# Plasma potential fluctuations and strong magnetic field effects on cold atmospheric pressure micro-plasma jets

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Cold atmospheric pressure micro-plasmas, are non equilibrium plasmas with widely different electron (~6000 K) and ion temperatures (~300 K) [1]. Unlike low pressure plasmas, which require expensive vacuum systems for plasma generation, and magnetic field for confinement, these plasmas can be produced rather inexpensively in the atmosphere. Consequently, these plasmas possess high electron densities ~$10^{19}$ $m^{-3}$, and the typical plasma frequency lies in the GHz range and the Debye length is in ~ µm. The coupling parameter which dictates the ratio between the mean Coulomb interaction energy to kinetic energy is relatively large (~ $10^{-2}$), as compared to conventional low-pressure plasmas (~ $10^{-4}$). Besides, the interaction of the charged particles with the ambient air, gives rise to a rich gaseous chemistry leading to the formation of reactive oxygen and nitrogen species (RONS) such as OH, $HO_2$, $H_2O_2$, including NO and $N_2O_5$ and radiation such as UV photons [2]. Moreover, the lower gas temperatures provide a conducive environment for interaction with biological cells and tissues. The RONS are critical for many biomedical applications such as sterilization [3], blood coagulation [4], faster healing of wounds [5], and in cancer therapy [6,7,8]. A recent work showed that APPJ interaction with a target depends upon target surface conductivity and permittivity that decides effective surface irradiation area [9].

An atmospheric pressure micro-plasma jet (APPJ) is the most commonly used device for such application. However, without proper understanding of APPJ physics, it is impossible to optimize the plasma for every application requirement. Currently, most of the efforts are based upon hit and trial. For example, an important problem is to determine the dependance of RONS production on experimental parameters such as applied voltage, discharge waveform and gas flow rates. Another important aspect is the plasma potential fluctuations which can lead to particle and energy transport, and thereby affect RONS and radiation generation. In this work we investigate plasma potential fluctuations and the effect of a transverse magnetic field in an atmospheric pressure micro-plasma jet, where strong field effects are expected. A future aim would be to look at the effect of potential fluctuations and magnetic field on RONS and radiation generation.

In experiments where control parameters such as the applied voltage, gas flow rate or gas mixing ratio are varied, plasma floating potential fluctuations grow in the APPJ and attain enhanced levels at certain magnitudes of these parameters, before decreasing. Such fluctuations are expected to influence the electron energy distribution function and the different plasma process rates. When the applied voltage is varied at a fixed gas flow rate of 1 l/m, the fluctuations reached a maximum at ~11 kV, and thereafter decrease at further higher voltages. The maximum fluctuation levels are associated with intense ionization taking place in the jet. When the gas flow rate is increased at a fixed applied voltage (14 kV), the fluctuations get enhanced for flow rates beyond 2 l/min, due to transition to turbulent flow occurring at a buoyancy induced Reynolds number of ~474. In case of gas mixing (Ar and He), increase in the concentration of Ar and reduction of He at a fixed applied power (80.6 W) and flow rate (1 l/min), give rise to higher level of fluctuations, this is considered to be due to lower thermal conductivity and ionization potential of Ar leading to gas heating, and ponderomotive force giving rise to filamentation. We are currently investigating the mechanisms of these higher levels of fluctuations, and also looking at the spatial asymmetry and fluctuations in electric field in the APPJ.

Strong magnetic fields (≥ 0.4 T) can significantly affect the physics of the plasma jets and reaction mechanisms. It is found to give rise to Zeeman splitting of the emission lines leading to further broadening, which may influence the plasma density determined from Stark broadening. Strong magnetic fields can lead to intense interactions in the APPJ, as the plasma gets magnetized. The collisionally broadened ion cyclotron resonance (ICR) is expected, when the applied frequency becomes equal to the cyclotron frequency of ionic species of RONS such as $OH^-$, $N_2^+$ in the discharge. It is found that ICR may lead to decrease in the emission intensity of important emission lines e.g. $N_2^+$ (391.4 nm) and OH (308 nm) radicals.

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