Investigating the characteristics of a coplanar-coaxial atmospheric pressure dielectric barrier discharge jet in argon

Citation: AIP Conference Proceedings 1657, 150002 (2015); doi: 10.1063/1.4915241
View online: http://dx.doi.org/10.1063/1.4915241
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1657?ver=pdfcov
Published by the AIP Publishing

Articles you may be interested in
A dielectric-barrier discharge enhanced plasma brush array at atmospheric pressure

Investigation on plasma parameters and step ionization from discharge characteristics of an atmospheric pressure Ar microplasma jet

Role of metastable atoms in the propagation of atmospheric pressure dielectric barrier discharge jets
J. Appl. Phys. 107, 043304 (2010); 10.1063/1.3295914

A large gap of radio frequency dielectric barrier atmospheric pressure glow discharge
Appl. Phys. Lett. 96, 041502 (2010); 10.1063/1.3299010

Characteristics of kilohertz-ignited, radio-frequency atmospheric-pressure dielectric barrier discharges in argon
Appl. Phys. Lett. 95, 201501 (2009); 10.1063/1.3263153
Investigating the Characteristics of a Coplanar-Coaxial Atmospheric Pressure Dielectric Barrier Discharge Jet in Argon

K. L. Lai\textsuperscript{a}, K. K. Jayapalan\textsuperscript{a}, O. H. Chin\textsuperscript{a}, P. F. Lee\textsuperscript{b} and C. S. Wong\textsuperscript{a}

\textsuperscript{a}Plasma Technology Research Centre, Physics Department, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia
\textsuperscript{b}Department of Mechatronics and BioMedical Engineering, Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, 50744 Kuala Lumpur, Malaysia

Abstract. Non-thermal atmospheric pressure plasma jet can easily be generated via a coplanar-coaxial dielectric (quartz tube) barrier discharge configuration driven by AC high voltage source at 11 kHz frequency in flowing argon gas. The plasma jet was characterized by its physical dimension, electrical and optical emission properties. It was found that smaller diameter of the quartz tube produced jets of shorter length. To generate a jet at maximum length for larger tube diameters, higher gas flow rate was required. Increasing the width of the active electrode also produced plasma jets of longer length. Current spikes superposed on the sinusoidal current waveforms were observed when the active electrode of shorter length was used. These spikes diminished when the width of the active electrode was increased to 15 mm. When the active and ground electrodes were inter-changed in position, no plasma jet was formed externally but upstreaming of the jet was observed. No discharge was ignited when the ground electrode was removed. The spectrum obtained showed emission lines from the second positive system, C\textsuperscript{3}\Pi\textsubscript{u} - B\textsuperscript{3}\Pi\textsubscript{g} of molecular nitrogen as well as Ar I state.

Keywords: atmospheric pressure plasma jet, dielectric barrier discharge.
PACS: 52.80.Tn

INTRODUCTION

Plasma is a gaseous environment with a mixture of ions, electrons and neutral particles that typically exhibit electrical quasi-neutrality. Laboratory plasma can be produced under high vacuum (e.g. vacuum spark [1]) to above atmospheric pressure (e.g. impermeable plasma [2]). The advantage of atmospheric pressure plasma is low production cost as it does not need any equipment for the creation of vacuum condition. Atmospheric pressure plasma can be categorized into thermal (e.g. plasma torch [3]) or non-thermal type (e.g. dielectric barrier discharge [4]). The non-thermal atmospheric plasma typically exhibits electron temperature in the range of 10,000 K – 100,000 K [5]. The ions and neutral particles which determine the overall plasma temperature, however, are slightly above room temperature. This makes it suitable for biomedical application as it will cause minimal or no thermal damage to the biological samples. In addition, most of the biological samples cannot survive in vacuum environment.

Dielectric barrier discharge (DBD) is one of the configurations suitable for generating non-thermal atmospheric plasma. In DBD, a dielectric barrier is placed between two electrodes to control the amount of transported charges, hence, avoiding the formation of arcs between electrodes and also allows for the surface area of the electrode to be distributed with microplasmas. To generate a plasma jet, gas flow is normally introduced. The plasma jet is useful as the sample would not be subjected to high electric field between the electrodes, and the jet can reach difficult to access places if it is sufficiently long. Hence, investigating the jet length dependence on operating factors is useful. In this work, the effects of variation in quartz tube diameter (dielectric) and active electrode length on the plasma jet length is demonstrated. The role of the ground electrode in generating plasma is also shown.

EXPERIMENTAL SETUP

The DBD arrangement is made up of two coplanar-coaxial cylindrical copper foil electrodes wrapped around a quartz tube which forms a cylindrical dielectric barrier as shown in FIGURE 1. The applied voltage was fixed at 15 kV (peak-to-peak) at 11 kHz. Inner diameter of the quartz tube was varied from 1 mm to 5 mm while the wall
thickness was fixed at 1 mm. The widths of the active and ground electrodes were 5 mm and 2 mm respectively. The distance from the edge of the quartz tube to the ground electrode was 5 mm, whilst the separation distance between the electrodes was also 5 mm. The gas flow rate was adjusted to create the longest jet. Additional configurations for the 4 mm diameter quartz tube were also investigated, i.e., changing the widths of the active electrode to 1.0 cm and 1.5 cm, interchanging the positions of the active and ground electrodes and lastly removing the ground electrode.

The voltage and current waveforms were measured using high voltage probe (Tektronix P6015A) and current monitor (Pearson Current Monitor 4100), respectively. Photos of the plasma jets were taken by using a digital camera (Canon EOS 40D), and the length of the plasma jets were measured from the digital image. The optical emission properties of the plasma jets were captured by using a miniature spectrometer (Ocean Optics Model USB2000-UV-VIS) which can capture emission lines from 200 nm to 850 nm with resolution of 1.5 nm FWHM. The optical emission was detected at an axial position 10 mm below the edge of the quartz tube and 5 mm (transversely) away from the plasma jet.

![FIGURE 1. Schematic diagram of the DBD jet arrangement.](image)

**RESULTS AND DISCUSSION**

The electrical characteristics of the DBD are represented by the voltage and current signals shown in FIGURE 2(a) for the configuration with 4 mm quartz tube and 5 mm active electrode. The spikes seen in the current signal are associated with microdischarges (filamentary mode). FIGURE 2(b) shows the voltage and current signals for the configuration of 4 mm diameter quartz tube and 15 mm active electrode. The spikes observed in the current signal in FIGURE 2(b) are also due to filamentary discharge. The amplitude of the spikes is observed to be much lower when the 15 mm active electrode was used. In the case of the 5 mm active electrode, the electric fields that generate the plasma is concentrated in a smaller surface area and the probability for high current filamentary spikes is higher. The
15 mm active electrode disperses the electric fields across a wider area, resulting in both lower amplitude filamentary spikes and more distributed ionization of the argon atoms over a larger area. This is observed in the longer jet length acquired with the 15 mm active electrode in comparison to the 5 mm active electrode (FIGURE 3).

![FIGURE 2. Voltage and current signals for the configuration of 4 mm diameter quartz tube for (a) 5 mm active electrode and (b) 15 mm active electrode.](image)

![FIGURE 3. The relationship between the longest plasma jet length and active electrode width in a fixed flow rate of 5.3 l/min.](image)

The relationship between the longest plasma jet length obtained at optimum gas flow rate and the quartz tube diameter is plotted in FIGURE 4. As the tube diameter is increased, the maximum achievable plasma jet length is also increased. Larger tube diameter increases the available surface area of the wrapped surrounding electrode, allowing for more ionization of argon atoms to occur. The optimum flow rate required to achieve the longest jet length is also seen to increase, coinciding with the increase in amount of argon atoms required to produce a laminar-turbulent transition flow. For all the configurations reported, the longest jet is typically seen when the flow rate is in transition mode.
FIGURE 4. The relationship between the longest plasma jet length recorded at optimum flow rate and quartz tube diameter.

FIGURE 5(a) shows the plasma jet generated by 4 mm diameter quartz tube and 5 mm long active electrode in typical configuration. When the active and ground electrodes for the configuration were interchanged, a plasma jet which extends upwards (upstream) into the quartz tube was observed without any downstream plasma jet (FIGURE 5(b)).

FIGURE 5. The plasma jet for the configuration of (a) 4 mm quartz tube diameter and 5 mm long active electrode and (b) where the position of the active and ground electrodes was interchanged.

The direction of the gas flow in FIGURE 5(b) is opposite to the direction of the plasma jet protrusion. This demonstrates that the direction of the gas flow does not affect the direction of the plasma jet. For the configuration in which the ground electrode was removed, no discharge (within the electrode wrapped tube) or plasma jet was generated. The plasma jet was found to be more easily produced with the presence of the ground electrode which lowers down the initial drive voltage of the discharge. Previous studies have shown that the position of the ground electrode both influences the initial drive voltage and the plasma jet stability [6]. This is due to intensity of the field produced as the position of the ground electrode defines the gap distance of the discharge. Without the ground electrode, zero potential is relatively at an infinite distance away, hence, the field is lower and active discharge is difficult to ignite.

The emission spectrum for the configuration of 2 mm diameter quartz tube with 5 mm active electrode is shown in FIGURE 6. The spectrum obtained showed emission lines from the second positive system, C$^3\Pi_u$ - B$^3\Pi_g$ of molecular nitrogen (originating from the surrounding air) as well as Ar I state. A hydroxyl (OH) peak attributed to the presence of moisture was also identified.
CONCLUSION

From this study it is seen that larger diameter quartz tubes and longer active electrodes result in longer plasma jet length. A larger electrode surface area would reduce large filamentary spikes in the discharge current. Higher flow rate is required for larger diameter tubes to obtain the maximum plasma jet lengths. This is because for all configurations used, the optimum flow rate for the discharge is at the laminar-turbulent transition which is at higher flow rate for larger tubes. When active and ground electrodes were interchanged in position for one of the configuration, upstreaming of the plasma jet inside the quartz tube was observed; showing that the direction of jet is not dependent on the direction of gas flow. No discharge was ignited when the ground electrode was removed. The emission spectrum showed lines for the second positive system, C$^3Π_u$ - B$^3Π_g$ of molecular nitrogen (from air), the Ar I state and a hydroxyl (OH) peak attributed to moisture.

ACKNOWLEDGMENTS

This work is supported in part by the Ministry of Education Malaysia and the University of Malaya under respective grants FRGS FP017-2013A and UMRG RP008B/13AFR.

REFERENCES