Gas temperature and electron density measurements in Ar and Ar-Cl_2 ICP discharges

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We present neutral gas temperatures in Ar and Ar-Cl_2 based ICP discharge measured by diode laser absorption spectroscopy (IRLAS) and Laser Induced Fluorescence (LIF) of argon metastable atoms. Electron densities were measured using a microwave hairpin probe. Both electron densities and gas temperatures were considerably higher then those predicted by hybrid fluid modelling or simple global models. This implies that a gas heating mechanism is ignored in the models, leading to gas heating and rarification, which in turn favours higher elecron densities

Gas temperature is an important parameter for the study of discharge modeling and in plasma etching process. We deduced the temperature from the Doppler width of the 1s5→2p7 transition at 772.38nm. The line averaged temperature was determined by diode-lsaer absorption spectroscopy (IRLAS), whereas the local gas temperature at the reactor centre was determined from the laser-excited 1s4←2p7 fluorescence at 810nm (IRLIF)[1]. The plasma was produced in a cylindrical chamber (hard anodised Al, 10cm high, 55 cm diameter) excited by an external 4-turn planar spiral coil through an alumina window. The coil is excited at 13.56 MHz via an L-type match box, and terminated to ground through a 150pF capacitor to minimise the coil voltage and therefore the amount of capacitive coupling. The gas temperature was measured as a function of power (50-500W), pressure (5-90mTorr) and %Cl_2 in Ar (0-90%). In pure Ar the temperature increases with gas pressure and RF power, reaching 615K at 90mTorr 500W, whereas in 50% Cl_2 /Ar temperatures as high as 1200K were found at 50 mTorr 500W. At higher pressures /fractions of Cl_2, quenching of the Ar metastables made measurements impossible.

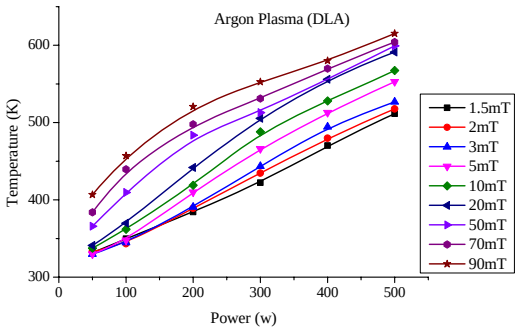

Fig. 1. Gas temperature in pure Ar as a function of gas pressure and RF power.

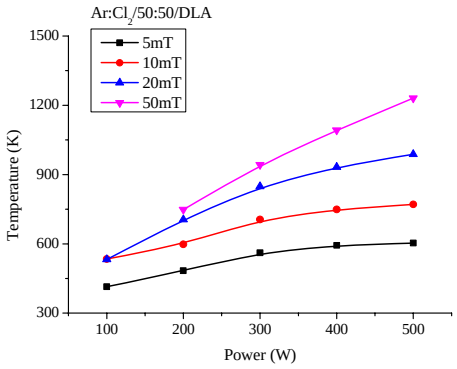

Fig. 2. Gas temperature in Ar/50% Cl_2 as a function of gas pressure and RF power.

Electron densities were measured using a microwave hairpin resonator [2]. The density at the plasma centre in pure Ar is shown in Fig. 3. The electron density increases monotonically with gas pressure and RF power. The plasma density reaches $6x10^{11}cm^{-3}$ at 20mTorr 400W. Measurements at higher pressure and power were not possible as the resonance frequency of the probe exceeded the range of our equipement. The electron density in pure Cl_2 is shown in Fig. 5. In this case the density passes through a maximum with pressure, giving a peak value of $8.5x10^{10}cm^{-3}$ at 10mTorr 500W.

The results were compared to simulations using the Hybrid Plasma Equipment Model (HPEM)[3]. In pure Ar the simulations indicated gas temperatures of around 350K, independent of gas pressure which is significantly lower than our experimental observations. The electron density was also compared with the simulation results for same range of operating conditions, and was again considerably lower in the simulation compared to the experiment. Similar discrepancies were found for the case of Ar/Cl2 plasmas, where the measured gas temperature is very high. These results are

probably related: if a gas heating mechanism is ignored or underestimated in the model, the gas density (at constant pressure) will be overestimated, leading to greater energy losses and thus lower electron densities.

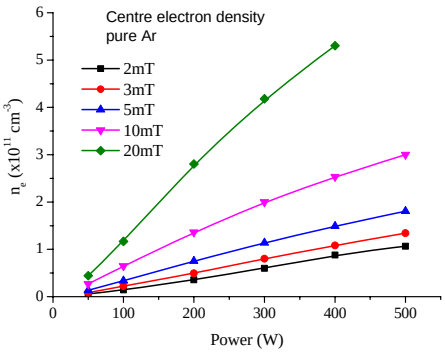

Fig. 3. Electron density in Ar plasma as a function of gas pressure and RF power.

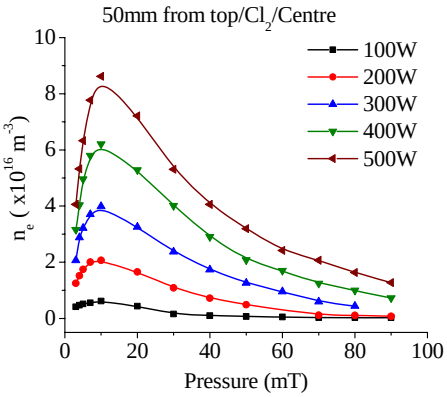

Fig. 4. Electron density in Cl_2 plasma as a function of gas pressure and RF power.

Acknowledgments

This work was partly financed by Agence Nationale de la Recherche project INCLINE (ANR-09 BLAN 0019) and by the Applied Materials University Research Partnership Program.

References

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