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Plasma potential fluctuations in cold micro-plasma jets : interactive surface feedback effects on reactive species generation

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Cold atmospheric pressure micro-plasmas, are non-equilibrium plasmas with widely different electron (T_e ~ 6000 K) and ion temperatures (T_i ~ 300 K). Unlike conventional low-pressure plasmas, these plasmas do not require expensive vacuum and magnetic systems for generation and confinement, and can be produced rather inexpensively in the ambient environment. The direct 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, NO, N_2O_5 and radiation such as UV photons [1]. The RONS play a critical role in biomedical applications such as sterilization, blood coagulation, wound healing, and cancer therapy [2]. Moreover, the lower gas temperatures of these plasmas provide a conducive environment for the treatment of biological cells. In our recent work, it has been found that the fluctuations in plasma floating potential (FP) lie in the frequency range from 0.5 to 9 kHz, and depend upon experimental operating parameters [3]. The time scale of the observed fluctuation frequencies (~ 0.1 – 1 ms) corresponds to the typical time scales of RONS evolution: 0.5 – 1 ms in RF [4] and ~1 ns – 100 µs in pulsed jets [5]. Hence, fluctuations can influence RONS development, and affect particle and energy transport.

A schematic of the experimental setup is shown in figure 1. A ring-to-ring electrode configuration is employed for generating the helium plasma jet by applying a sinusoidal waveform of amplitude 11 kV (pp) and frequency of 10 kHz [3]. After ignition, the plasma emerges out of the orifice of the capillary tube as a fine jet of diameter ~ 0.9 mm. The plasma plume is diagnosed by a single-pin probe, whose signal (voltage or current) is fed to the input of a lock in amplifier for FP and current measurements, using a Keithley multimeter. A TTL output of the applied voltage signal and the signal of the internal oscillator of the lock in amplifier have been used as reference signals.

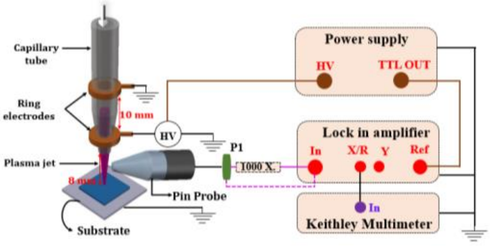

Figure 1 Schematic diagram of experimental setup to measure fluctuations in the jet interacting with the substrates

In this work, the fluctuations are investigated for a jet interacting with substrates of varying permittivity such as copper, p-type silicon, quartz, Teflon, and goat skin. Beside FFT analysis, the amplitude of FP through frequency locked measurements has been estimated in the frequency range from 0.5 to 9 kHz. Figure 2 shows the amplitude of FP as a function of frequency. The inset shows the potential captured by the probe pin without any plasma which is considerably lower (approx. 5 order), implying that the lower frequencies arise after plasma ignition. The peak amplitude of FP lies at around 1 kHz and comparatively higher for low permittivity samples such as goatskin, quartz, and teflon. The intensity of typical RONS (OH and N_2^+) lines, especially OH, drastically drops to about 98 % for quartz and teflon from its maximum value (in case of copper), possibly due to higher level of fluctuations. The results of the frequency locked measurements are compared with the peak value of the fluctuation frequencies determined from the FFT. The plasma potential and plasma current locked at driving frequency (10 kHz) have also been looked into, as a function of applied voltage, to understand the effect of sample's permittivity on the ignition voltage of plasma.

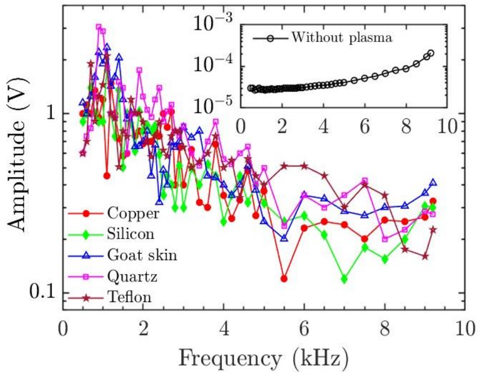

Figure 2 Floating potential as function of frequency in case of different samples, near the sample's surface. The inset shows the potential captured by pin probe without plasma

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