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Control of nonlinear sheath dynamics and plasma kinetics in a capacitively coupled plasma by the change of voltage waveforms and surface interactions

Hae June Lee[1]
[1] Department of Electrical Engineering, Pusan National University
e-mail (speaker): haejune@pusan.ac.kr

The kinetic analysis of low-temperature plasma sources by a particle-in-cell (PIC) simulation is required for a nonlinear and transient system, which is common in a high-power capacitively coupled plasmas (CCPs). The kinetic aspect of electron heating and ion transports are introduced and discussed in this talk utilizing a high-performance two-dimensional GPU-based PIC simulation [1-3]. The nonlinear sheath dynamics and the transition of electron energy probability function (EEPFs) by the change of heating mode are investigated by applying dual-frequency or non-sinusoidal voltage waveforms and asymmetric electrode geometry such as hollow cathode shower-head. The temporal and spatial variation of the sheath dynamics provides a control knob to improve the spatial uniformity and EEPF profiles. The effect of the surface interactions is also reported, such as electron emission and reflection coefficients and the angle distribution of the reflected electrons, for the control of the EEPFs and the plasma uniformity.

Figures 1 and 2 show the effect of the power variation of a dual-frequency RF capacitive discharges of 3 Torr Argon on the profiles of time-averaged electron densities and temperatures. Here, the RF waveform of a high frequency (HF) of 13.56 MHz has an input power of 100 W. The power of the low frequency (LF) driver at 1.356 MHz varies from 0 to 100W and 200 W. Even though both the HF and LF waveforms are applied on the top electrode, the overall plasma densities are symmetric between the two electrodes. However, the plasma density increases near the edge because of the enhanced heating.

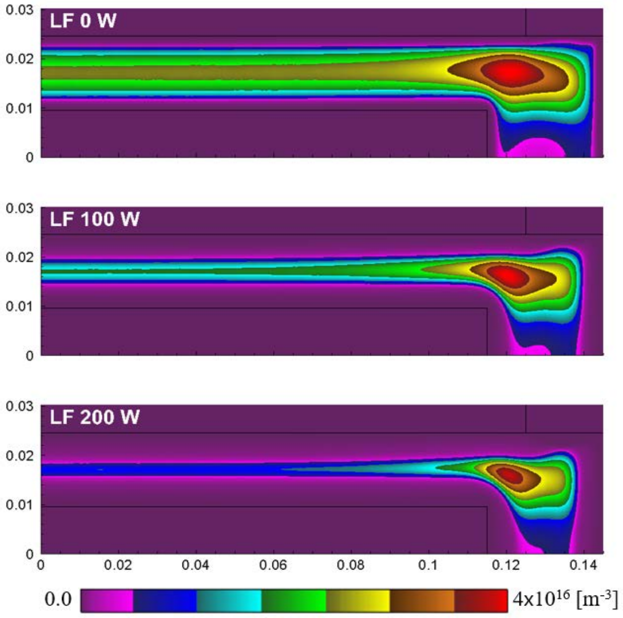

Figure 1. Electron density profiles for the variation of the power applied to the low-frequency driver.

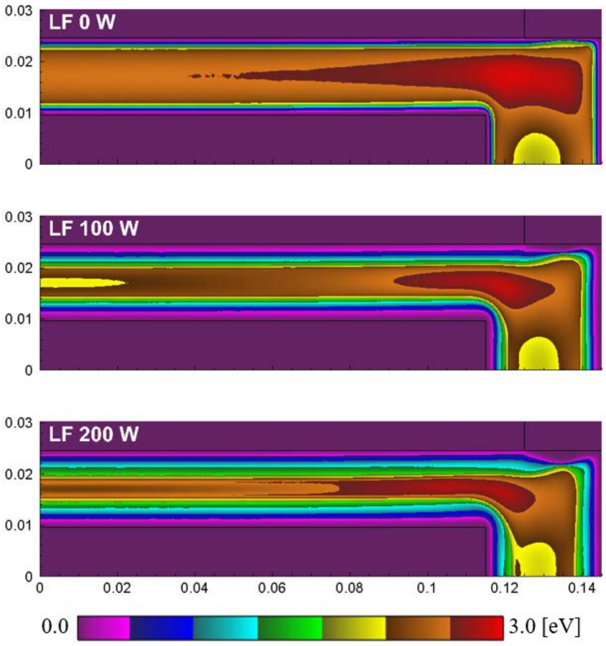

Figure 2. Electron temperature profiles for the variation of the power applied to the low-frequency driver.

The sidewall effect cannot be treated correctly in a one-dimensional simulation. Another good example of the geometric effect is the simulation of a hollow cathode (HC) discharge. Even without the pendulum effect of the trapped electrons inside of the HC, the plasma density increases near the hole entrance only because of the enhanced electron heating by the geometry effect. Figure 3 shows the enhanced electron heating and ionization near the HC.

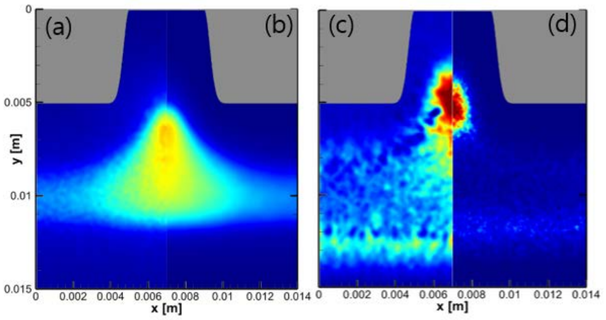

Figure 3. A hollow cathode Ar discharge at 1 Torr shows time-averaged (a) electron density, (b) ion density, (c) electron power deposition, and (d) ionization profiles.

References

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[2] J. S. Kim, M. Y. Hur, H. J. Kim, and H. J. Lee, J. Appl. Phys. **126**, 233301 (2019).