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Simulation Study of Capacitively Coupled Radio Frequency Plasma Discharges with Hollow Cathode Structure on Grounded Electrode

Wei-Kang Tseng[1], Hsin-Chang Chang[1], Chia-Yu Chen[1] and Keh-Chyang Leou[1]
[1] Engineering and System Science Department, National Tsing Hua University
e-mail (speaker): tsweikang@gmail.com

Abstract:
Capacitively coupled plasma (CCP) sources have been widely used for material processing. In this simulation study, 3 gaseous species and 4 reactions of argon plasma discharge which generated by a 27.12 MHz radio frequency (RF) power are included and it have been investigated by fluid model numerical simulations (CFD-ACE+, ESI Corp.). Furthermore, the trench at the ground electrode (GE) is added to the model and the simulation results will be compared with the previous literature which add the trench at the powered electrode (PE). The correlation between the plasma properties and the operating parameters will be discussed further. According to the simulation results, the spatial profile of the plasma density is modified significantly, the plasma density(4×10^{16} m^{-3}) of the CCP is enhanced by the hollow cathode effect (HCE) of the trench which the width is wider than the sum of twice the thickness of the plasma sheath and electron-neutral mean free path ($2d_s+\lambda$), as expected. HCE is enhanced as trench depth, applied power, operating pressure and frequency increase. In addition, the simulation results also reveal that the plasma uniformity can be tailored by the HCE of GE trench.

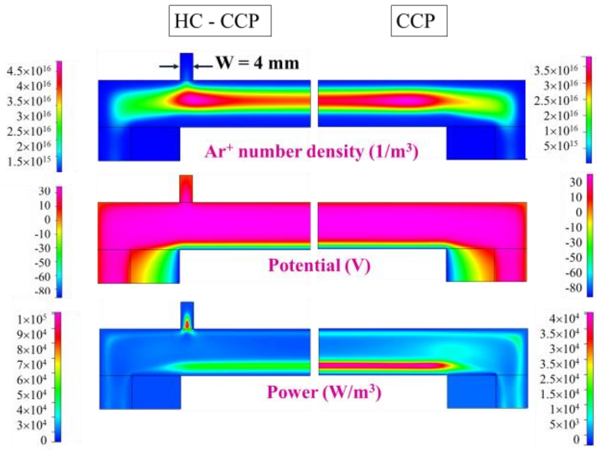
1. Introduction

Capacitively coupled plasma (CCP) sources driven by radio frequency power have been widely used for material processing, e.g., dry etching, plasma enhanced chemical vapor deposition (PECVD), and physical and reactive sputtering processes[1]. There have been also a great of interests to take the advantage of the plasma density enhancement by HCE to tune the CCP discharge characteristics[2, 3]. In this study, numerical simulation analysis based on 2D fluid model (CFD-ACE+, ESI Corp) is carried out to investigate the effect of a trench in GE of a 27.12 MHz CCP discharge.

2. Simulation results

Figure 1 shows the spatial distributions for basic plasma parameters, such as Ar^+ number density, potential and power density for Ar CCP discharges of the two different structures. Because of HCE, it is obvious that RF power absorption in the GE trench and plasma density near the GE trench are enhanced after adding a 4 mm × 8 mm trench on the GE.

Figure 2 shows radial distributions of electron density in CCP chamber under different trench depth (a), applied power (b), operating pressure (c), frequency (d). From figure 2(a), as the trench depth become deeper, the ratio of position at center of trench to the center of bulk plasma increased. Figure 2(b) shows the electron density enhance proportionally with power increasing from 1 W to 4 W. Figure 2(c) indicates that higher operating pressure cause electron density enhance and the ratio of position at center of trench to the center of bulk plasma increased. From figure 2(d), it reveals that electron density is higher at frequency operating at 54.24 MHz than 27.12 MHz.



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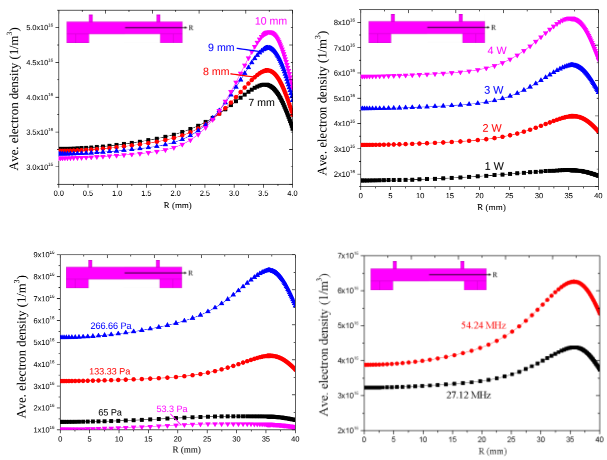

Fig. 2 shows radial distributions of electron density in CCP chamber under different trench depth (a), applied power (b), operating pressure (c), frequency (d).

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