Impedans PLASMA MEASUREMENT

Evolution of electronegativity during the E to H transition in RF inductively coupled plasma using Impedans' Langmuir Probe System

INTRODUCTION

Radio Frequency (RF) excited Inductively coupled plasmas (ICPs) operating in electronegative gases experiences a mode transition from the capacitive mode (E-mode) to the inductive mode (H-mode) with the increase of the applied power. Although many investigations have been carried out in this regard, there are few measurements of the negative ions and the electronegativity during the E- to H-mode transition, especially for O_2 and O_2-containing ICPs. Therefore, in this paper, the measurements of the electron density, negative ion density and the electronegativity (measured by Impedans Langmuir probe and the photo-detachment combined with a microwave resonance probe) during the E to H mode transition are executed under different pressures and O_2 contents in continuous wave (CW) Ar/O_2 ICPs.

EXPERIMENTAL SETUP:

The schematic diagram of the experimental setup including the diagnostics is shown in figure 1. The cylindrical stainless steel chamber is grounded and a quartz window, placed at the top of the chamber, was used for the chamber seal as well as for feeding of the RF power (via two-turn planar antenna made of copper pipe). The total flow rate was fixed at 50 sccm via a mass flow controller. Experiments were performed at different RF power (20 – 350 W) and Ar/O_2 gas pressure (3 – 11 Pa) variations. An Impedans Langmuir Probe System was used to measure the electron density

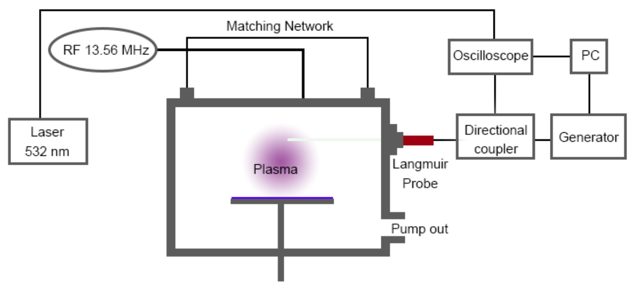

Figure 1. Schematic of the ICP experimental setup.

on the axis of the chamber 3 cm below the quartz window. The other diagnostics are also used at this location.water-cooling system. The 13.56 MHz RF power was applied via a tuneable L-type matching network.

RESULTS:

Figure 2 shows the electron density (n_e) measured by Langmuir probe as a function of the applied power under different O_2 contents when the pressure was fixed at 5 Pa. At low powers, ne is within the range of plasmas operated in the E mode. By increasing the applied power, ne increases gradually. When the applied power reaches a threshold power, n_e jumps dramatically to a higher value, suggesting that the E to H-mode transition happens. After that, the plasma is operated in the H-mode. It can also be found that as the O_2 content increases, the threshold power of the E to H mode transition monotonously increases, due to the fact that with the increase of the O_2 content, the energy consumed via the inelastic collision processes gradually increases, as a consequence, the mode transition occurs at a higher applied power.

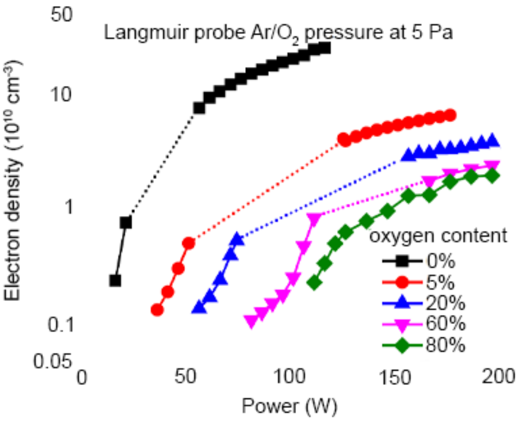

Figure 2. The n_e measured by the Langmuir probe as a function of the applied power for different O_2 contents.

Further, in this experiment, the optical probe i.e. Nd:YAG (neodymium-doped yttrium aluminium garnet; Nd:$Y_3Al_5O_{12}$) laser system was placed at the same height as the Langmuir probe (3 cm below the quartz window). Thus to make sure, that the Langmuir probe does not exhibit severe discrepancies in ne for different laser wavelengths, a comparison with plasma densities measured by the microwave resonance probe is carried out. This comparison of the electron densities at the O_2 content of 60% is shown in figure 3. Results clearly shows that the ne measured by the microwave resonance probe exhibits a good agreement with that by the Langmuir probe. As the applied power increases, the plasma density first increases gradually, and then rise abruptly to a higher value, after that, its growth slows down again. It can also be seen in figure 3 that with increasing pressure, the electron density monotonously decreases and the E- to H-mode transition threshold power gradually increases.

The electronegativity (α) of the ICP operating in Ar/O_2, is defined as the ratio of the negative ion density (n_-) to the electron density (n_e) and is given as,

$$\alpha = n_- / n_e \quad (1)$$

In this work, a laser photo-detachment technique was employed to determine the densities of the negative ions. Figure 4 shows the electron density, the negative ion density and electronegativity as a function of the applied power for different pressures at different O_2 contents of 20%, 40%, and 60%.

Figure 4 (d-f) shows that negative ion density

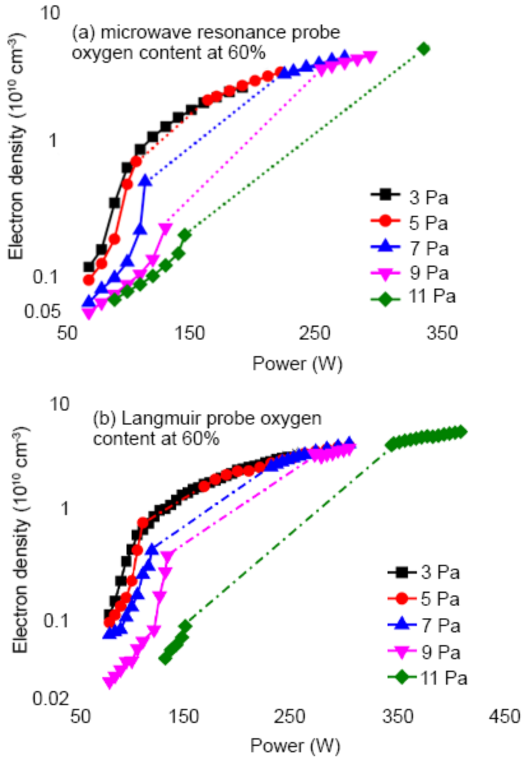

Figure 3. The electron density measured by (a) a microwave resonance probe and (b) a Langmuir probe as a function of the applied power at different pressures.

changes with the applied power in a similar fashion as the electron density figure 4 (a-c). However, as the pressure increases, the negative ion density exhibits opposite trends during the E- to H-mode transition. This is because in the E-mode the negative ion density closely depends on the electron density, whereas in the H-mode the negative ion density is primarily determined by its loss channels, i.e., their collisions with the high-energy electrons and the O atoms. Besides, as the applied power was increased, the electronegativity shows an abrupt drop during the E mode to H mode (Figure 4 (g-i)). This is attributed to the fact that in the H-mode the plasma exhibits a higher dissociation rate of the O_2 molecule due to inductive heating, which contributes significantly to the production of the negative ions.

CONCLUSION:

This work reports the evolution of the electronegativity with the applied power during the E to H mode transition in a RF-ICP in a mixture of Ar and O_2. The densities of the negative ion and the electron, as well as their ratio, i.e., the electronegativity, are measured as a function of the applied power and pressure.

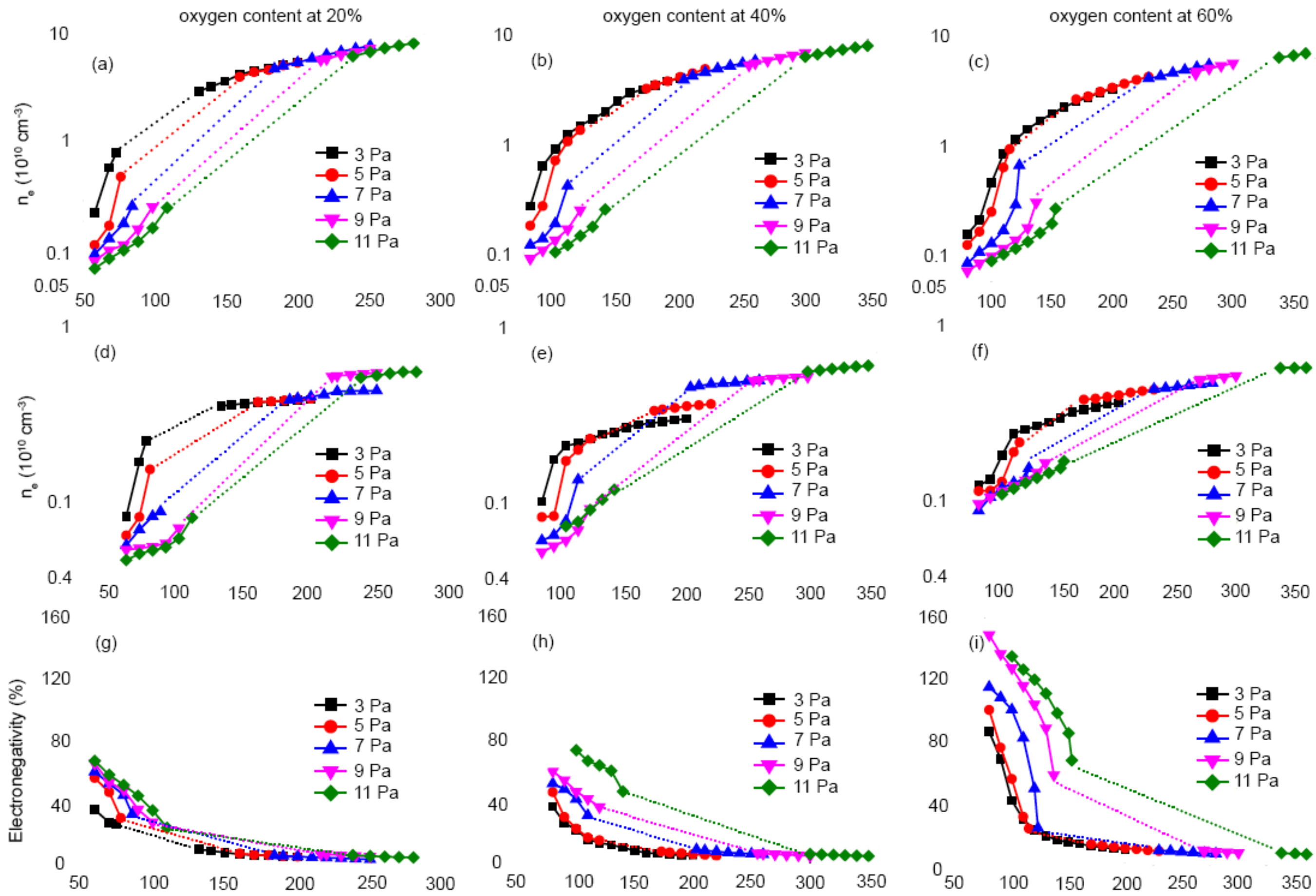

Figure 4. The electron density [(a)–(c)], the negative ion density [(d)–(f)], and electronegativity [(g)–(i)] as a function of the applied power during E- to H-mode transition at different pressures

It was found that by increasing the applied power, the electron increase abruptly at a threshold power, suggesting that the E to H mode transition occurs. With the increase of the pressure, the negative ion density presents opposite trends in the E-mode and the H-mode, which is related to the difference of the electron density and energy for the two modes. Also, as the applied power was increased, the electronegativity shows an abrupt drop during the E- to H-mode transition.

REFERENCE:

*Peng-Cheng Du et al., “Measurement of electronegativity during the E to H mode transition in a radio frequency inductively coupled Ar/O_2 plasma”.

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