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

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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 ($\lambda \sim 172$ 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 ($\sim 1$ W cm$^{-2}$), 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 Xe$^{3+}$ ions with the density magnitude of 10$^9$ 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 ($\lambda \sim 172$ 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$^{**}$, Xe$^2(\Sigma_u^+)$, Xe$^2(\Sigma_u^+_g)$) were considered as species in the RF-DBDs in xenon.

3. Results and Discussion

In this section, as an example of simulation results, fundamental discharge properties in xenon RF-DBDs at low input-power ($\sim 1$ W cm$^{-2}$) 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...
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 π/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 Xe³⁺ ions with the density-magnitude of 10⁹ cm⁻³. The density-magnitude of the excited atoms (Xe⁺(m) and Xe⁺(r)) and excimers (Xe₂⁺(³Σᵘ⁺) with long lifetime of about 100 ns) are on the order of magnitude of 10¹⁰ 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.

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**References**