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Characterization of electric field fluctuations and turbulence under different flow modes in a cold micro-plasma jet

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Atmospheric pressure plasma jets (APPJs) have gained significant interest due to their wide variety of applications such as surface modification, environmental, food industry, agriculture, microelectronics, biomedicine, and cancer cell or tumor treatment [1]. These plasmas are non-equilibrium in nature due to widely different electron ($T_e \sim 0.5 - 1$ eV) and ion ($T_i \sim 0.025$ eV) temperature [2]. The low gas temperature of the plasma jet provides a conducive environment for treatment of heat sensitive material and biological matters [1]. Additionally, as these are produced in atmospheric conditions, hence have a rich gaseous chemistry through interactions with ambient air and contain reactive oxygen and nitrogen species (RONS).

The RONS concentration is one of the key components for the treatment of biological samples, as it determines the plasma dosage. The potential or electric field fluctuation in the plasma jet can affect the RONS concentration, as the time scale of these fluctuations (~0.1-1 ms) [3-5] closely agrees with the time scale of RONS production (~0.5-1 ms) [6]. Moreover, flow-induced turbulence in the plasma jet can disrupt energy and particle distribution, hence can alter the RONS concentration. We, therefore, investigated the electric field fluctuation both in E_z and E_φ components along the axial and poloidal direction of the jet under different flow conditions. Furthermore, the flow of the helium plasma jet has been visualized by Schlieren imaging setup to distinguish the laminar, transition, and turbulent regime along the axial direction of the plasma jet. Fig.1 (a) and (b) show the Schlieren images of the plasma jet at three different flow rates along with their Reynold number (R_e): 1 lpm (R_e: 237), 2.5 lpm (R_e:593), and 5 lpm (R_e:1185), and variation of laminar length (*l/d*) of the jet with gas flow rates (0.5 – 5 lpm), both in plasma OFF and plasma ON condition, respectively. The laminar length is found to be comparatively larger in plasma OFF condition, as the plasma ignition introduces the electrohydrodynamic force and gas heating factors, which can cause early onset of turbulence and reduction in *l/d*. In Plasma OFF condition, the laminar length tends to increase initially, and then starts to decrease with increase in gas flow rate. Whereas, in Plasma ON condition, it decreases right from a flow rate of 0.5 lpm. Fig. 1(c) shows the peak amplitude of E_φ electric fluctuations along axial and poloidal locations of the jet, at three different flow rates (1, 2.5 and 5 lpm). An enhanced level of fluctuation has been seen at a higher R_e, especially at 1185 where the jet fully transits to turbulent mode. Also under all flow conditions, the fluctuations tend to increase along the jet axis, downward from the orifice of the capillary due to laminar to turbulent transition. We, therefore, anticipate that the flow-induced turbulence can be linked to the enhanced level of fluctuations which affect the RONS concentration. In my talk, I'll give a comprehensive overview of the nature of fluctuations and turbulence in APPJ.

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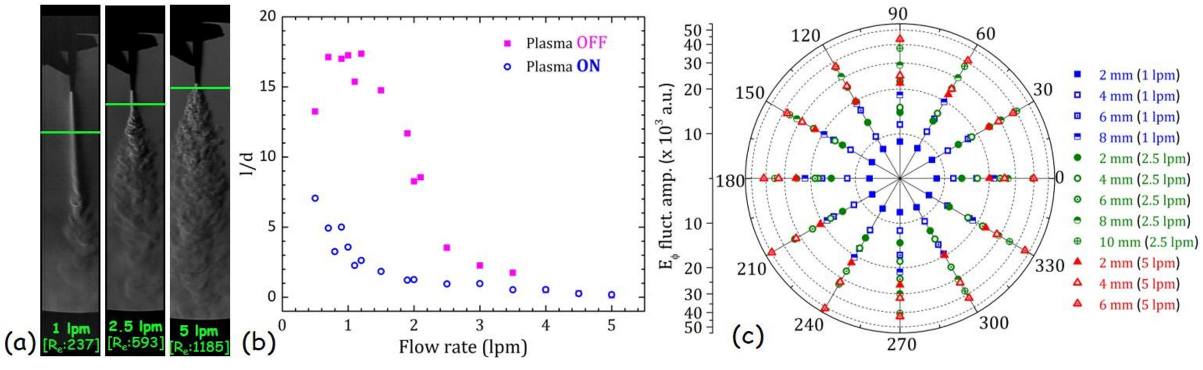

Fig.1 (a) Schlieren image of the helium plasma jet, (b) laminar length in plasma OFF and plasma ON condition, and (c) peak amplitude of E_φ electric field fluctuations along axial and poloidal direction of the jet, under varying flow conditions.