Experimental platform for the study of gliding discharges: determination of plasma densities and temperatures from Ar 4p-4s transitions

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Abstract: Gliding discharges gained interest for supposed existence in nonequilbrium and equilibrium regimes. Yet, key fundamentals remain unresolved. We present an experimental platform using Bayesian analysis and high-resolution optical emission spectroscopy to determine plasma densities and temperatures from measured Ar 4p-4s line emission. The findings serve as a foundation for applications in gas conversion processes.

1. Introduction

Through preliminary investigations, it was postulated that the gliding discharge (GD) can exist in two regimes – equilibrium and non-equilibrium – and thus give rise to qualities desired in a plasma processing reactor – high powers which generate high electron densities, yet high levels of nonequilibrium and chemical selectivity. Upon their discovery, GDs were rapidly propelled into plasma chemistry applications and exhibited initial success in combustion control, chemical reformation, and surface treatment [1]. The GD is complicated to study physically – it has inherent temporal and spatial variation and is stochastic by nature, especially when operated in turbulent flow regimes and high current levels. And though the promise for an energy-efficient plasma processing reactor is there, it is still not fundamentally well understood – an essential step for further application development.

In this study, we investigate a low-current (< 0.5 A), low-flow rate (300 sccm), pulsed DC argon GD in an open-to-air configuration using a Bayesian framework coupled with optical emission spectroscopy measurements of line intensities [2] and line profiles [3] of Ar 4p-4s transitions to generate a comprehensive dataset of plasma densities and temperatures resolved spatially and temporally. We hope this platform can inform and further optimize gas conversion processes using the GD.

2. Methodology

A high-voltage, pulsed-power (9 kV, 15 μs) supply is used to ignite flowing Ar gas in the shortest electrode gap of the GD. At the same time, a DC current follower supplies a constant voltage to the copper electrodes. A 3D-printed optical fiber holder allows for optical emission spectroscopy measurements at multiple points along the discharge and electrodes. Two spectrometers are used in this study: a high-resolution (1.8 pm) spectrometer to obtain direct neutral gas temperature measurements through broadening of selected Ar lines, and a broadband spectrometer for obtaining multiple-line intensity measurements to obtain Ar 4s densities via marginal likelihhood methods. These values are then used to calculate electron temperature at each optical fiber position along the discharge path via an in-house developed collisional-radiative model.

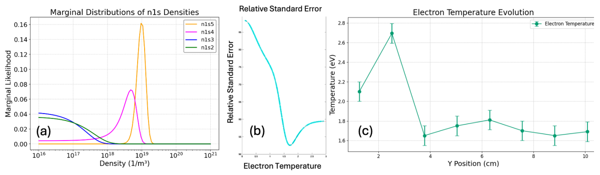

Fig. 1. (a) Marginal distributions of Ar n1s densities at a given position used to calculate electron temperature (b), where relative standard error is minimized to determine a value per position. (c) shows the evolution of electron temperature in the GD.

3. Results and Discussion

Figure 1 illustrates a sample set of marginal distributions of the Ar 4s densities at a single position, which are used to inform the collisional radiative model for calculating electron temperature. The model's sensitivity to 1s3 and 1s2 densities (Paschen notation) is limited because these densities fall within a region where the escape factor indicates optically opaque plasma, rendering the model surjective and unable to determine a precise value, only providing an upper limit. The determined densities are used to calculate electron temperature. The evolution of the electron temperature in the GD is shown, indicating a plasma that exhibits energy transport phenomena in the early stages, where temperatures appear to change drastically before plateauing.

4. Conclusion

A fundamental study of the GD enables the determination of spatially- and temporally-resolved plasma densities and temperatures. Understanding its evolution requires a thorough investigation of energy transport within the GD, which is crucial for its effective application in gas conversion processes. We hope this platform can provide a framework for reactive gas GD experiments.

References

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