2D Spatial Mapping of the Electron Temperature, Electron Density, and Electric Field Intensity in a Microwave Argon Plasma Jet

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Abstract: Hyperspectral imaging measurements of Ar 4p-4s line emission intensities were combined with the predictions of a collisional radiative model (describing the populations of Ar 4p states) and a fluid model (describing the electron energy balance) to extract 2D spatial mappings of the electron temperature, electron density, and electric field intensity in a microwave argon plasma jet at atmospheric pressure. The approach offers high diagnostic precision and unprecedented spatial resolution, making it a valuable tool for further understanding and optimization of microwave plasma systems.

1. Introduction

Microwave Atmospheric-Pressure Plasmas (MW-APPs) are increasingly used in diverse fields of applications such as nanomaterials synthesis, surface modification, plasma conversion, and environmental remediation. Fundamental plasma parameters such as the electron temperature (T_e), electron density (n_e), and electric field intensity $\left(|\vec{E}|\right)$ govern the plasma's behavior and the resulting plasma chemistry. This study focuses on detailed characterization of these parameters within a contracted plasma jet, shedding light on complex 2D plasma gradients.

2. Methods

A microwave argon plasma jet was generated using a surfatron connected to a 2.45 GHz, solid-state microwave generator operating in continuous mode. The plasma was sustained in pure argon (1 L/min) flowing through a fused silica discharge tube with a 2 mm inner diameter, with the outlet positioned 5.6 mm from the surfatron. A recently developed hyperspectral imaging system (HSI) [1] was used to record optical emission spectra from the plasma with very spatial resolution (each pixel sees a spectrum corresponding to a 13.9 µm x 13.9 µm zone over a 16.68 × 16.68 mm^2 area). Post-processing of the hyperspectral data ensured that no spectral information from the hyperspectral imaging data is lost [1].

3. Results and Discussion

The electron temperature (Fig.1-c) was determined by comparing the measured HSI-recorded 2D mapping of the Ar 4p-4s line emission intensities with those predicted by a collisional radiative model in optically thick conditions [2] (Fig.1-a and b). The minimum relative standard error obtained at each spot in the HSI data provides the most likely value of T_e in this zone. As for the electron density (Fig.1-d), it was first calculated in relative units from the line emission intensity of a selected Ar 4p state (and the corresponding particle balance equation) and then converted to absolute values from a known plasma condition. These plasma parameters, along with others, were then used in the electron energy balance equation to determine the 2D mapping of the electric field intensity

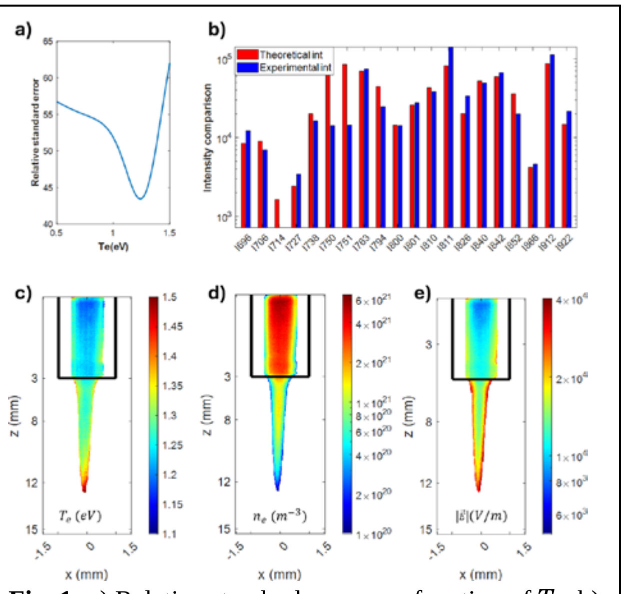

Fig. 1- a) Relative standard error as a function of T_e, b) Comparison of the optimal theoretical and experimental Ar emission line intensities, 2D mappings of c) the electron temperature, d) the electron density, and e) the electric field intensity.

(Fig.1-e). High-resolution 2D mappings of T_e and n_e show that the electron temperature peaks at the edges of the plasma jet and decreases towards the center, while the electron density is highest at the jet's core. These trends align with established behaviors of surface-wave plasmas. As for the electric field intensity, it decreases towards the plasma center, with maximum values at the edges, consistent with theoretical and experimental studies of microwave plasmas.

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References

[1] F. Khazem et al., *Rev Sci Instrum*, 2024.
[2] A. Durocher-Jean et al., *Phys Plasmas*, 2019.