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RESEARCHARTICLE

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EFFECT OF FLOATING ELECTRODE ON THE LENGTH OF THE CAPACITIVELY COUPLED ATMOSPHERIC PRESSURE PLASMA JET

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ABSTRACT

Atmospheric Pressure Plasma Jet (APPJ) has got a lot of attention in recent year due to its possible application in material processing, surface modification, biomedical material processing and thin film deposition. This paper reports the use of floating electrode for enhancement of APPJ jet length in Argon environment. Floating electrode is found to decrease the applied voltage needed to sustain plasma jet thereby increasing the jet length. It is observed that there is significant increase in jet length with increase in applied voltage and decrease in distance between floating electrode and jet nozzle. The best distance between nozzle and floating electrode is found to be 0.5 cm. The optical characterization along with the study of polymers treated with plasma jet is also discussed. The treatment of polymer along with floating electrode shows the application of plasma jet produced using floating electrode.

Keywords: plasma jet, atmospheric pressure, jet length, floating electrode

1. INTRODUCTION

After the first description of plasma as a "radiant matter" by William Crookes, numerous researches have been carried out in plasma science [1]. Many researchers are attracted towards plasma research due to its wide range of applications in materials processing and medicine. Being atmospheric pressure cold plasma, plasma jet has wide range of application in medicine as well as treatment of polymers. It is also reported that, APPJ has been used for the deposition of thin films like (SiO_2, TiO_2, etc.) [2] - [5].

Due to its wide range of application, optimization of system for production of plasma jet has become of keen interest in research. Many works have already been carried out for enhancement of jet length. Hamid *et. al.* studied the effect of flow rate and diameter of tube for enhancement of jet length [6]. Enhancement of jet length in Helium plasma has been reported by Xionget. *al.* [7]. Similarly, Georgescureported the effect of applied voltage on length of jet [8]. The work done by Hu *et. al.*showed significant improvement in jet length using floating electrode. The research work reported in this paper is similar, however the position of floating electrode is different [9].

This paper deals with the enhancement of jet length using floating electrode parallel to the jet length. The research work reported in this paper is different from previous works on the basis of arrangement of floating electrode and plasma generation system. The advantage of using floating electrode is that it will significantly reduce the applied voltage and gas flow rate. Similarly, the works done by Tyataet. *al.* and Hoffman *et. al.* have been utilized to design system for this experiment [3],[10].In firstpart of the paper, the use of floating electrode is discussed. In second part, characterization of produced plasma jet is presented. Lastly, the treatment of polymers using plasma jet with floating electrode is presented. Polymers like polypropylene (PP) and polyethylene (PET) are treated by plasma jet with floating electrode whose surface properties are changed without change in their bulk properties.

2. Experimental Setup

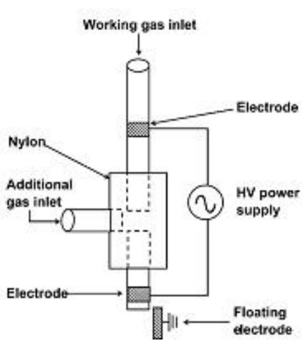

Fig 1: Schematic diagram of experimental setup

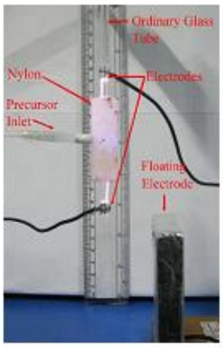

Fig 2: Experimental Setup

The experimental setup used for this study is shown in Fig. 1 with a floating electrode placed near the nozzle of plasma jet. It consists of capacitively coupled electrode system made up of aluminum foil of width 0.3 cm wrapped around two silica glass tubes of outer diameter 0.49 cm and innerdiameter 0.3 cm. The aluminum electrode is connected to high voltage power supply and the glass tube is coupled with nylon coupler of length 4.9cm, which has fine bore of 5mm. The distance between two electrodes is kept at 7.3 cm and the distance between tip of the nozzle and lower electrode is 0.3cm.

The system consists of one additional inlet with a third tube connected with nylon coupler horizontally in the middle as shown in Fig. 1. This third inlet can be used to introduce additional gas into the systems when it is used for the deposition of thin films. Argon is used as a main working gas in this experiment and plasma is produced capacitively in between two electrodes. The photograph of the system with the discharge is shown in Fig. 2.

The system consists of third electrode termed as floating electrode whose effect on jet length is discussed in this paper. Use of atmospheric pressure plasma jet for surface modification of polymers having similar system but without the floating electrode has been reported in our earlier work [5].

Study of the effect of floating electrode introduce various parameters. The distance between floating electrode and the tip of the nozzle has been varied from 0 cm to 2 cm. The flow rate of argon gas (Q_{Ar}) is varied from 1 ltr/min to 4ltr/min and variation of applied voltage (V_{Ap}) and its effect on jet length is studied from 4 kV to 7 kV. .For characterization of the plasma jet, Optical Emission Spectroscopy (OES) and current – voltage measurement were studied. PINTEK HVP-28HF, high voltage probe and TEKTRONIX TDS 2002 two channel digital oscilloscope was used for electrical characterization. The use of plasma jet for treatment of polymer is also studied by varying treatment time and distanceof sample from the nozzle using contact angle goniometer.The polymers were received fromGoodfellowLtd., UK and for treatment sample size of 4 cm x 1cm were made. Before treatment, the samples were washed in methanol for 5 min, cleaned ultrasonically for 10 min and dried in ambient condition.

3. Results and Discussion

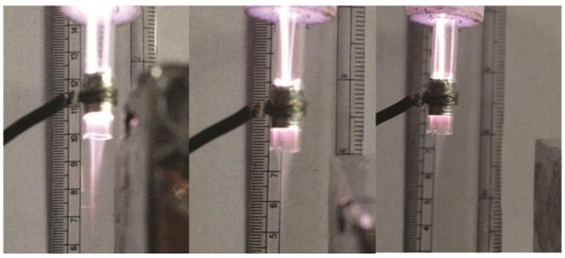

Fig 3: Effect of variation of distance between nozzle and floating electrode (0.5cm, 1cm, 2cm) at V_{Ap}=5 kV, Q_{Ar}=2ltr/min

When high voltage is applied, discharge is seen between the electrode at V_{Ap}=5 kV andQ_{Ar}=2 ltr/min. It is seen that the applied voltage and flow rate of argon is insufficient to flush discharge out of the tube. When the applied voltage is increased to 7 kV, a small plume of plasma jet is seen. As studied by Hu *et. al.* andNi*et. al.*, the length of plasma jet is affected by floating electrode [9], [11]. So, when a floating electrode is brought near the nozzle at a distance of 2 cm, a small plume of about 1.2 cm is observed even at V_{Ap}=5 kV and Q_{Ar}=2 ltr/min. Different lengths of jet were observed as the distance between nozzle and floating electrodewas decreased. Fig. 3 shows the images of the jet length measured for three different position of floating electrode from the nozzle. The applied voltage V_{Ap} was 5kV and the gas flow rate Q_{Ar} was 2ltr/min. It is evident that the length of the jet decreases as the floating electrode is moved away from the nozzle. The result of the variation of jet length as a function of the distance between nozzle and floating electrode is plotted in Fig. 4. A maximum length of the jet was obtained when the floating electrode kept at a distance of 0.5 cm from the nozzle. When it was moved to a distance of 2 cm, the length of jet reduced to 1 cm.

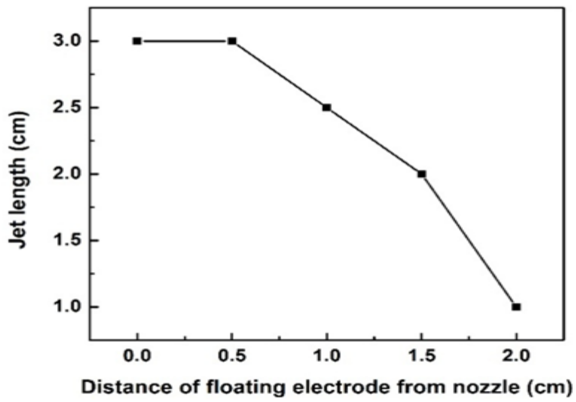

Fig 4: Variation of jet length with distance of floating electrode from nozzle

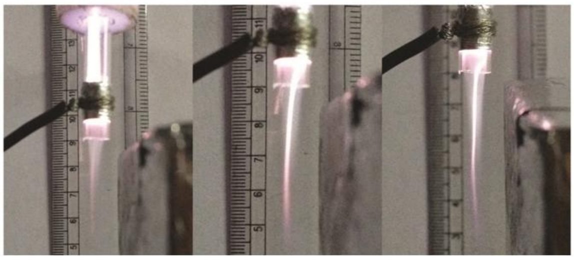

Fig 5: Effect of variation of applied voltage (4kV, 5kV, 7kV) at Q_{Ar} =2 ltr/min and 0.5 cm distance between nozzle and floating electrode

The variation of jet length with applied voltage is shown in Fig. 5. The gas flow rate was kept fixed at 2 ltr/min and distance between nozzle and floating electrode was 0.5 cm. It is found that the length of the jet increased with the increase in applied voltage. Fig. 6 shows the graph of jet length plotted against applied voltage. A jet length of 3.5 cm was observed at V_{Ap}=4 kV and gradually increased upto 5cm at V_{Ap}=7 kV. When the applied voltage was further increased, heating was seen at the nozzle as a result jet was not observed.

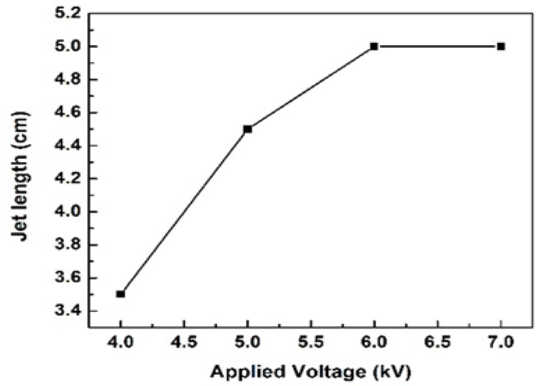

Fig 6: Variation in jet length with applied voltage when distance between floating electrode and flowrate are kept fixed

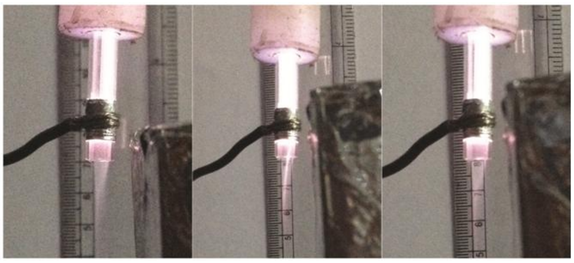

Fig 7: Effect of variation of flowrate (1, 2, 4 ltr/min) at 5kV 0.5cm distance between nozzle and floating electrode

Similarly, Fig. 7 depict variation of length of jet with flow rate when V_{Ap}=5kV and distance between nozzle and floating electrode was kept fixed at 0.5 cm. A plot of jet length as a function of flow rate is shown in Fig. 8. The result shows maximum jet length of about 3.5 cm at 4 ltr/min which decreased upto 2.5 cm at 1 ltr/min.

The electrical characterization of stable plasma jet in presence of floating electrode is shown in Fig. 9. The power consumed by the system is calculated to be ~30 watt and the frequency of the power supply was 25 kHz. The current waveform in the graph contains two negative peaks at the interval of 40 µs similar to dielectric barrier discharge as describedby Xiaogui*et. al.* [12].

The optical characterization of plasma jet is shown in figure 10. Space resolved optical emission spectroscopy (resolution: 0.1 nm) has been performed to characterize plasma species present in the jet. Figure 10 shows emission spectra of argon in plasma jet. The most intensive OH line is found at

308.928 nm indicating emission of significant amount of UV radiation. The most intensive argon line is found in the region 695 nm to 850 nm, which can be assigned to different transition of argon atom. Similarly, the peaks in the region 330 nm to 350 nm shows transition of nitrogen [13].

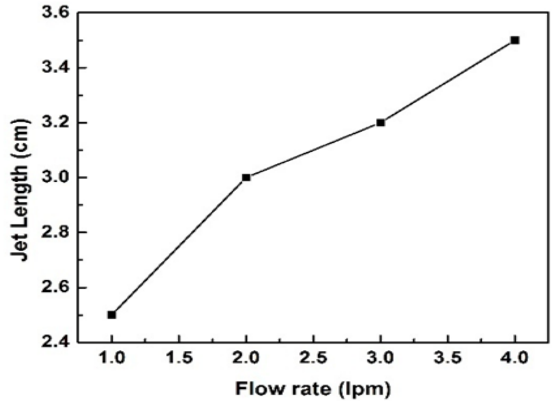

Fig 8: Variation in jet length with flow rate when distance between floating electrode and applied voltage are kept fixed

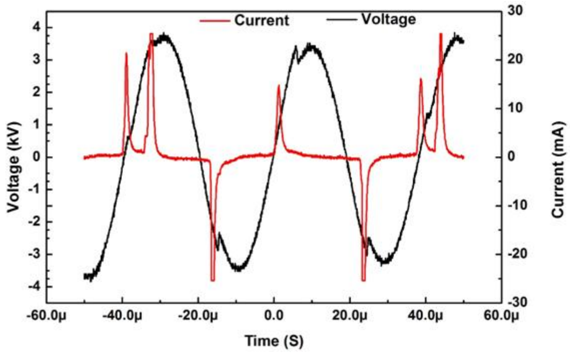

Fig 9: IV graph of jet at Q_{Ar}=2ltr/min

Figure 11 shows graph of variation contact angle of PP as a function of treatment time. It shows that few seconds of treatment time (about 20 seconds) reduces the contact angle drastically. Beyond 20 seconds of treatment time the value of contact angle decreased very less quantity. Likewise, the variation of contact angle of PET as a function of distance between sample and nozzle is depicted in figure 12. It clearly shows the increment of contact angle with the increase in distance indicating the effectiveness of plasma jet for treatment of polymers.

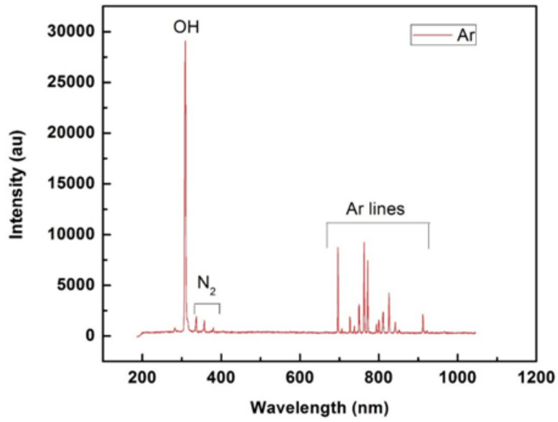

Fig 10: Optical Emission Spectroscopy of Argon Plasma Jet

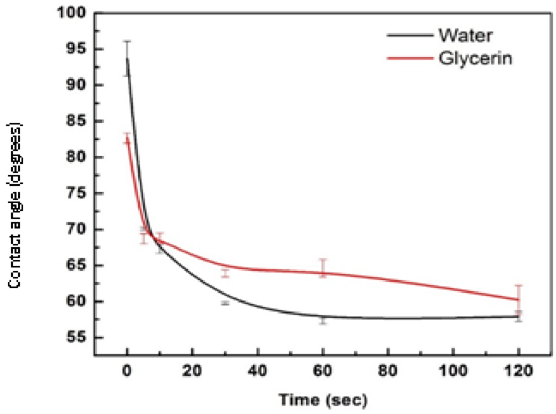

Fig 11: Variation of contact angle of PP with treatment time

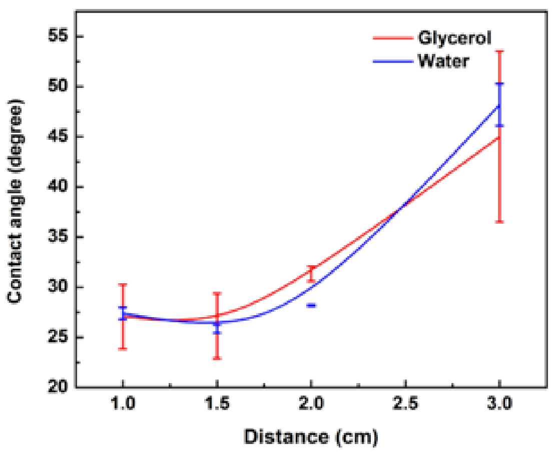

Fig 12: Variation of contact angle of PET with distance between sample and nozzle

4. Conclusion

Thus, from all the results, it is evident that floating electrode has significant effect on the improvement of jet length. When the distance between nozzle and the floating electrode is decreased, the significant improvement in jet length is observed. The system developed in this research has many advantages over those developed in previous works by researchers. It can be used to change the surface properties of polymers. This systemcan also be implemented for deposition of thin films as there is no obstacle in the path of jet. Similarly, there is significant decrease in applied voltage and gas flow rate due to the application in floating electrode. In conclusion, floating electrode can be used for reduction of operating cost of atmospheric pressure plasma jet devices.

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