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Numerical Analysis of Radio-Frequency Barrier Discharges in Xenon for Excimer Lamps

エキシマランプ用高周波キセノンバリア放電の放電基礎特性の解析

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Fundamental discharge properties in rf-excited dielectric-barrier discharges (RF-DBDs) in xenon have been analyzed using a one-dimensional fluid model, for the purpose of further performance optimization of xenon excimer lamps (λ~172 nm). This fluid model consists of the continuity equations for electrons, positive ions, excited atoms and molecules, the Poisson equation and the electron energy balance equation. In lower input-power case (~1Wcm^{-2}), simulated discharge- current waveform is similar to sinusoidal one. In xenon RF-DBDs, it is found that dominant positive ion species is found to be Xe3+ ions with the density magnitude of 109 cm-3. Other fundamental discharge properties in xenon RF-DBDs are also analysed.

1. Introduction

Excimer lamps using dielectric barrier discharges (DBDs) have been investigated and developed [1-4] as a vacuum-ultraviolet light source for photo-chemical applications such as photo-deposition of thin films, dry etching and surface modification of plastics etc [5-7].

Until now, in order to examine a further performance improvement of the lamps, we have reported the dependence of output power and efficiency of vacuum-ultraviolet light (λ~172 nm) on input-power for various driving frequencies and gas-pressures [8], waveform of applied voltage and gap lengths [9], from the aspect of numerical analysis in xenon DBDs.

In this paper, as one of the possibility to improve the characteristics of the lamps, rf-excited dielectric-barrier discharges (RF-DBDs) in xenon have been simulated using a one-dimensional fluid model, and then analyzed the fundamental discharge properties, focused on the spatiotemporal behavior of the charged-species, and the voltage and current waveforms.

2. Modeling of DBDs in Xenon

Figure 1 shows a schematic diagram of present simulation model. The xenon gas with the total pressure of 600 Torr and gas temperature of 300 K is filled between two parallel-plate metallic electrodes covered with dielectric-layer (width: 0.2 cm and relative permittivity: 3.8). The RF-DBDs are generated and sustained by applying AC voltage with driving frequency of 13.56 MHz. The discharge-gap spacing and secondary emission coefficient due to ion bombardment are set to be 0.8 cm and 0.01, respectively. In this work, four charged-species (e^-, Xe^+, Xe_2^+, Xe_3^+) and six excited-species ($Xe^*(m)$, $Xe^*(r)$, Xe^{**}, $Xe2^*(O_u^+)$, $Xe2^*(^1\Sigma_u^+)$, $Xe2^*(^3\Sigma_u^+)$) were considered as species in the RF-DBDs in xenon.

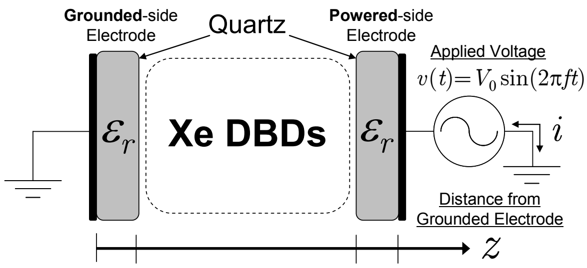

Fig. 1. A schematic diagram of xenon RF-DBDs.

3. Results and Discussion

In this section, as an example of simulation results, fundamental discharge properties in xenon RF-DBDs at low input-power (~1Wcm^{-2}) are discussed below. Simulation conditions considered here are chosen to be similar to actual working conditions of the excimer lamps.

Fig. 2 shows (a) the temporal variations of voltage-current waveforms, and the cyclic-averaged spatial distributions of (b) the charged-species density, (c) the excited-species density, and (d) the

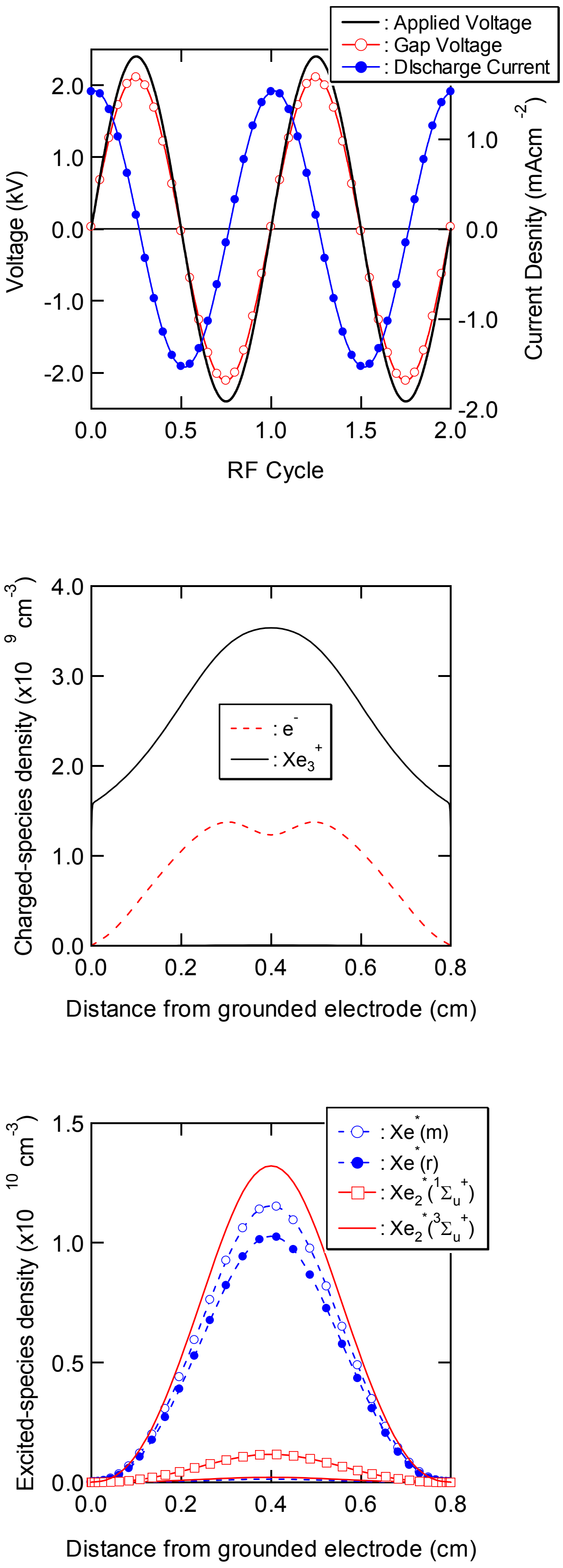

Fig. 2. Simulated fundamental discharge properties in xenon RF-DBDs at lower input-power (1 Wcm^{-2}): (a) the voltage-current waveforms; the cyclic-averaged spatial distributions of (b) the charged-species density; (c) the excited-species density.

electron-temperature and electric field. As shown in Fig 2(a), simulated discharge-current appears to be almost the same as sinusoidal waveform. The amplitude of the current is 1.5mAcm^{-2}. The phase angle between the current and the gap-voltage is almost $\pi/2$. This result indicates that the electrical characteristics in xenon RF-DBDs may be the same as those of capacitive discharge. In Fig 2(b) and 2(c), the spatial density-profiles of charged- and excited-species have like a cup-profile with density-peak at the middle of the whole discharge-gap. In Fig. 2(b), the dominant positive-ion species is found to be Xe_3^+ ions with the density-magnitude of 10^9 cm^{-3}. The density-magnitude of the excited atoms (Xe*(m) and Xe*(r)) and excimers ($Xe_2^*(^3\Sigma_u^+)$ with long lifetime of about 100 ns) are on the order of magnitude of 10^{10} cm^{-3} . The magnitude of the excited species is about three times higher than that of positive ions, as shown in Fig. 2(c). As a result, xenon RF-DBDs at low input-power density (~1 Wcm^{-2}) is found to be almost pure capacitive discharges. The other results on RF-DBDs in xenon will be shown at the conference.

Acknowledgments

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