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Spectroscopic investigation of the plasma jet interaction with water

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Abstract. In this paper, the emission spectra from plasma jet-water interaction is investigated. The plasma system consists of a quartz tube which is surrounded by two copper strips separated by 14 mm, the upper stripe is connected to AC high voltage power supply and the lower is grounded. A quartz-cuvette containing the water sample is placed at 13 mm down to the tube nozzle. Emission spectra from three regions; the distance between the two electrodes (A), the distance between the grounded electrode and the sample surface (B), and through the sample (C), are investigated. The results show clear differences between the spectra emitted from the three regions. Region A emits the highest intensities for the line spectra and argon 763 nm was the maximum. As well as, O radical emission spectra were detected with the highest intensities in region B. However, new bands and lines appear in the spectra from region C, due to interaction of the jet with water, depending on the water conditions and plasma operating parameters. These results declare that plasma jet interaction with water can be used as indicator for water quality and a detector for which species play the rule in plasma sterilization too.

1. Introduction

Atmospheric pressure plasma jets have a considerable high interest form researchers due to its wide variety of biomedical and industrial applications. Plasma jet has a high potential to be used in sterilization, blood coagulation, teeth bleaching, skin treatment, water purification, and surface modifications [1,2]. The plasma jet applications cover a wide range of dimensions from micro-scales “for a precise treatments” up to large-scale objects. Moreover, plasma jet is accessible to be used for treating trenches and grooves. Recently many researchers generated plasma jets by different means and configurations such as microhollow cathode, gliding, and dielectric barriers discharge.

Emission spectroscopy is a powerful technique to diagnose the generated species in the atmospheric pressure plasma jet. Moreover, it gives the thermodynamic conditions of the generated plasma through the measurements of the plasma species temperatures (i.e. gas, rotational, vibrational, and electron temperatures) [3,4].

In gas discharge electrons are gaining their energies from external electric filed and transfer it to the surrounding plasma species in elastic and inelastic collisions. These collisions produce the ionization, excitation, to atoms and molecules. Moreover, the electron collisions could also produce reactive species such as NOx, OH, O, and N^+ which play an important role in plasma applications practically in medicine and industry.

2. Experimental set up

The argon atmospheric pressure plasma system consists of a quartz tube which is surrounded by two identical copper strips at 31 mm and 10 mm from tube nozzle. The copper strips have 7 mm width. The upper strip is connected to a high voltage sinusoidal AC power supply while the lower is grounded, as illustrated in figure 1. A quartz cuvette containing the water sample is placed at 13 mm below the plasma jet tube nozzle. The jet is generated when 14.5 kV and 25 kHz is applied to the upper stripe at 5 SLPM argon flow. The generated plasma voltage and current waveforms are recorded using person current probe (model 6585) and high voltage probe (Tektronix P6015) with 1 Gs/s Tektronix oscilloscope (model DPO 4104B). A compact LD spectrometer system is used to record the plasma emission spectra. In this experiment, the emission spectra from three regions are investigated. The regions are: (A) the space between the two electrodes in the quartz tube, (B) the distance between the grounded electrode and the water surface, and (C) through the water in the cuvette. Optical fiber bundle is placed at 11 mm from the plasma coulomb center and used to collect the emission spectra. A CCD camera is used to capture plasma images to study plasma formation as shown in figure 1 for the jet.

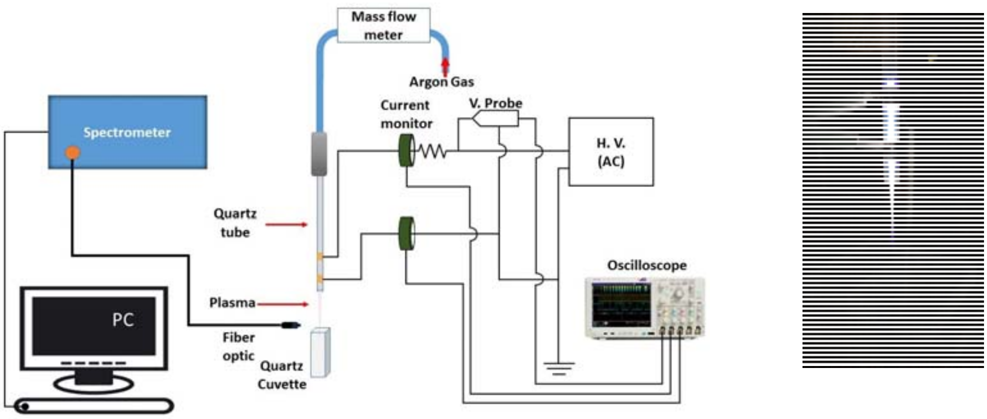

Figure 1. Experimental set up of the atmospheric pressure argon plasma jet with an image for the jet on the right side.

3. Results and discussion

3.1 Current –Voltage Waveforms

The current and voltage waveforms for the investigated plasma jet with and without discharge are shown in figure 2. An average of 16 times is used to collect the wave forms. The peak to peak voltage is 14 kV and the operating frequency is 25 kHz at 5 SLPM argon flow rate. The results show about π/2 phase difference between the current and the voltage waveforms before plasma ignition. This indicates that plasma jet system has a capacitive impedance, which means the voltage waveform lags behind the current waveform by π/2. Once the plasma is ignited the current-voltage phase difference reduces and the current waveform increased and get deformed. At breakdown, the voltage peak-to-peak value get reduced from the ignition voltage 14.5 kV to 11.7 kV at 25 kHz applied frequency. When the jet ignites an additional nonlinear load is employed to the plasma electric circuit. The plasma jet current waveforms presents a single sharp pulse per each half cycle which indicates the formation of a homogenous plasma between the two electrodes inside the quartz tube.

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However, a current waveforms show repels over it which means streamers or filament discharges are formed too. The plasma jet length has been found to depend on the applied voltage and argon gas flow rate. When the plasma jet is imaged on a nanosecond time scale, it appears to be consisted of transient series of plasma pulses which is called plasma bullets [5].

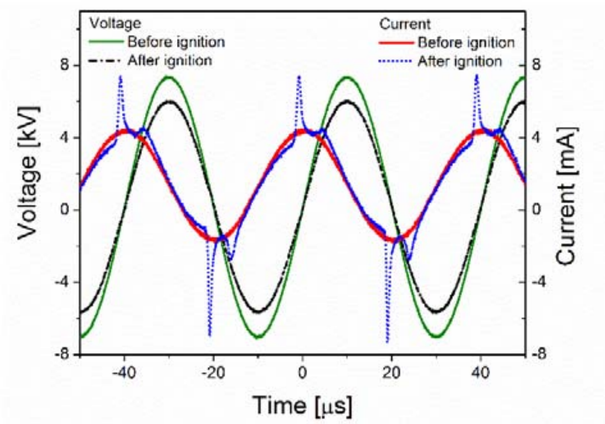

Figure 2. Current-voltage waveforms of atmospheric pressure plasma jet before and after ignition.

3.2 Plasma jet emission spectra

The emission spectra from the three investigated regions are presented in figure 3(a) and (b). The spectra from the three regions show that the neutral argon is the dominated lines from 690 to 1000 nm. The 763.51 nm line that is due to the transition $3s^23p^5(^2p^0_{3/2})4s \rightarrow 3s^23p^5(^2p^0_{3/2})4p$ has the highest intensity in three investigated regions. The O radical lines at 777.41 nm and 844.63 nm are detected in the emission spectra in the three regions with highest intensities in region B. The lines and bands (357.6, 375, 380, 405.5, 436 and 546 nm) are observed in the plasma water interaction in region C, figure 3(b).

Generally, the line spectra in region A have the highest intensities while it have the lowest in region B. The emission spectra from the water plasma jet interaction, region C, is higher than that from region B. Plasma in region A emits the highest line spectra due to the high energy transfer from the electrons, which gain their energies from the external electric field, to ambient gas in an inelastic collision process. However, plasma in region B has no external field and thus their emission spectra is minimum. Moreover, in region C the water works as a floating electrode. Therefore, a gradient potential is formed that accelerates the charged particles that increases the lines emission spectra compared with plasma in region B[6].

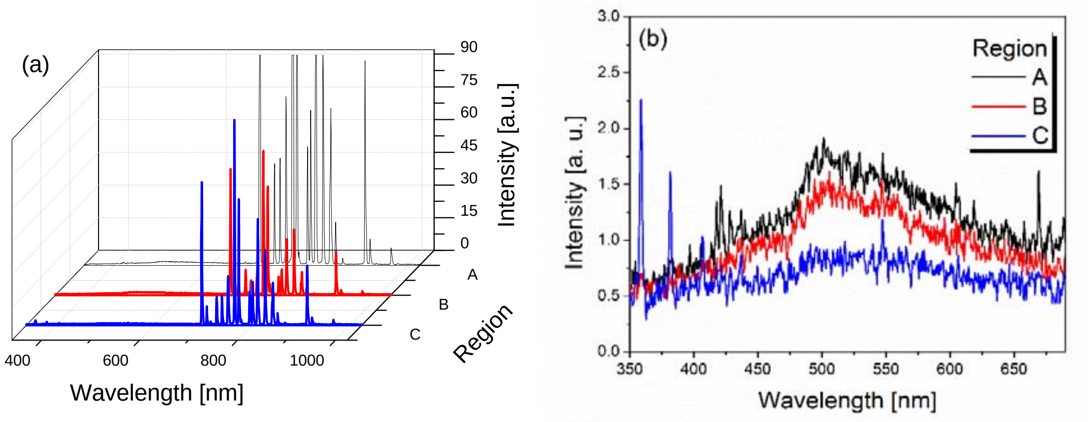

Figure 3. Plasma jet emission spectra in the range: (a) 350 to1000 nm and (b) 350 to 680 nm.

4. Conclusion

In this work, argon atmospheric pressure plasma jet interacting with water is investigated. The jet is operated at 14 kV AC sinusoidal high voltage, 25 kHz frequency and 5 SLPM argon flow rate which are optimal conditions to generate the longest jet with the lower applied voltage. The current waveform declares the generation of diffused and filamentary modes of plasma. The emission spectra show the presence of O radical which plays a very important role in plasma applications in medicine. The water sample plays as a floating electrode and new species are generated due to plasma water interaction. These new species are confirmed by the appearance of new lines and bands in the spectra from plasma interaction with water. Therefore, the plasma jet water interaction can be used as a probe for water quality.

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