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Nonmonotonicity of power transfer efficiency and transition threshold power during the E to H mode transition in inductively coupled plasmas

Peng-Cheng Du[1], Fei Gao[1], and You-Nian Wang[1]
[1]Key Laboratory of Materials Modification by Laser, Ion, and Electron Beams (Ministry of Education), School of Physics, Dalian University of Technology.
e-mail (speaker): pchdu@mail.dlut.edu.cn

Inductively coupled plasma (ICP) has been widely used in etching process and film deposition, and it has two different operation modes of the capacitive (E-) mode and the inductive (H-) mode. Compared with the E-mode operation, the H-mode discharge has advantage in low ion bombardment damage and independently controllable ion energy. Using the Faraday shield can efficiently reduce the E-mode influence, but in the meanwhile, it will bring the difficulty for discharge and reduce the inductive coupling efficiency. Therefore, in order to better understand and optimize the power coupling state and mode transition node, the study for the influence in the E to H power transfer efficiency and the transition threshold power of ICP is significant.

The schematic diagram of the experimental setup is shown in Fig. 1(a), the discharge chamber is a planar type ICP cylindrical reactor with two-turn water-cooled copper coils[1]. The experiment is carried out under Ar/O_2 discharge, the pressure changes from 0.3 Pa to 11 Pa, operating at a 13.56 MHz RF power and varies from 10 to 300 W, and the matching network is fixed. Both the electron density (n_e) and the power transfer efficiency (η) are measured during the E to H mode transition by a Langmuir probe and a current monitor. At the ultimate pressure, i.e. 7×10^{-4} Pa, the equivalent resistance has been calculated and shown in Fig. 1(b). Using the equivalent resistance (R = 0.2092 Ω) and the coil current (I), the power transfer efficiency can be obtained.

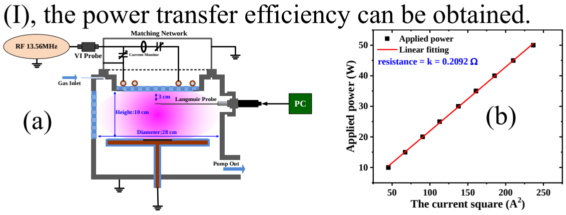

Fig. 1, the schematic diagram of the experimental setup (a) and the measured equivalent resistance (b).

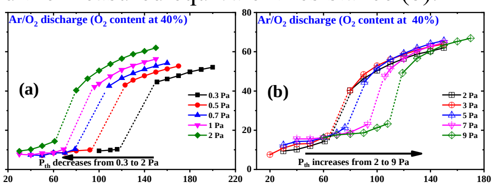

Fig. 2, the η against the applied power during the E to H mode transition at the pressure from (a) 0.3 to 2 Pa and (b) 2 to 9 Pa for Ar/O_2 discharge and the O_2 content is 40%, respectively.

Fig. 2 shows power transfer efficiency against the applied power during the E to H mode transition in Ar/O_2 discharge at different pressures. It can be seen that, with the pressure increasing, the power transfer efficiency shows a nonmonotonicity trend for first increases and then decreases. The evolution of η has a close relationship with the electron density and the effective collision frequency[2]. Indeed, the n_e also shows a nonmonotonicity trend and the result is shown in Fig. 3.

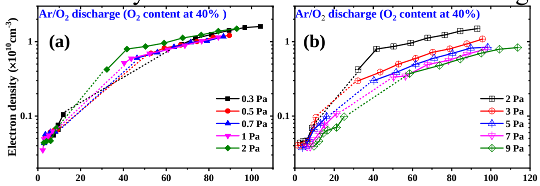

Fig. 3, The electron density against the absorbed power at the pressure from (a) 0.3 to 2 Pa and (b) 2 to 9 Pa for Ar/O_2 discharge and the O_2 content is 40%, respectively.

Using power transfer efficiency, the E to H mode transition threshold power (P_{th}) is calculated in the form of absorbed power. As can be seen in Fig. 4, for all the O_2 content, the P_{th} presents a trend for first decrease then increase with the pressure raising, which is caused by the various for the radio of the effective electron collision frequency to the power frequency[3,4]. The H mode critical power also presents a nonmonotonicity trend against pressure, the reason for it needs further studies in future.

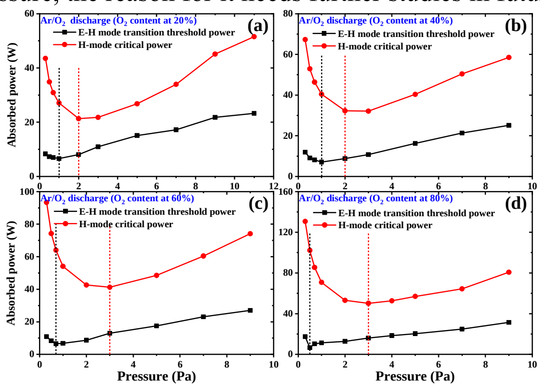

Fig. 4, the transition threshold power in absorbed power against the pressure for Ar/O_2 discharge in different O_2 content at (a) 20%, (b) 40%, (c) 60% and (d) 80%, respectively.

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