2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Plasma characteristics in an electrically asymmetric capacitive discharge sustained by multiple harmonics: operating in the very high frequency regime

Yu-Ru Zhang, Yan-Ting Hu, Fei Gao, Yuan-Hong Song and You-Nian Wang
School of Physics, Dalian University of Technology
e-mail (speaker): yrzhang@dlut.edu.cn

In order to control the ion flux and ion energy independently, the so-called electrical asymmetry effect (EAE) was proposed by Heil *et al.*[1] They revealed that the discharge became electrically asymmetric when the voltage waveform contained an even harmonic of the fundamental, even in a geometrically symmetric reactor. Subsequently, the study of the EAE has been extended from dual frequency (DF) to multi-frequency discharges, to broaden the control range of the ion energy without affecting the ion flux.[2] In discharges driven by multiple harmonics, especially when the frequency of the highest harmonic is in the very high frequency regime, the excitation wavelength may become comparable to the reactor dimension, and the electromagnetic effects start to have a significant influence on the discharge parameters.[3] Therefore, in this work, a two-dimensional fluid model combined with the full set of Maxwell equations, the so-called Multi-physics Analysis for Plasma Sources (MAPS), is employed for a comprehensive description of the plasma properties in an electrically asymmetric capacitively coupled plasma (CCP) excited by multiple harmonics.

Figure 1 shows that in a discharge sustained by 8 consecutive harmonics, the electron density displays an off-axis peak at $\theta_1 = 0$. As θ_1 increases to $\pi/2$, the electron density at the radial edge decreases slightly, whereas the value at the center exhibits a slight increase. Therefore, the best radial uniformity is observed at $\theta_1 = \pi$, with the nonuniformity degree $\alpha \approx 1.9\%$. As θ_1 increases further to $5\pi/4$ and $3\pi/2$, the electron density at the radial edge increases steadily, whereas the magnitude at the center almost keeps constant, giving rise to the worse radial uniformity again. The influence of θ_1 on the electron density can be explained by examining the power density, which is the product of the current density with the electric field. It is clear from figure 2 that the power density P_r exhibits a pronounced peak at the radial edge, and the absolute value first decreases and then increases with θ_1. Whereas, the axial component of the power density P_z is characterized by a broad maximum at the reactor center, and the magnitude is comparable to the peak value of P_r at $\theta_1 = \pi$, resulting in the best radial uniformity under this condition.

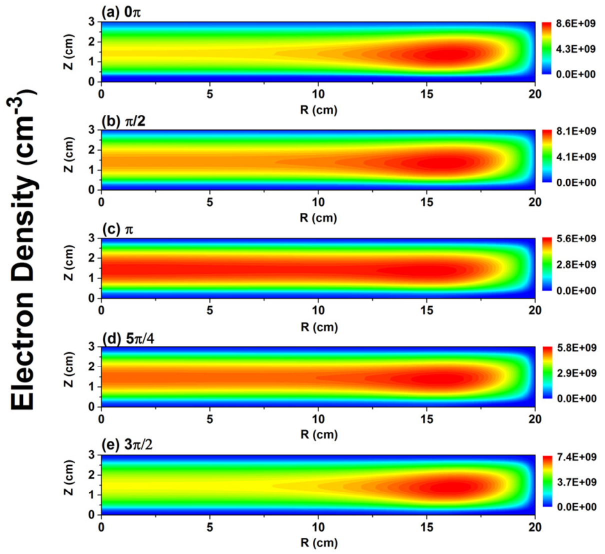

Figure 1 Distributions of the electron density for various θ_1 in discharges sustained by 8 consecutive harmonics.

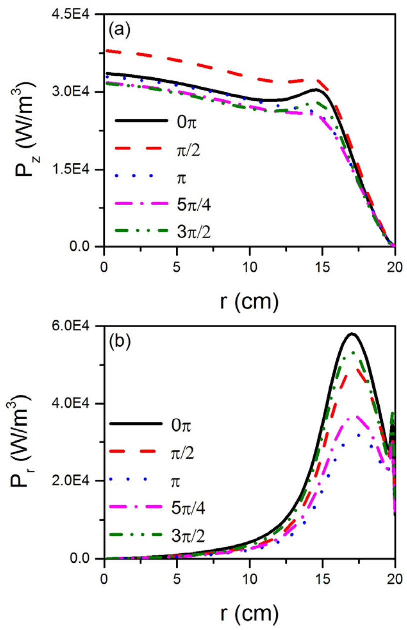

Figure 2 Radial distributions of the power density along the reactor centerline ($z = L/2$) for various θ_1 in discharges sustained by 8 consecutive harmonics.

References

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