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Effect of N_2 swirl gas on an RF-driven Ar atmospheric plasma

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A compact cold atmospheric-pressure plasma device driven by 13.56 MHz frequency RF power is being designed, assembled, and tested. The employment of N_2 swirl gas injection into Ar plasma stabilizes the plasma flow out of device. A swirl gas nozzle structure is adapted to a hand-held atmospheric-pressure plasma pen. The N_2 swirl gas injection yielded a more homogeneous and stable plasma plume out of the pen. Visible range OES data show increase in excited nitrogen species as compared to Ar excited species by increased flow rate of N_2 swirl gas.

1. Introduction

Atmospheric pressure plasmas have been gaining attention over the years in research because of their ease of use for not requiring vacuum equipment. This advantage reduces the cost for developing atmospheric pressure plasma device and enlarges the dimension of materials to be treated by plasma.

A main disadvantage of atmospheric pressure plasmas is that it possesses an inhomogeneous, filamentary structure in contrast to the homogeneous plasmas that can be produced at low-pressure [1]. Because of this, the application of atmospheric-pressure plasmas is limited. On the other hand, the produced localization of atmospheric pressure plasmas can be advantageous for exposing plasma into hard-to-reach regions such as porous and hollow surfaces [2].

It has been reported that the employment of swirl gas injection in atmospheric pressure devices stabilize the filamentary plasma hence producing a more uniform plume discharge [3-4]. In this study, a swirl gas nozzle is incorporated into the structure of a cold atmospheric plasma pen. To understand its effect on the cold atmospheric plasma pen, the plasma species and plume length and their dependence to swirl gas flow rate are investigated.

2. Methodology

A schematic diagram of the RF-driven cold atmospheric plasma pen (RF-CAPP) utilizing a capacitively-coupled setup is shown in Fig. 1. The RF-CAPP operates at 13.56 MHz frequency with input forward powers from 25 W to 40 W. The RF power supply has a built-in tuning unit to match the impedance between the source and the plasma load.

In this study, Ar is used as the main gas for plasma discharge production while N_2 as the swirl gas. Flow rates of these two kinds of gas are varied from 1-5 lpm.

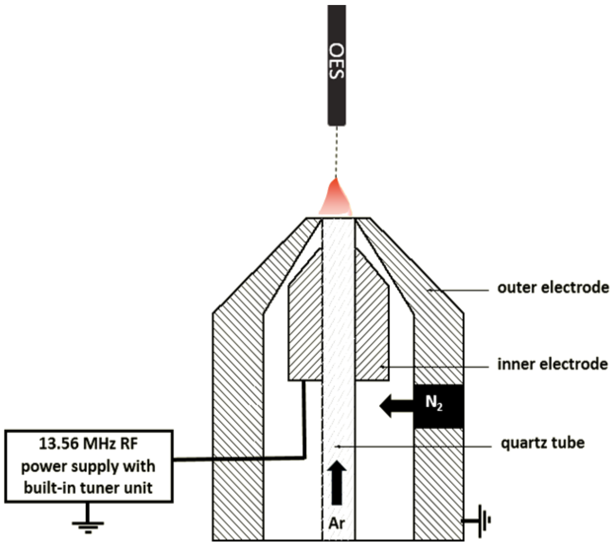

Fig.1. Schematic diagram of the RF-CAPP.

Images of the plasma plume for different input parameters were captured using *Pentax K7* camera with fixed shutter speed of 1.3 s, aperture of F5.6 and ISO 800 sensitivity. The plasma plume lengths are then calculated using an image analysis freeware called *ImageJ*.

Emission spectra of plasma produced at various input parameters are recorded using a USB 4000 optical emission spectrometer from Ocean Optics with spectral range of 342 to 1040 nm. The spectral lines are then identified using *PLASUS Specline*.

3. Experimental results

3.1 *Dependence of plume length to swirl gas*

The effect of N_2 swirl gas to Ar plasma can be observed in Fig. 2. Without swirl gas input, Ar plasma is barely visible even at high input power. Increasing the swirl gas flow rate up to 3 lpm yields to longer plasma plume length. However, at 5 lpm N_2 flow rate, the swirl gas extinguishes the plasma leading to smaller and fainter plasma plume. The longest plume of 12.9 mm is achieved at 5 lpm Ar, 3 lpm N_2, and 40 W forward power.

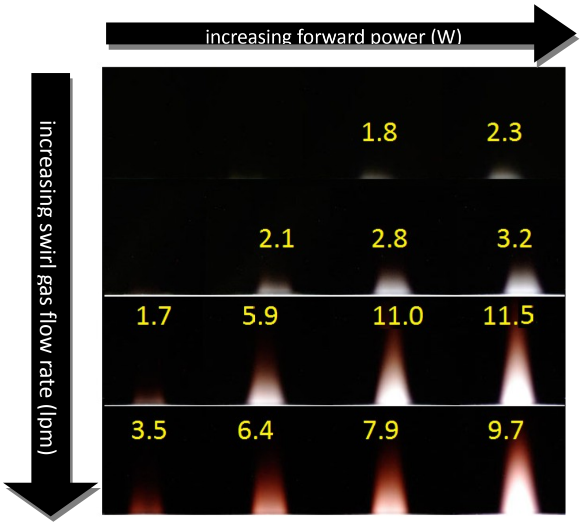

Fig. 2. Plasma plume lengths (mm) of 3 lpm Ar plasma at varying input power (25, 30, 35, 40 W) and N_2 swirl gas flow rate (0, 1, 3, 5 lpm).

3.2 *Swirl gas effect on plasma species*

The spectrographs obtained for various input parameters reveals that the RF-CAPP is mainly composed of N_2 second positive system that are detected from 357 to 420 nm wavelengths and Ar I species present from 696 to 966 nm range. To clearly see the effect of the swirl gas, the intensities of N I and Ar I lines are plotted in Fig. 3 and Fig. 4.

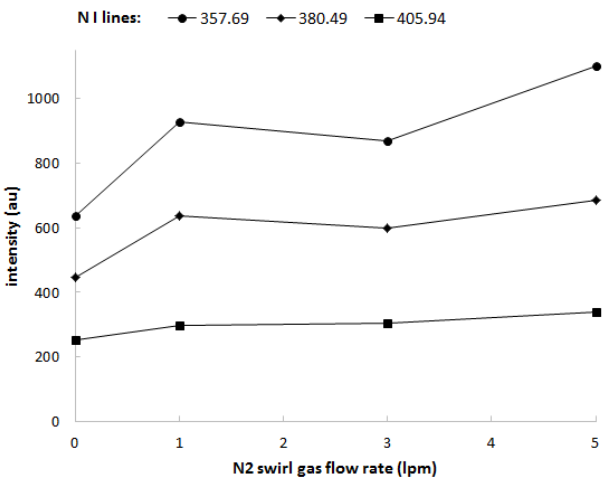

Fig. 3. Intensities of N I species for varying nitrogen swirl gas flow rate (lpm) at 3 lpm Ar plasma.

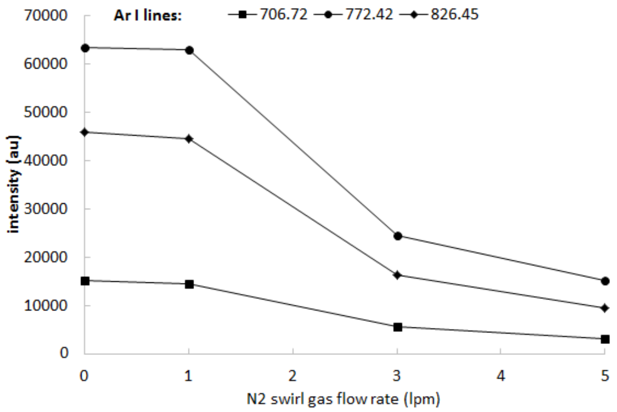

Fig. 4. Intensities of Ar I species for varying nitrogen swirl gas flow rate (lpm) at 3 lpm Ar plasma.

Since the N_2 swirl gas envelopes the plasma, some amount of nitrogen from the swirl gas mixes into the Ar plasma and is ionized when there is an increase in the N_2 gas flow rate. This in turn results in increase of molecular N_2 intensity as shown in Fig. 3, and the decrease in of Ar I species as shown in Fig. 4 due to Ar deexcitation.

4. Conclusion

The effect of swirl gas injection to an RF-driven cold atmospheric plasma pen is experimentally investigated through image analysis and optical emission spectroscopy. The input of swirl gas at a proper flow rate yielded a more homogeneous plasma plume. Also, increasing the flow rate of swirl gas aids the plasma plume to be transported farther which can be optimized for specific application that would require similar plasma plume geometry. The addition of nitrogen swirl gas into the RF-CAPP has also caused excitation of N_2 species presumably due to accompanying reduction of Ar I species.

References

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