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Spectroscopic Measurement of Atmospheric-pressure Non-equilibrium Ar Plasma Based on Line Spectra under Constraints of Undetected Level Densities

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Atmospheric-pressure non-equilibrium plasmas (APNEPs) are attracting attention for biomedical, agricultural, and surface-processing applications. Optical emission spectroscopy (OES) combined with collisional-radiative model (CRM) provides a non-intrusive method to the electron energy distribution function (EEDF). Not only line spectra but continuum spectra provide electron density and EEDF, however wide wavelength range and high SNR are required. Therefore, for convenience, to improve accuracy of APNEP diagnostics only with line spectra and CRM, we recently introduced a penalty term for undetected line intensities to stabilize the inversion from level densities to the EEDF [1]. Therefore the objective function to minimize is

$$f(\alpha, \boldsymbol{T}_\mathbf{e}, \boldsymbol{n}_\mathbf{e}, \boldsymbol{\gamma}) = \mathrm{MSLE}(\boldsymbol{T}_\mathbf{e}, \boldsymbol{n}_\mathbf{e}, \boldsymbol{\gamma}) + \alpha \mathrm{PEN}(\boldsymbol{T}_\mathbf{e}, \boldsymbol{n}_\mathbf{e}, \boldsymbol{\gamma}).$$

In this work, we extend the diagnostics to an atmospheric-pressure plasma jet (APPJ) operated in argon in addition to the previously studied sealed dielectric-barrier discharge (DBD) reactor. The jet expands into ambient air and therefore offers a stringent test for the robustness of the technique. In the previous report, we pointed out that the larger the penalty coefficient, the closer the solution is to one conducted from continuum spectra[2], therefore it is possible to solve as constrained optimization instead of penalty coefficient. However, the CRM solver had been misconfigured last time, then the corrected analysis was performed again, it was found that too high penalty coefficients lead to too high electron temperatures (over 1.2 eV).

For the DBD (input voltage 2.7–8.1 kV) we obtain $T_\mathrm{e} = 0.77 - 0.97$ eV and $n_\mathrm{e} = (1.2 - 2.0) \times 10^{13}$ cm^{-3}. For the APPJ (power 0.4–1.2 W) we find $T_\mathrm{e} = 0.72 - 0.88$ eV and $n_\mathrm{e} = (0.9 - 1.5) \times 10^{13}$ cm^{-3}. The dependence of α is smooth for both devices, confirming that the information contained in undetected lines efficiently regularizes the fit.

These results show that the line-spectrum-based method, strengthened by undetected-level constraints, is transferable between closed and open Ar plasma geometries. The combined use of line and continuum spectra is expected to further constrain the high-energy tail of the EEDF in future work.

References:

[1] W. Kikuchi, *et al.* Proceedings of 50th EPS Conference on Plasma Physics, EPS, (2024)
[2] Wataru Kikuchi, *et al.*, J. Phys. D: Appl. Phys., IOP Publishing, **57**, 33, 335202, (2024)

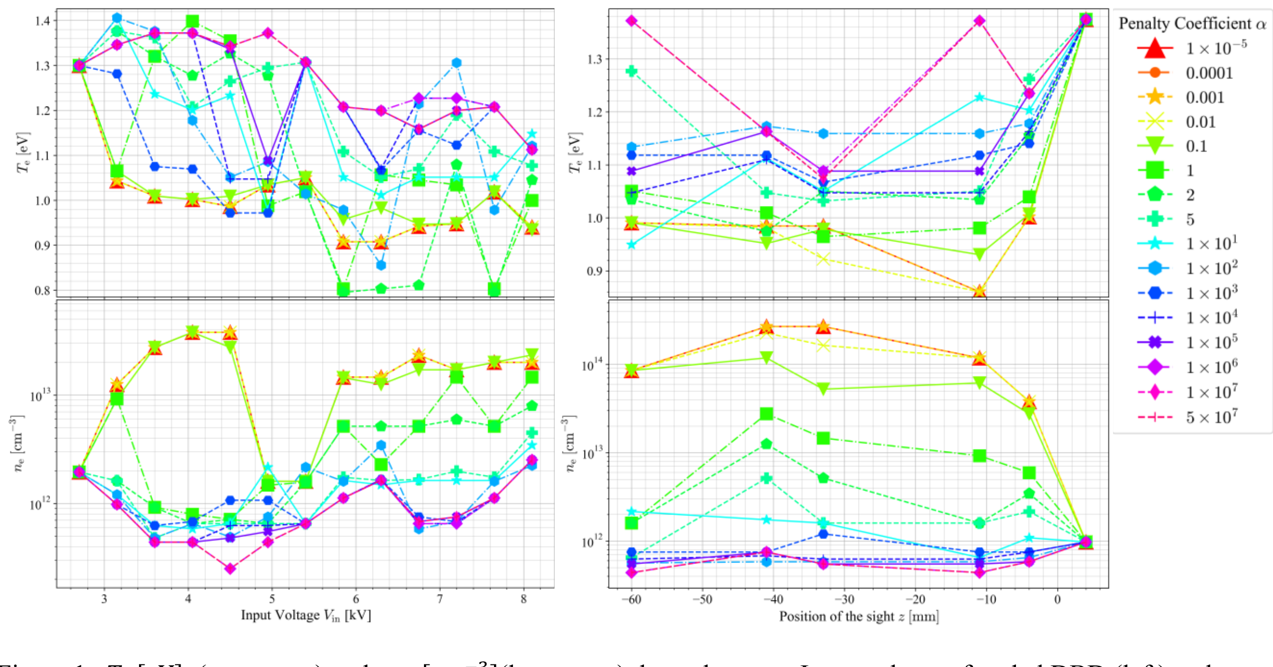

Figure 1. T_e [eV] (upper row) and n_e [cm^{-3}](lower row) dependency on Input voltage of sealed DBD (left) and on Position of the sight of APPJ (right). They share the same legend. n_e decreased in order to maintain penalty minimum as penalty coefficient α increased, on the other hand, T_e increased for compensation of decreased n_e to minimize the objective function. This tendency was confirmed despite Input Voltage on sealed DBD or Position of sight on APPJ.