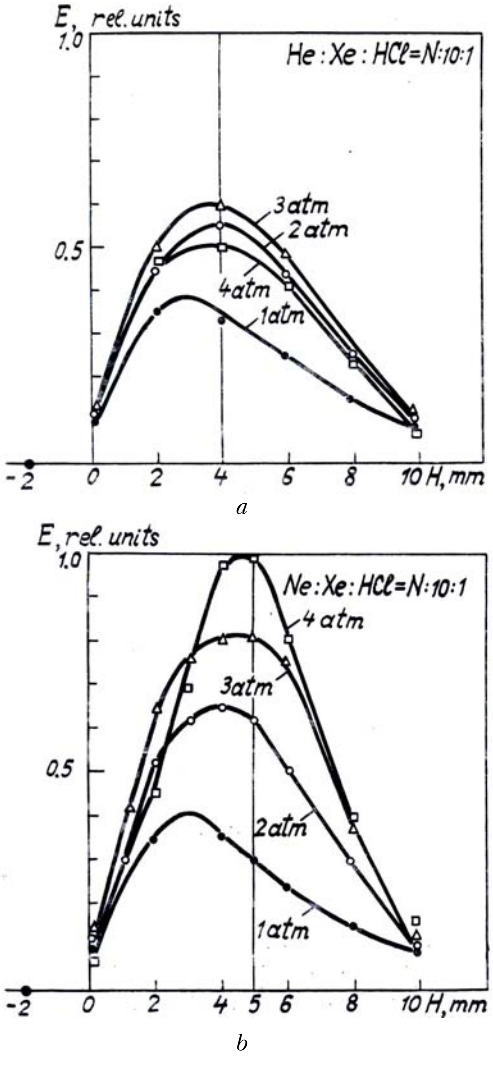

FIG. 3. Distribution of the laser radiation energy across the width of the electrodes (10 mm) in the gas mixture with He (a) and Ate (b) at different pressures: Xe:HCl = 10:1.

The character of the distribution of the laser radiation over the cross-section of the discharge gap can be of definite importance for some applications. Investigations were carried out by Watanabe et al.[1] of the dependence of the gain coefficient of the XeCl laser with spark-preionization through a grid electrode on the buffer gases He and Ne and the working pressure. A weak amplification near the cathode was observed in a zone about 0.5 cm in diameter in all of the gas mixtures. The authors of Ref. 1 connected this fact with the appearance of a region of inhomogeneities with increase of the voltage as a result of a shortage of electrons. They also observed weak amplification near the edges of the electrode but only in the gas mixture with He. Figure 3 shows the measured distributions of the laser pulse energy across the electrode. The bold face point on the abscissa shows the position of one of the rows of the spark points which together with one of the electrodes forms the spark gap, which is 2 mm in width. The distribution was measured using a diaphragm 1 mm In diameter and a FEK-22 SPM photocathode. It can be seen from this figure that the maximum of the energy distribution In He Is shifted toward the spark gap and is independent of the pressure. At the edges of the electrode there was observed a decrease of the radiation intensity, which corresponded to the strongest distortion of the electric field. In the case in which Ne was the buffer gas the distribution of the radiation was more symmetric and tended to improve at higher pressures. In contrast to the results of Ref. 1, we observed a fall of the radiation intensity at the edges of electrodes. The distribution was greatly improved in the case of symmetric spark-preionization.

We note in conclusion that even a simple and compact pumping unit with automatic inductive-spark stabilization of the discharge can provide the possibility of obtaining both fast and quasi-stationary regimes for pumping and lasing in XeCl lasers. In the case in which Ne is used as the buffer gas the shape of the laser pulses can be varied by properly choosing the parameters of the elements of the excitation circuitry and the conditions under which energy is pumped into the discharge.

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