Discharge Stability in the Gas Mixtures with Halogen at High Specific Pump Power

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Abstract – Conditions of stability of the discharge various forms in a gas mix of discharge XeCl laser depending on changes of conditions pumped by up to 60 ns pulses is studied experimentally. Influence of the discharge forms on parameters of output radiation, specific output energy from the active medium and laser efficiency is defined. It is shown, that conditions of formation and the subsequent burning of the discharge, depended on a ratio of components concentration of Ne:Xe:HCl mix and value of specific pump power

1. Introduction

In some papers was shown that arising discharge instability can have [1–4] or not have [5–8] binding to cathode spots. For these variants, the various theories explaining effect of non-uniformity formation are offered. However, the uniform theory for an explanation of the nature of discharge instability development does not exist. Only experimental by it was possible to develop the some recommendations permitting to form the homogeneous volume discharge in excimer lasers. Thus, the basic requirements concern conditions of formation of an initial stage of the volume discharge. These conditions include: maintenance of preliminary electron concentration in a discharge gap more then 10^7 cm^{-3}, presence of an optimum time delay between beginning of preionization and the basic discharge, application of additional power supplies for formation of an initial stage of the volume discharge, realization of conditions of the fastest achievement of working electron concentration in discharge plasma. Realization all these conditions demands the use of complicated electric schemes that reduces a work reliability of the laser and increases its cost. Therefore, in practice in commercial excimer lasers the simple two-circuit electric pump schemes with automatic UV-preionization are usually used [11–13]. For such pump circuits the search of the conditions of efficiency increase and a laser generation specific energy remains now an actual problem. Physical processes in the discharge plasma responsible for the various forms of discharge also are interest.

In this paper, the stability modes of discharge burning in mix of XeCl laser for various concentrations of Xe and HCl components are investigated and the reasons leading to discharge instability development are discussed.

2. Experimental installation and measurement techniques

Researches were carried out on commercial discharge XeCl laser of EL series [14] working with pulse repetition rate up to 200 Hz and pulse energy up to 0.7 J The typical charge–transfer electric circuit was used for laser pumping (Fig. 1). The storage capacity C_1 = 106.2 nF (TDK UHV-6A, 2700 pF & 30 kV capacitors) is charged from high voltage power supply. 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 = 74.8 nF (TDK UHV-6A, 2700 pF & 30 kV capacitors) is pulsed charged and then it discharges providing pumping of active medium. The discharge electrodes had length of 65 cm and the inter-electrode distance was 2.8 cm. Assemble of the laser chamber and peaking capacitors allowed reaching inductance in the discharge second circuit being equal 4 nH. Gas operating mixture Ne/Xe/HCl was used in experiments with total pressure of 3 bar. The length of resonator was 110 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.

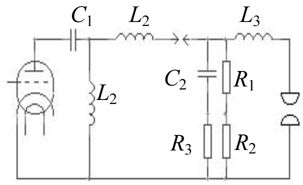


Fig. 1. Schematic diagram of excitation circuit: C_1 = 106.2 nF; C_2 = 74.8 nF; L_1 = 150 nH; L_2 = 4 nH; R_3 – current shunt, R_1/R_2 – resistor divider

3. Results and discussion

In our works [8, 13] it has been shown that heterogeneity in the discharge have various spatial scale and the different nature. These researches were carried out on lasers with different pump circuit parameters. However, for comparison correctness all experiments have been carried out at the same entry conditions of discharge formation.

The typical time behavior of a current and voltage on a C_2 pick capacity for gas mix Ne/Xe/HCl = = 900/13/1 at pressure of 3.8 bar is presented in Fig. 2. Charging voltage in this case was 24 kV. Analyzing of a current and voltage oscillograms it is possible to allocate some basic stages of discharge. The first stage (I) is a preliminary stage of discharge formation, the second (II) is a transition phase from a discharge formation to a pump stage, and the third (III) is a stage of the basic pump discharge. Nevertheless, the current and voltage oscillograms do not permit to reveal the heterogeneousness formation in the volume discharge.

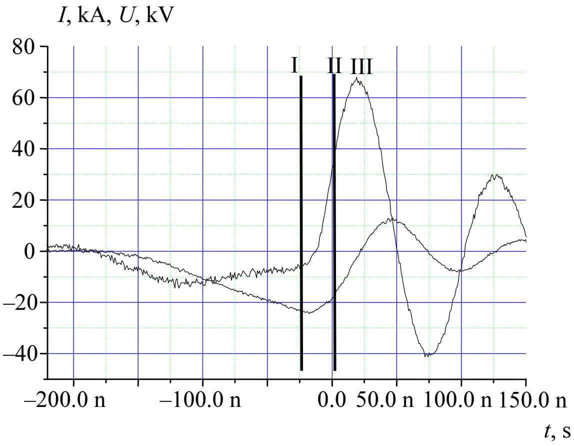


Fig. 2. Experimental temporal evolutions of capacitor C_2 voltage U, current I, and lasing power (P)

Dependences of discharge width vs Xe concentration to mixes for various parities Ne/HCl are presented in Fig. 3. A total mix pressure was $P = 3.8$ bar and charging voltage was $U_0 = 22.5$ kV. For definition of the discharge width the photo of the discharge and a laser beam print were compared. The cross-section size of 80% of the general current was accepted to the discharge width. The boundary intensity of radiation chosen by this criterion allowed defining the discharge width for other experimental conditions.

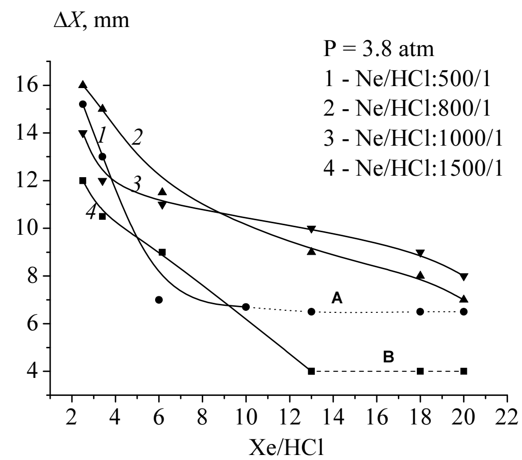


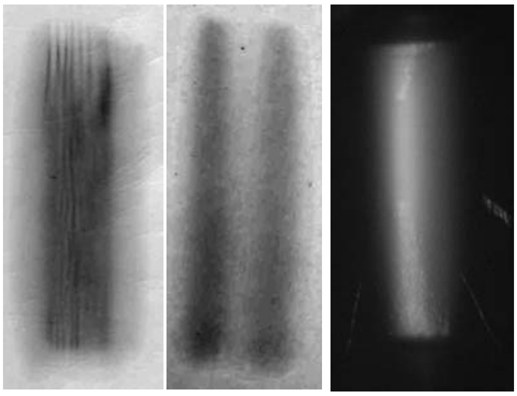
Fig. 3. Dependence of discharge width from Xe concentration

The electrodes used in the laser had the cylindrical form with radius of a working surface of 60 mm. At voltage increase up to 22 kV the intensity of static electric field in the central area of interelectrode space reaches 7.63 kV/cm. It is known that UV-preionization allows the initial electron concentration to reach 10^6–10^8 cm^{-3}. In the assumption of that preliminary formed electrons have equal density along a surface of electrodes the profile of intensity of electric field in a preliminary stage of discharge formation will be set by a configuration of a discharge gap. At width discharge of 16 and 6 mm heterogeneity of electric field across an axis of electrodes will make 3.3 and 0.45%, accordingly. The further change of electric field profile in the subsequent stages of discharge burning will be set by evolutionary development of electron density in a discharge gap.

It is visible from Fig. 3 that in the range of small concentrations of Xe/HCl = 2–4 at wide change of a halogen concentrations Ne/HCl from 500 to 1500 the homogeneous volume discharge is formed. At discharge photographing on the cathode are visible a small light cathode spots. The discharge has high resistance and burning conditions are close to the coordinated mode. For active volume of 290 mm^3 in case of width of discharge burning of 16 mm specific pump power was 1.2 MW/cm^3. However, at such pump power the laser efficiency did not exceed of 1.1%. Increase of a parity of Xe/HCl concentrations up to 5–10 leads to change of discharge burning behavior. On the cathode in some cases and on the anode there are plasma spots to which the diffusion plasma channels are adhered. On some distance from the cathode occurs overlapping these channels and the volume discharge of certain uniformity is formed. In this case, the discharge conductivity grows, the mode becomes more unmatched, but at the expense of reduction of the discharge width up to 10 mm the specific pump power to 2.2 MW/cm^3 increases and the laser efficiency grows to 1.7%.

The further increase of Xe/HCl concentrations up to 12–20 leads to the further reduction of discharge width and in certain conditions one leads to discharge heterogeneity occurrence. For concentration of halogen in mix of Ne/HCl = 800–1000 the discharge width is reduced up to 7–9 mm and the distance from a cathode surface on which are blocked the diffusion channels increases. At the expense of discharge compression the specific pump power to 3 MW/cm^3 increases and the laser efficiency reaches of 2.42%. Zones A and B allocated with a dotted line on curves *1* and *4* (Fig. 2) correspond to formation of various heterogeneities. In a mix of Ne/Xe/HCl = 500/(12–20)/1 macro-heterogeneities are formed and in a mix of Ne/Xe/ /HCl = 1500/(13–20)/1 – micro-heterogeneities [13].

Photos of prints of laser beam and discharge fluorescence are presented in Fig. 4. The image of a laser beam for a mix Ne/Xe/HCl = 500/20/1 is presented in Fig. 4, *a*. The laser efficiency in this case was 1.1%. In a photo of the discharge fluorescence and a beam print it is visible that diffusion high current channels are not bridged the gap of discharge. On the cathode and the anode there are strongly pronounced plasma spots. Photos of the laser beam and discharge fluorescence for mix of Ne/Xe/HCl = 1500/20/1 are shown in Fig. 4, *b*, *c*. In this case, the laser efficiency did not exceed 0.56 %. It is visible that distribution of laser beam intensity and a discharge luminescence are variously. The discharge width was 4 mm and pump power level – 4.6 MW/cm^3. On a discharge photo the ill-defined cathode and anode plasma spots are visible and the diffusion channels with a binding to cathode spots in the discharge are absent.



a *b* *c*

Fig. 4. laser beam autographs: *a* – Ne/Xe/HCl:500/20/1; *b* – Ne/Xe/HCl:1500/20/1 and photo the discharge; *c* – Ne/Xe/HCl:1500/20/1

The dependences of a current and voltage for the big and small concentration of halogen in mix for various Xe concentrations are presented in Fig. 5. From our point of view, the most essential influence on formation and discharge burning renders a share part of Xe in a mix, as the ionization of Xe is responsible for creation of electrons and ions in discharge plasma. In work [15] it is shown that at concentration $Xe^* < 10^{13}$ cm^{-3} more than 90% of pump power are transferred to excited levels of Xe^* and HCl^*. Hence, the increased percentage in mix of Xe leads to essential growth of entered energy losses being in the period of a preliminary stage of formation pump discharge. The given condition will lead to reduction of an operating time of electron concentration as the basic energy delivered in the discharge is spent for Xe^* excitation. Small electrons concentration allows increasing the breakdown voltage in discharge gap and one forms the discharge on a site with small distortions of electric field. It is coordinated with the found dependences represented in Figs. 3 and 5. However, the further growth of electrons concentration caused by inclusion of step ionization does not allow realizing a condition for formation of the homogeneous discharge. In this mode, it is possible to observe discharge development under three various scenarios set by concentration of halogen.

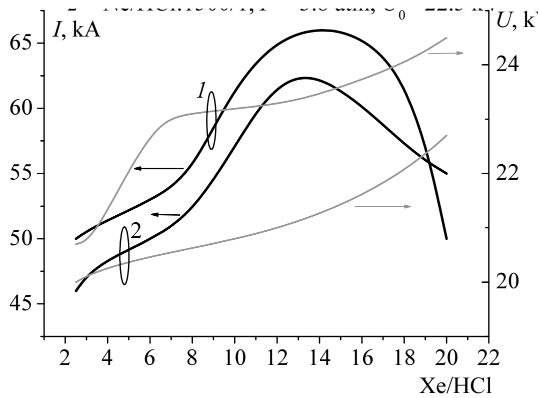


Fig. 5. Dependences of current and voltage for various concentration of halogen in the mix Ne/HCl = 500/1 (*1*) and *2* – Ne/HCl = 1500/1 (*2*) at P = 3.8 atm., U_0 = 22.5 kV for various Xe concentrations

At high concentration of halogen (Ne/HCl = = 500/1) the speed of electrons destruction at the expense of growth of halogen concentration in the excited states in addition increases. These conditions are favorable for development of cathode spots on an electrode surface that allows using them as effective suppliers secondary electrons in high current phase of discharge. Observable plural diffusion high current channels (dimension of 0.5–1 mm) adhered to cathode spots keep the properties to amplify during the pump power.

In the conditions of small concentration of halogen (Ne/HCl = 1500/1) there are no cathode spots hence a secondary electrons source is photoemission and an ion-electron emission. However such discharge does not allow to pass a high current density (in our case ~ 1.5 kA) that leads to formation in the volume discharge of a current threads (dimension ~ 10–100 microns) with fast burning out in them of halogen [8].

At concentration of halogen in mix Ne/HCl = = (800–1000)/1 the mode of development of cathode spots with a binding to them of diffusion channels and their overlapping on some distance from an electrode is realized. The given conditions allow to increase the pump power ≥ 3 MW/cm^3 and to increase of the laser efficiency more than 2.5%.

In equal conditions but at use of a mix with small Xe concentration the remained considerable part of pump energy passes to electrons creation, ions and the excited particles. It is shown in reduction of breakdown voltage on discharge gap (Fig. 5) and in increase of discharge width up to 16 mm. Reduction of current density to 0.5 kA at the expense of decrease of pump power has allowed to keep the volume discharge during duration of 100 ns pump power.

4. Conclusion

Results of experimental researches of possible realizations of steady discharge burning in a gas mix of commercial discharge XeCl laser with total pulse duration of 60 nanoseconds and high pump power were resulted. It was shown that formation conditions and the subsequent discharge burning essentially depend on concentration of components of Ne:Xe:HCl mix and specific pump power. Influence of the spatial form of discharge current on parameters of output radiation, specific laser energy of the active volume and a laser overall performance were defined.

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