Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2026

Electron Temperature and Density determination of Xenon plasma using Collisional-Radiative model and Optical Emission Spectroscopy

Sakshi Patwal[a,b], Kil-Byoung Chai[a,b*]
[a]*Nuclear Physics Application Research Division, Korea Atomic Energy Research Institute, Daejeon*
[b]*University of Science and Technology, Daejeon*
spatwal@kaeri.re.kr

Keywords : low-temperature plasma, optical emission spectroscopy, collisional-radiative model

1. Introduction

Xenon (Xe) is of particular interest due to its inert nature, relatively low ionization potential, high atomic mass, and well defined emission lines. It has various applications in space propulsion [1], semiconductor fabrication using extreme ultra-violet light sources and advanced light source technologies. Accurate estimation of plasma parameters is therefore essential for the optimization of such applications. This study presents an integrated approach to investigate Collisional-Radiative (CR) [2] model based on Optical Emission Spectroscopy (OES) for measuring the Xe plasma parameters.

2. Experimental setup and CR model formulation

The Xe plasma was generated in an Inductively Coupled Plasma (ICP) source and OES data (Xe plasma spectra) was collected under various gas pressures and radio frequency (RF) powers using high-resolution (Dongwoo Optron Monora 750i) and low-resolution(Ocean Optics HR4000) spectrometers. Simultaneously, the electron temperature (T_e) and electron density (n_e) were measured by a Langmuir probe (LP).

To interpret the OES data, a self-consistent 15-level CR model was developed that incorporates excitation, deexcitation, and ionization processes with rate coefficients obtained from [3-5], along with radiative and metastable diffusion processes to solve the rate balance equations of excited atoms. In this model, radiative trapping was treated using Mewe escape factor. The complete CR matrix was solved iteratively to obtain the level populations and the plasma parameters were extracted by minimizing a logarithmic deviation between experimental and modeled emission intensities over a T_e and n_e grid.

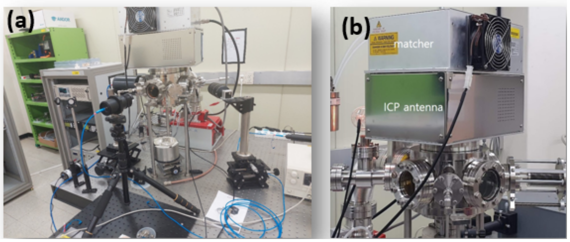

Fig. 1. (a) ICP laboratory setup and (b) impedance matcher

3. Results and Discussions

The recorded plasma spectra are shown in Figs. 2 and 3 displaying prominent transitions in near-infrared region under various power and pressure conditions. The emission intensities increases systematically with increasing RF power due to enhanced electron impact excitation at higher input powers as described in Fig. 3(b).

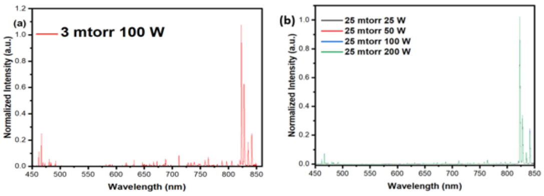

Fig. 2. (a) Emission spectra measured by HR 4000 spectrometer at RF power 100 W and pressure 3 mtorr (b) Emission spectra measured by HR 4000 spectrometer for various RF power and pressure 25 mtorr.

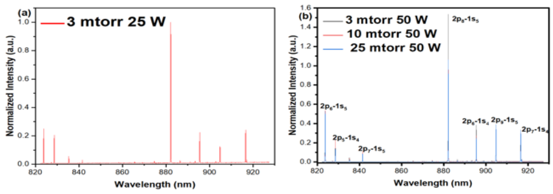

Fig. 3. (a) Emission spectra measured by Monora 750i spectrometer at RF power 25 W and pressure 3 mtorr (b) Emission spectra measured by Monora 750i spectrometer for various pressure and RF power 50 W.

LP measurements depicted in Figs. 4(a) and (b) show that the electron density increases with RF power and electron temperature decreases with increasing RF power. The measured T_e ranges between (1-3 eV) while n_e ranges between 10^{15} - 10^{17} m^{-3}.

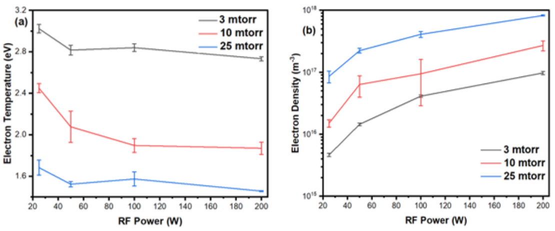

Fig. 4. (a) Variation of electron temperature with RF power and pressure 3,10,25 mtorr (b) Variation of electron density with RF power and pressure 3,10,25 mtorr.

Using the developed CR model, electron temperature and electron density were obtained by comparing simulated emission intensities with experimentally measured line intensities. The results are shown in Fig. 5. The obtained T_e values were found to lie between (1-2.8) eV while n_e ranges between (10^{17}-10^{18}) m^{-3} depending on the RF power and pressure conditions. As RF power increased, electron density exhibits increasing trend whereas electron temperature showed decreasing trend. The extracted parameters demonstrated good agreement with Langmuir probe measurements confirming the reliability of CR-OES diagnostic approach.

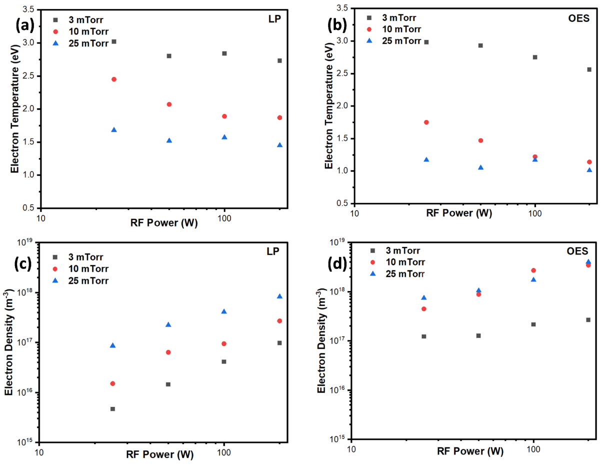

Fig. 5. Electron temperature and density determined by LP measurement (a) and (c) and OES based CR modelling in (b) and (d) for different gas pressures and RF powers.

4. Conclusions

In this work, a self-consistent CR model has been developed and validated for the determination of plasma parameters in low temperature Xe plasma over the RF power range 25-200 W and a gas pressure range of 3-25 mTorr. The electron temperature and electron density of plasma obtained by OES based CR modeling were systematically compared with LP measurements to assess the reliability of the model. The good agreement between the experimental data and the simulated spectra confirms the accuracy of extracted plasma parameters.

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