7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Spatio-temporal behavior of electric field fluctuations in a cold microplasma jet: modeling and experiments

Deepika Behmani and Sudeep Bhattacharjee
Department of physics, Indian Institute of Technology, Kanpur, Uttar Pradesh: 208016, India
e-mail (speaker): deepika@iitk.ac.in

Atmospheric pressure plasmas jets (APPJ) have been studied intensively because of their potential use in a wide variety of applications ranging from material processing to biomedical. They have drawn significant attention, primarily due to presence of reactive oxygen and nitrogen species (RONS) and capability to transport these species to remote locations for localized surface treatment, particularly in case of biological matter [1]. The concentration of RONS i.e., plasma dosage plays a crucial role in surface treatment, therefore any factor which influences the RONS concentrations needs to be investigated. Recently, it has been reported that the experimentally obtained time scale (~0.1-1 ms) of plasma potential fluctuations [2] matches with the time scale (~0.5-1 ms) of RONS evolution [3]. Therefore, the fluctuations can affect the RONS generation and their spatio-temporal evolution. Keeping the criticality of the RONS in mind, a detailed theoretical and experimental study has been carried out, to understand the fluctuating behavior of plasma jet and its effect on RONS.

Helium plasma jet having a ring-to-ring electrode configuration has been used in this work [2]. The plasma is created inside a tapered quartz capillary tube. After ignition, the plasma comes out from the orifice of the capillary as a fine jet of diameter ~0.8-0.9 mm, as shown in Fig.1 (a). A double-pin probe has been used to estimate the electric field fluctuation and a spatial mapping of the fluctuations has been done experimentally along the axial and poloidal direction of the plasma jet.

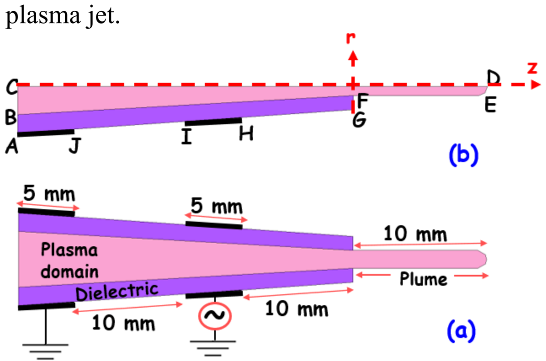

Fig.1 Schematic diagram of (a) experimental set up and (b) computational domain of atmospheric pressure plasma jet

A two-dimensional, axisymmetric, plasma dynamics model has been developed for the aforementioned experimental configuration. The computational domain of the model with a description of boundaries is presented in Fig. 1 (b). In this, negatively charged (e^-), positively charged (He^+, He_2^+, N_2^+), and neutral (He*) species are considered. The model solves the Poisson equation (Eq. (1)), continuity equation (Eq. (2)) for all species and electron energy transport equation (Eq. (3)) using finite difference method (FDM). The governing equations are given below,

$$\nabla^2\varphi = -\frac{e\,(n_p-n_e)}{\varepsilon_0} \quad (1)$$

$$\frac{\partial n_{p,e}}{\partial t} + \nabla.\,\Gamma_{p,e} = S_{p,e} \quad (2)$$

$$\frac{\partial (n_\epsilon)}{\partial t} + \nabla.\Gamma_\epsilon = -e\Gamma_e.E - S'_{el.} - S'_{inel.} \quad (3)$$

Here, φ is potential, n is number density, Γ is the flux and S is the source term. The subscript p, e and ϵ stand for the positively charged species, electron and energy, respectively. Three terms on the right-hand side of Eq. (3) represents the Joule heating, elastic and inelastic collisional energy exchange. Eq. (2) and Eq. (3) are constrained by zero gradient condition at all the boundaries of plasma zone except the plasma-dielectric intersection wall (***FB***) (cf. Fig. 1 (b)), where solid surface flux condition is applied. Poisson equation is solved by considering $V = 0$ and $V = V_{App}$ (applied voltage) condition at electrode boundaries ***JA*** and ***HI***, respectively. Furthermore, the charge accumulations condition has been imposed at solid wall ***FB***, rest of the boundaries are treated with zero gradient condition. This model will provide the spatio-temporal profile of plasma potential, and from this, the electric field fluctuation has been aimed at being estimated theoretically to verify already obtained experimental results. Fig.2 shows the experimentally obtained degree of fluctuation in E_Z component of electric field, defined as E_{zm}/<E_Z>. The degree of fluctuations tends to increase axially downward from the orifice of capillary tube under all the flow regime (1 l/min, 2.5 l/min and 5 l/min). Similar trend is expected from the theoretical model under development.

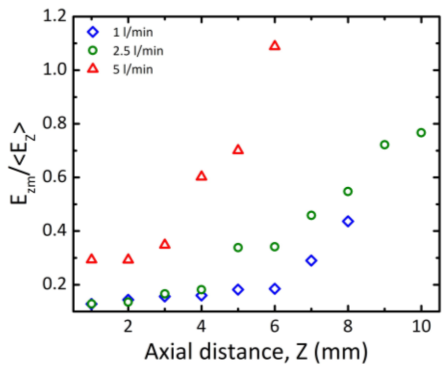

Fig.2 Axial variation of degree of fluctuation in E_Z component of electric field under different flow regimes

References

[1] L. Lin and M. Keidar, Appl. Phys. Rev. **8** 011306 (2021)
[2] D. Behmani, K. Barman, and S. Bhattacharjee AIP Adv. **11** 085128 (2021)
[3] W. V. Gaens and A. Bogaerts Journal of Physics D: Applied Physics **46** 275201 (2013)