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Theoretical study of the pre-ionized XeCl laser

Z. HARRACHE[1,2] and A. BELASRI[1]

[1]Laboratoire de Physique des Plasmas, des Matériaux Conducteurs et leurs Applications (LPPMCA) El M'Nouar BP-1505, Université des Sciences et Technologie d'Oran, Algerie (zharrach@fundp.ac.be)

[2]Laboratoire de Spectroscopie Moléculaire de Surface (LASMOS), 61, Rue de Bruxelles, B-5000, Université de Namur (FUNDP), Belgique

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Abstract. In this paper, we use numerical modeling to study some characteristics of the XeCl laser under homogeneous pre-ionization conditions. The study is executed using a model combining external circuit and plasma kinetics. The model validity is checked by comparing the model results to the experimental data from the literature. A qualitative agreement was found.

1. Introduction

In the development of laser technology, excimer lasers operating in the ultraviolet (UV) region may be considered as the third generation of industrial lasers. The high photon energy of excimer laser leads to a wide range of new applications. Excimer lasers pumped by pre-ionized electrical discharges have been proved very efficient devices for the production of high-power UV radiation. Among the different discharge schemes, the so-called phototriggered discharge [1–3], which removes the high-power switch between the main storage line and the laser head, appears a simple and reliable excitation means for the development of high-power industrial UV lasers. Laser output energies of greater than 10 J were obtained in large-aperture systems using this discharge scheme [4,5]. The present work is, therefore, a logical extension of our previous works [6,7]. Here, we focus on the computation of the electron reaction rate coefficients, breakdown delay time and impulse duration, $NeXe^+$ species concentration, and discharge current.

2. The phototriggered XeCl laser model

In the frame of the local field approximation [8] and under the assumption of a spatially homogeneous discharge, our model self-consistently couples the solution of the electron Boltzmann equation (EBE), the kinetic equations (KEs) describing the temporal evolution of heavy particles, and the electrical circuit (EC). It is a zero-dimensional model since a homogeneous positive column in the glow discharge is assumed in place of the laser processes [9–11]. In this model, the plasma is represented by a resistance R_L:

$$R_L(t) = \frac{d}{Aen_e(t)\mu_e(t)} \tag{2.1}$$

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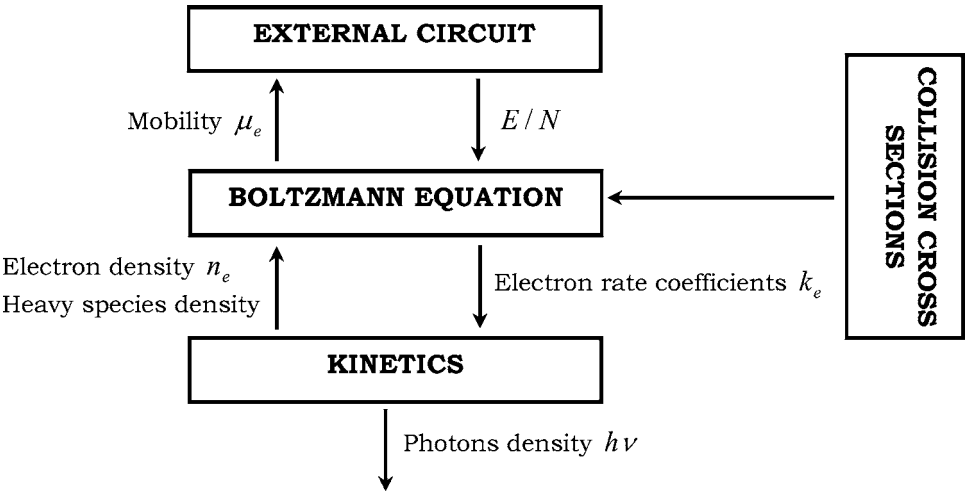


Figure 1. Simplified scheme of the present zero-dimensional model.

where e, $n_e(t)$, $\mu_e(t)$ are the electron charge, the time-dependent electron density, and mobility, respectively.

The EBE, as shown in Fig. 1, is of central importance as it enables us to calculate, on the one hand, the electron mobility μ_e needed for the resistance calculation, and, on the other hand, the electron reaction rate coefficients k_e required by the kinetic model. The solution of the KE leads to the determination of the electron density also required for the resistance calculation. The set of reactions and their rate coefficients used in the present calculations of the characteristics of the Ne–Xe–HCl mixture for laser discharge are reported in our previous works [6, 7].

The density evolution for electrons, metastable xenon (Xe^*), Xe_2^*, positive and negative ions ($NeXe^+$, Xe_2^+, Cl^-), photons, $XeCl^*$, and, finally, HCl on the vibration levels ($v = 0, 1, 2, 3$) can be described by associating a set of equations to each element of the plasma.

3. Results and discussion

In this section, we present some general results for the case of a uniform plasma. The scheme of the discharge model and external circuit are also shown in [6, 7].

It is known that the electronic rate coefficients depend on the discharge electric field and the gas mixture concentration. Their values give information on the relative importance of the reactions under normal operating conditions. Figure 2 shows a selection of some important electron rate coefficients as a function of the reduced electric field (E/N) calculated from the EBE in a Ne(99.37%)–Xe(0.5%)–HCl(0.13%) gas mixture at 2.5 bar. We note that the highest value corresponds to the rate coefficient of metastable xenon ionization for this type of gas mixture.

Figure 3 represents, for the same conditions as used in Fig. 2, the breakdown delay time and impulse duration of the discharge as a function of charging voltage. The breakdown delay time is defined here as the time elapsed from initiation to 10% of the current peak [12]. We can see from this figure that the discharge impulse duration is relatively insensitive to the charging voltage in the range (15–35 kV).

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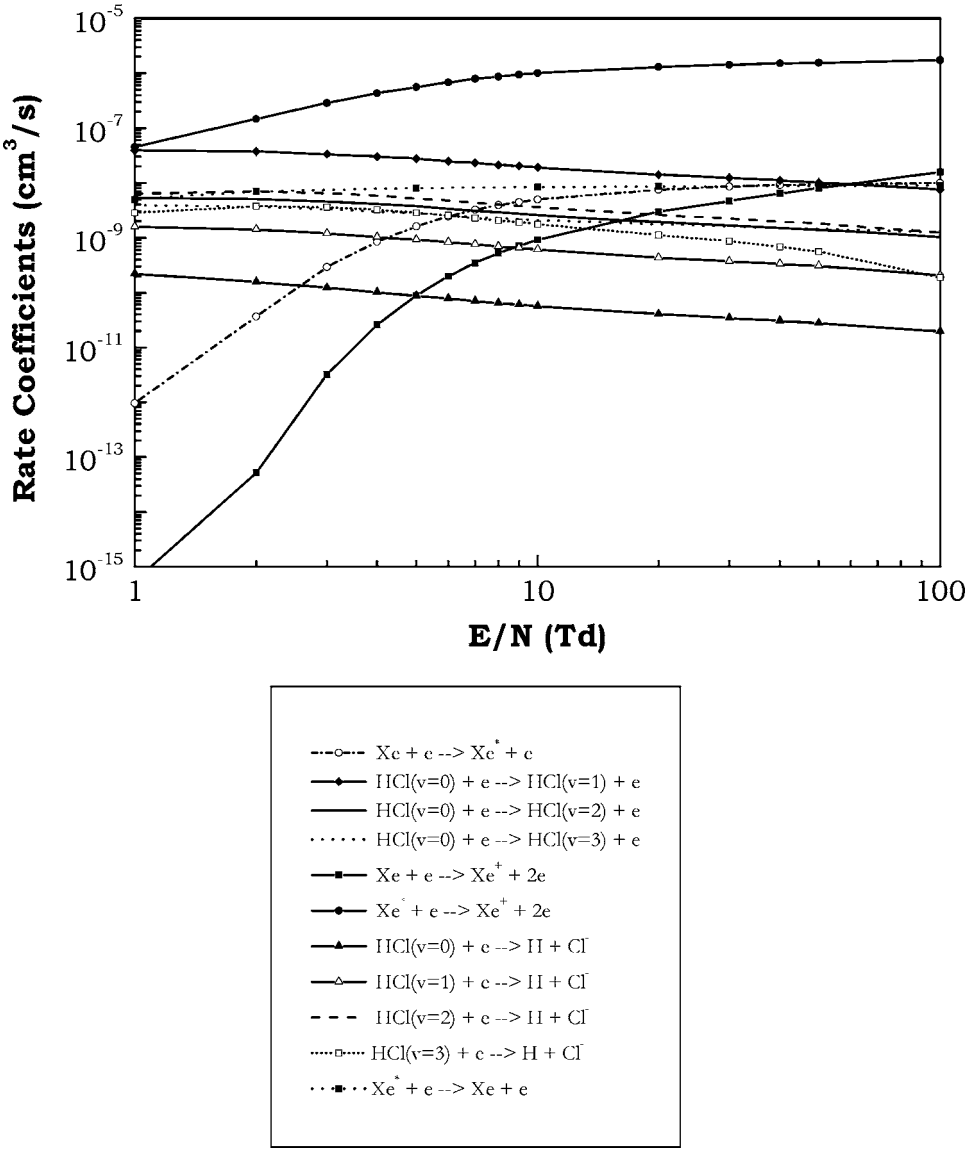


Figure 2. Selection of some important electron impact rate coefficients as a function of E/N for a Ne(99.37%)–Xe(0.5%)–HCl(0.13%) mixture at 2.5 bar gas pressure (1 Td = 10^{-17} V cm^2).

However, the breakdown delay time decreases very quickly with the increase in the charging voltage (the breakdown delay time varies as the reverse of the ionization frequency, which varies in an exponential way with the reduced field and therefore with the charging voltage).

Owing to its important role in the discharge, we have plotted in Fig. 4 the variation of the peak of $NeXe^+$ ion versus the applied voltage V_0. This peak increases with the increase of V_0 for the various gas mixtures studied and is more significant in the gas mixture with a weak concentration of HCl(0.01%). This is

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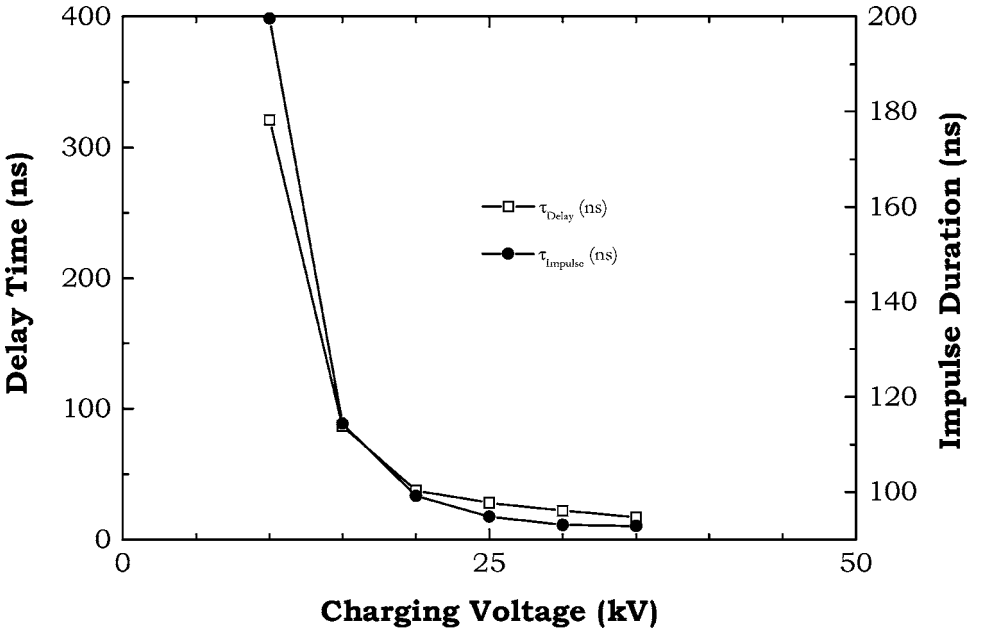


Figure 3. Evolutions versus the charging voltage of the breakdown delay time and the impulse duration.

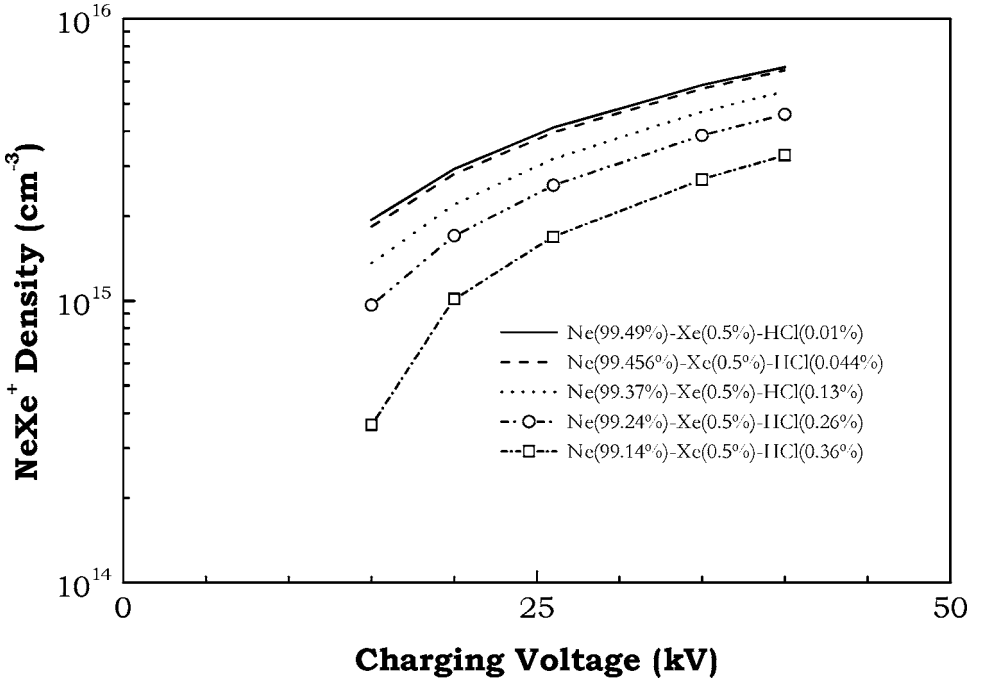


Figure 4. Variation of the $NeXe^+$ density peak versus the charging voltage for different Ne–Xe–HCl gas mixtures.

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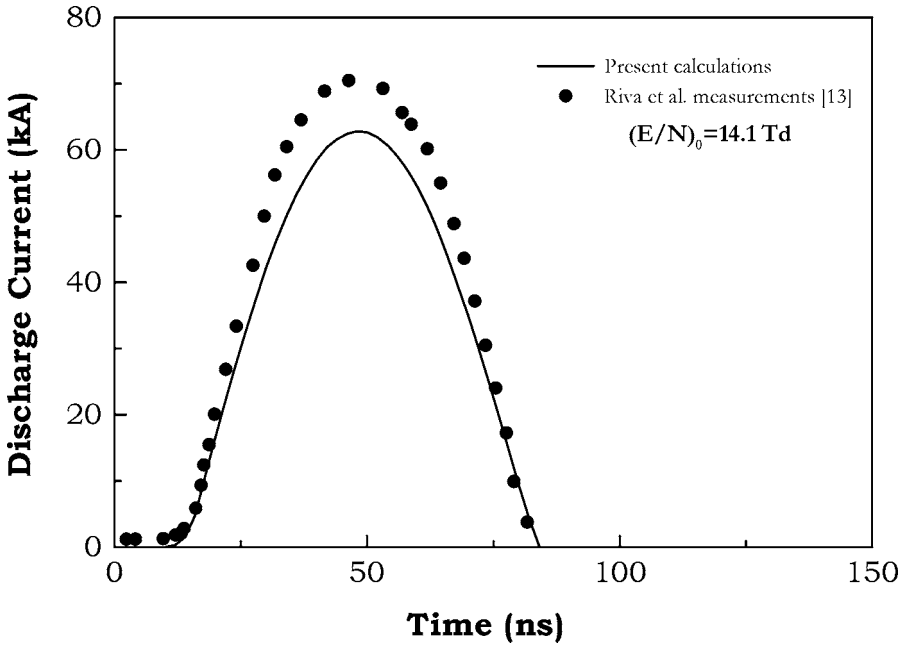


Figure 5. Comparison of the discharge current between measurements of Riva et al. [13] and our calculations for the following conditions: gas mixture composition Ne(99.33%)–Xe(0.5%)–HCl(0.17%), $C = 144$ nF, $L = 3.3$ nH, $P = 4$ bar, electrode area 50 cm^2, gap distance of 1 cm, and $E/N_0 = 14.1$ Td.

the result of the reduction in the attachment on the HCl molecule for the weak concentration of the halogen.

In order to verify the validity of our computations, in Fig. 5 we present the discharge current obtained by our model and the measurements of Riva et al. [13] for the initial reduced electric field $E/N_0 = 14.1$ Td. The impulse of current has the same form and the current calculated by our model is always slightly lower than that of the experiment with the same rise time and impulse duration.

4. Conclusion

In this work we have discussed our results obtained for the discharge characteristics of a XeCl laser. A self-consistent model has been utilized for a discharge-pumped XeCl laser. This model allowed us to study the characteristics of an electric-discharge XeCl laser under homogeneous pre-ionization conditions. We have calculated the reaction rate coefficients, the breakdown delay time and impulse duration, the density evolution of $NeXe^+$ ion versus applied voltage, and, finally, the discharge current. A comparison of the theoretical and experimental results has shown that a qualitative agreement exists between the two. Further study is now in progress for possible improvements in the chemical kinetic scheme.

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