Characterization of the E-H transition of an inductively coupled radio frequency oxygen plasma

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1. Introduction

The transition from the E- to the H-mode [1] of a planar inductively coupled oxygen radio frequency (RF) discharge (ICP) driven at 13.56 MHz was investigated using enhanced diagnostic methods. The mode transition leads to a change of the electrical and plasma parameter, electron heating mechanisms, and electronegativity.

2. Experimental Setup and Diagnostics

The vacuum vessel and the used diagnostics are already described in detail by Dittmann *et al.* [2] and by Küllig *et al.* [3]. The inductive electrode arrangement consist of a planar double spiral copper antenna and a quartz cylinder which separates the antenna from the vacuum and serves as dielectric barrier. The RF power is transferred through a matching network in to the center connection of the antenna by the RF power generator. The input power is varied in the range of 1 and 600 W which leads to peak-peak-values of the voltage and current of 1 and 9 kV and 1 and 50 A, respectively. The total gas pressure is in the range between 5 and 35 Pa.

For the investigation of the mode transition, the Langmuir probe measurement, the 160 GHz Gaussian beam microwave interferometry, the optical emission in the visible wavelength range and the VUV absorption spectroscopy were used. Therewith, the positive ion saturation current, the line integrated electron and metastable density ($O_2\left(a^1\Delta_g\right)$), the gas and electron temperature and the optical emission intensity of the atomic oxygen can be measured.

3. Experimental Results

The E-mode at low RF power is characterized by low positive ion saturation current and line integrated electron density at high electron temperature (6 eV). The rotational temperature which is equal to the gas temperature for these plasmas is comparable to room temperature (300 K). The spatially resolved positive ion saturation current reveals only in the E-mode a collision dominated RF sheath s with the pressure dependency of $s \propto p^{-1/3}$. Additionally, the electron heating could be determined by phase and space resolved optical emission spectroscopy. It reveals two excitation patterns in the E-mode due to the RF sheath expansion and the electric field reversal during the sheath collapse [4]. This is a sign for high electronegativity. A confirmation for the high electronegativity is the electron density peak in the early afterglow of a pulsed ICP [5]. This peak results from the collisional detachment of negative ions by metastable oxygen molecules ($O_2\left(a^1\Delta_g\right)$). The line integrated metastables density is about 2% of the ground state density in the E-mode.

By increasing the RF power, the E-H transition occurs at a critical coil voltage strongly depending on the pressure. Simultaneously, the coil voltage and the coil current decrease due to a change of the discharge impedance. At low total gas pressure, the mode transition is continuously and a hybrid mode (E/H) exists. Here, the capacitive and inductive heating mechanism are simultaneously present. For higher total gas pressure, the discharge transits stepwise from the E- to the H-mode.

The H-mode is characterized by high positive ion saturation current and line integrated electron density at lower electron temperature (3 eV). Further, the gas temperature is two times higher. The heating mechanism change into two heating phases within one RF cycle and the electric field reversal vanishes. In addition, the electronegativity is reduced. The line integrated metastables density in the H-mode increases up to 6% of the ground state density.

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References

[1] J. Hopwood 1992 *Plasma Sources Sci. Technol.* **1** pp 109
[2] K. Dittmann et al. 2012 *Plasma Sources Sci. Technol.* **21** pp 024001
[3] C. Küllig et al. 2015 *Plasma Sources Sci. Technol.* **24** pp 015027
[4] K. Dittmann et al. 2012 *Plasma Phys. Control. Fusion* **54** pp 124038
[5] A. Brockhaus et al. 2006 *Plasma Sources Sci. Technol.* **15** pp 171