NUMERICAL MODELING OF PLASMOCHEMICAL PROCESSES IN ACTIVE MEDIA OF XeF AND XeCl LASERS PUMPED BY A LONG PULSE

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Kinetics of active media of XeF *and* XeCl *lasers pumped by an electron beam with pulse duration* 20–100 μs *and specific power* 2–20 kW/cm^3 *is numerically modeled.*

It is well known that XeF and XeCl excimer lasers operate effectively when pumped by rather short and powerful pulses whose length varies from several tens to several hundreds of nanoseconds, and specific power varies from several hundreds of kilowatts to several megawatts per cubic centimeter. Only a few papers reported the pumping pulses of several microseconds.

However, for some practical applications it is of interest to investigate the operation of excimer lasers pumped by a pulse 10–100 μs long with specific power 1–10 kW/cm^3. Such a pumping mode can be realized only by a hard ionizer, in particular, by an electron beam.

There are a number of papers (see, e.g., Refs. 4, 5, and 7) where the detailed numerical models were presented of XeF and XeCl lasers pumped by an electron beam with pulse duration 20–100 μs and specific power 2–20 kW/cm^3. However, the length of pumping pulse of these lasers was ~1 μs.

In the present paper, kinetics of active media of XeF and XeCl lasers pumped by an electron beam 20–100 ms long with specific power 2–20 kW/cm^3 is numerically modeled.

DESCRIPTION OF THE MODEL

The gas mixtures Ne, Xe, and NF_3 and Ne, Xe, and HCl were selected for XeF and XeCl lasers, respectively, because they provide the maximum efficiency of these lasers.[2,7] The pressure was equal to 3 atm in both cases.

The model includes the system of the balance equations for the components of an active medium. It was solved by the Rosenbrock method of the third order of accuracy.[1] To determine the constants of a number of reactions with participation of electrons, the Boltzmann equation[7] was solved.

Several tens of plasmochemical reactions were considered for the model. Their constants were borrowed from Refs. 3–7. The effect of an electron beam on a gas medium was modeled by means of introducing the excitation and ionization frequencies.[5]

CALCULATION RESULTS

Many plasmochemical processes occur in the active media of XeF and XeCl lasers. However, only some of them essentially affect the upper laser energy level population. They are ionization, charge transfer to the Xe containing ion, dissociation adhesion with production of the negative halogen ion, and the ion-ion recombination between Xe^+ or Xe_2^+ and F^- or Cl^-, being the principal mechanism of production of the molecules XeF(B) and XeCl(B), i.e., of the upper laser energy level. The processes in both media are similar. The difference is that the dissociation adhesion to HCl, unlike NF_3, occurs not from the ground, but from the excited state (HCl(v)), so reasonably large amount of (HCl(v)) is necessary for efficient production of XeCl(B). The delay in the amplification coefficient increase of the XeCl medium in comparison with the XeF medium is explained by the time required for this process (Fig. 1).

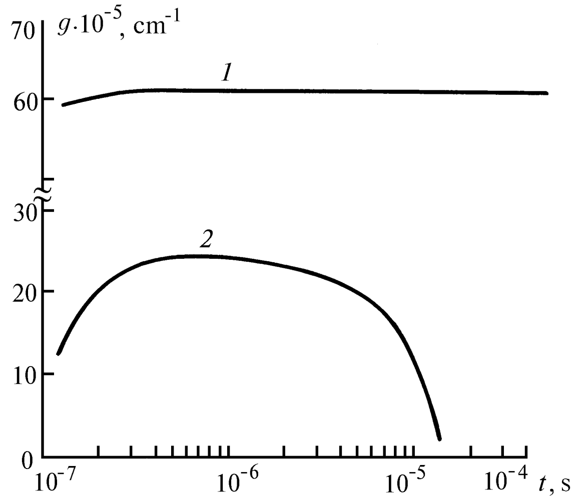

FIG. 1. Temporal behavior of the amplification coefficient for a specific pump power of 5 kW/cm^3: *1)* XeF *medium, 2)* XeCl *medium.*

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As it has been mentioned above, the ion-ion recombination is the principal mechanism of pumping of the excimer lasers. So the working mixture composition must provide the maximum activation of this mechanism. One of the necessary conditions of its realization is the charge transfer to the Xe containing ions. It is clear that to increase the rate of this process, it is necessary to increase the Xe concentration; however, its surplus will increase both the rate of deactivation of the upper laser level and the concentration of Xe_2^+, which absorbs the laser radiation. Therefore, there is the optimum Xe concentration that provides the maximum value of the amplification coefficient g. The dependence of the optimum Xe concentration on the specific pumping power is shown in Fig. 2.

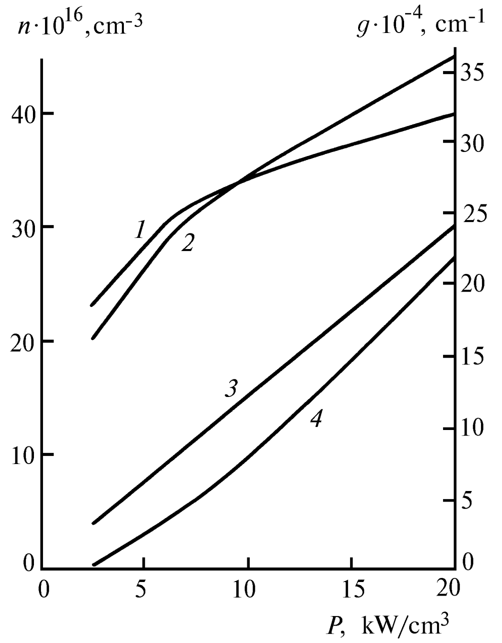

FIG. 2. Optimum Xe *concentration (1 and 2) and amplification coefficient of the active medium (3 and 4) as functions of the specific pump power: 1, 3)* XeF *medium; 2, 4)* XeCl *medium.*

The increase of the optimum Xe concentration with increase of the pumping power is explained by the necessity to increase the rate of charge transfer to the Xe containing ions. The halogen donor concentration should be such that to provide the rate of production of the F^- and Cl^- ions being approximately equal to the rate of the charge transfer to the Xe containing ions. This concentration is approximately 1/5 of the Xe concentration.

The presence of negative ions is the necessary condition for production of the molecules XeF(B) and XeCl(B). The ion Cl^-, unlike F^-, is the strong absorber of the working radiation. The lower amplification coefficient of the XeCl medium at identical specific pumping powers is explained by the absorption on Cl^-. However, with increase of the pumping power, a difference in amplification coefficients becomes less (Fig. 2).

The important factor affecting the characteristics of the active medium is degradation of the working mixture. Decomposition of the halogen donor is the necessary condition for the excimer molecule production. So the excimer laser operation is possible only with sufficient amount of the halogen donor. However, its concentration constantly decreases during the pulse. Therefore, it is necessary to elucidate the degree of this decrease and how it affects the characteristics of the active medium. The dependence of the concentration of NF_3 and HCl as well as F_2 and Cl_2, i.e., the products of decomposition of the halogen donors being the absorbers of the working radiation, it is shown in Fig. 3.

It is seen that the XeF medium undergoes less degradation than XeCl. It is connected with the fact that the reaction of combination

$$NF_2 + F + M \rightarrow NF_3 + M \qquad (1)$$

has the constant being one order of magnitude greater that of the reaction

$$H + Cl + M \rightarrow HCl + M . \qquad (2)$$

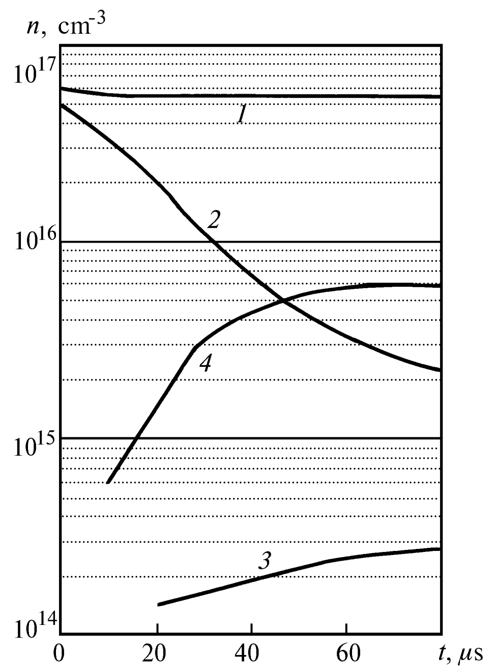

FIG. 3. Temporal behavior of components containing halogen: 1) NF_3, *2)* HCl, *3)* F_2, *and 4)* Cl_2.

The behavior of curve *1* in Fig. 1 shows that the decomposition of NF_3 does not affect the amplification coefficient of the XeF medium. It is explained by the low degree of NF_3 decomposition and the low concentration of produced F_2 that has the small cross section of the working radiation absorption. The amplification coefficient of the XeCl medium depends strongly on the HCl decomposition (curve *2* in Fig. 1). Its decrease is primarily caused by production of Cl_2, the strong absorber of the working radiation. The decrease of the rate of XeCl(B) production due to HCl decomposition affects not so strongly. The amplification pulse duration, i.e., the time at which the amplification coefficient is above zero, is shown in Fig. 4 as a function of the pumping power. Contrary to the expectations the amplification pulse duration does not increase when the pumping power decreases, though the HCl decomposition process is slowed down. It is caused by the increase of the role of absorption by Cl^-.

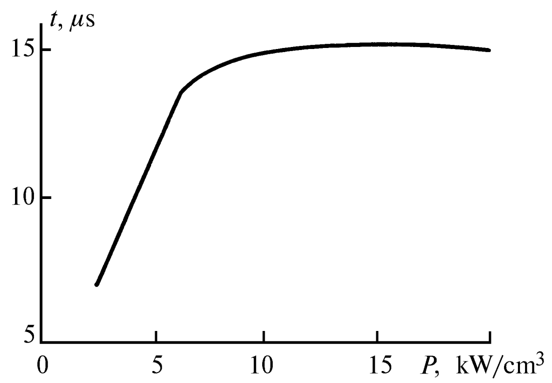

FIG. 4. Amplification pulse duration in the XeCl *medium as a function of the specific pumping power.*

CONCLUSION

The active media of excimer lasers have been investigated. The mixture composition has been optimized, and the amplification coefficients of these media have been compared for different specific pumping powers (2–20 kW/cm^3). The degradation of the working mixture has been also investigated as well as its effect on the characteristics of both media.

It has been shown that at lower specific pumping power the XeF medium has the higher amplification coefficient than the XeCl medium. However, when the pumping power increases, the difference between the amplification coefficients of both media decreases.

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