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Experimental–Numerical Characterization of Cold Atmospheric Pressure Plasma Jet for Biomedical Applications Using Moiré Deflectometry

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ABSTRACT

Introduction: Cold atmospheric pressure plasma jets (CAPJs) have shown significant potential for biomedical applications due to their non-thermal nature and high production of reactive species. In this study, we assessed the experimental-numerical characterization of CAPJs for using in biomedicine using Moiré deflectometry.

Materials and Methods: The electron density and refractive index distributions measured in the original Moiré deflectometry experiment were used as input data. A numerical model was implemented in MATLAB to reconstruct the continuous axial profiles $n_e(z)$and $\Delta n(z)$ based on exponential fitting of the experimental points. The plasma was generated using a helium jet at atmospheric pressure, with an inner quartz tube of 1 mm diameter and a central stainless-steel electrode of 0.3 mm diameter. The applied voltage and gas flow rate were 5 kV-10.2 kV (18 kHz AC) and 0.5-2 L/min, respectively. Refractive index variation was calculated using the empirical relation is, $n-1=C_1\, p/kT-C_2\, N_e$, where $C_2=1.9292\times10^{-8}$ (cm^3). The medically relevant parameters—plume length (for $n_e\geq10^{18}$ ' ' m^{-3})) and the RONS-proxy (integral of $n_e(z)$)—were then derived from the reconstructed profiles.

Results and Discussion: The numerical reconstruction successfully reproduced the experimental Moiré results, showing an exponential decay of $n_e$along the plasma axis. At 10.2 kV and 2 L/min, the maximum $n_e$near the nozzle was 3.1×10^{19} ' ' m^{-3}, decreasing to 1.3×10^{19} ' ' m^{-3}at 16 mm. The effective plume length, defined as the distance where $n_e\geq10^{18}$ ' ' m^{-3}, was about 5.6 mm for high-power mode and 3.2 mm for low-power mode. The change in refractive index (Δn) derived from the Moiré analysis exhibited values of the order of 10^{-6}, confirming the optical sensitivity of the plasma region close to the nozzle. From a biomedical perspective, the obtained electron density range (10^{18}–10^{19} m^{-3}) is sufficient to produce reactive oxygen and nitrogen species (RONS) while maintaining gas temperatures below 50°C—safe for biological tissue exposure. Hence, the helium plasma jet characterized in the original experiment can be directly utilized for plasma medicine applications such as surface sterilization, cell stimulation, and wound treatment.

Conclusion: The combination of Moiré deflectometry and numerical reconstruction provides a powerful approach to link plasma diagnostics with biomedical functionality. The reconstructed axial profiles reveal that the plasma jet operates within the safe and effective range for biological applications. The model also offers a predictive tool to optimize voltage and gas flow parameters for future plasma medicine studies.

Keywords: Biomedical application, Cold atmospheric plasma, Electron density, Moiré deflectometry, Refractive index

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