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Measurement of Electron Density in Atmospheric Pressure Cold Argon Plasma Jet

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Abstract - Non thermal atmospheric pressure plasma jet [APPJ] generated in argon by the application of AC high voltage source in the range of 0-20 kV at 27 kHz frequency can protrude several centimeters into the ambient air; therefore it is suitable for many innovative applications. In this paper electrical techniques to investigate the characteristics of the produced plasma jet were reported. Properties of the jet discharge were studied by electrical diagnostics, including the waveform of discharge voltage, discharge current and the Q-V Lissajous figures. It was found that the discharge current increases with the increase in applied voltage. The plasma jet starting from the active electrodes is essentially the propagation of streamers induced by corona discharge. Plasma jets can be generated in both downstream and upstream directions simultaneously. Our interest is to study the plasma jet in downstream direction. The plasma jet in downstream only of jet length up to 60mm was generated at a significantly reduced voltage.

***Keywords* - Atmospheric pressure plasma jet [APPJ], discharge current, Lissajous Figure**

I.INTRODUCTION

Atmospheric pressure non equilibrium plasma has been widely applied in different fields of science and technology i.e. material processing such assurface modification of textiles or organic materials for improvement ofhydrophilicity and hydrophobicity[1], new material preparation such as carbon nanotubes[2,3], element analysis, environmental protection, toxic gas removal, sterilization and decontamination of liquids and medical instruments[4,5].During the past decade, an increasing interest was devoted towards the atmospheric pressure plasma use for medicalapplications. The list of plasma applications in relation with living organisms can be continued with woundhealing [6,7] blood coagulation, treatmentof dental cavitiesand induction of apoptosis for cancercells, trials in cancer therapy [8,9,10], However, due to the relative high breakdown voltage of working gases at atmospheric pressure, the discharge gaps are normally small, which limit the size of materials to be treated for direct treatment.

To overcome these problems atmospheric pressure plasma jets (APPJ) have drawn much attraction because of their potential application for different technologies[11,12,13,14]. The plasma jet devices generate plasma plumes in open space and can be adjusted from a few millimeters down to the several centimeters rather than in confined discharge gaps only. Thus, they can be used for direct treatment and there is no limitation on the size of the object to be treated.

In the physical and biomedical application of plasma jet, it is important to characterize the plasma so that we can understand the mechanism of the process and control them. In this study, properties of the jet discharge were characterized by electrical methods, including the measurement of waveform of discharge voltage, discharge current and the Q-V Lissajous figures.

II. EXPERIMENTAL ARRANGEMENT

The atmospheric pressure plasma jet concerned in this paper is generated in a glass tube with an inner diameter of 3.0 mm and an outer diameter of 5 mm. The electrodes, 10mm wide, are made of aluminum foil wrapping the capillary tube and the distance between the inner edges of two electrodes is 130mm. The ground electrode is on the upstream side; the active electrode is on the downstream side and with its outer edge at about 5mm from the tube orifice. Photograph and Schematic diagram of the present experimental setup of the atmospheric-pressure plasma jet apparatus is shown in Fig.1. Argon gases are used as the working gas; and the flow rate is controlled by a volume flow meter.

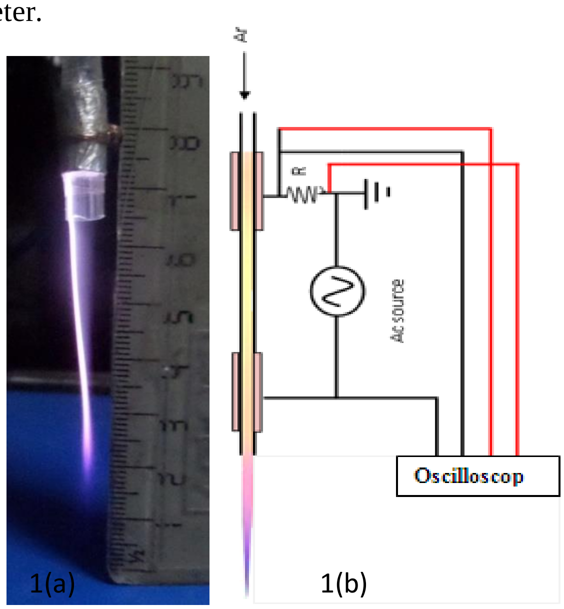


Fig.1. Photograph (a) and schematic diagram of experimental setup of APPJ (b)

The flow rate of the argon gas was 2 l/m so that the flow velocity would not exceed the limit for a laminar argon flow. We used a high frequency power supply in the range (1-30kHz) and voltage in the range of (0-20 kV) for the excitation and sustaining the discharges. In this way an atmospheric pressure argon plasma jet is generated and operates freely in air.

III. ELECTRICAL MEASUREMENTS

The discharge current and applied voltage waveforms of atmospheric pressure plasma jet for different applied voltage were recorded digitally by using current probe and voltage probe (Tektronix 2000TDS) . The data obtained were transferred to a personal computer for further analyses. The estimation of electron density was done by the power balance method, in which the total energy lost by the electron in the plasma is balanced by the input power. [16].

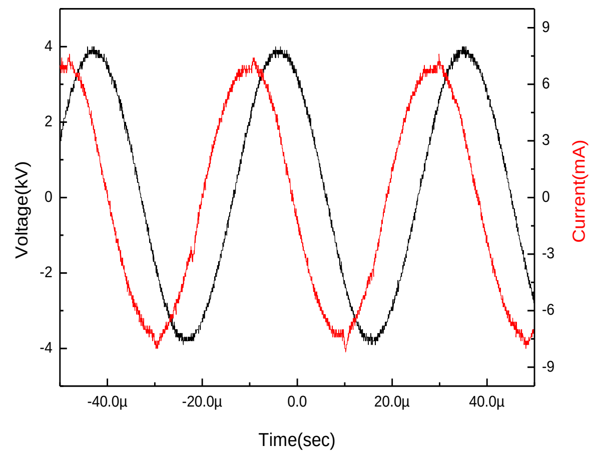


Fig 2:Applied voltage and current wave form of discharge

$$n_e = \frac{P_{ab}}{2Av_bE_{lost}} \qquad (1)$$

Where $P_{ab}=VI$ is the input power during the discharge, A is the surface area of the electrode, i.e. $A=\frac{\pi d^2}{4}$ the cross sectional area of the plasma, d is diameter of the plasma jet. e is the charge on the electron, v_b is the Bohm velocity. E_{lost} the energy lost by the system per electron -ion pair which depends on the electron temperature T_e. Electron temperature is expected to be between 1eV and 2eV and under this condition E_{lost} can be reasonably approximated to 50eV for the argon. The use of equation (1) was made to estimate the electron density in atmospheric pressure plasma jet for different applied voltages.

IV. RESULTS AND DISCUSSION

The time evolution of applied voltage , discharge current and charge - voltage curve of atmospheric pressure argon plasma jet for different applied voltage for fixed frequency f=27kHz is shown in the figures.

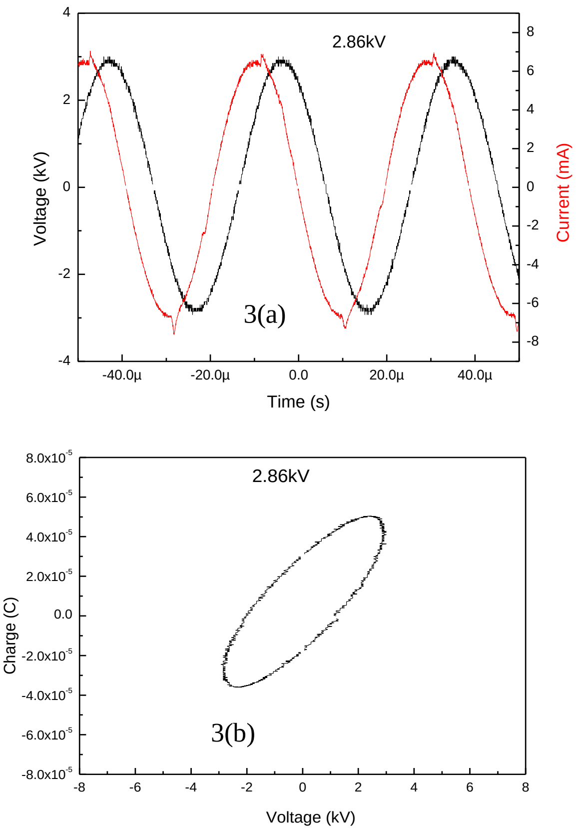


Fig: 3: a) Time evolution of discharge current appliedvoltage b) Charge voltage curve for APPJ Conditions:V_{peak}=2.86kV,Frequency = 27kHz, flow rate =2Lmin^{-1}

Theapplied voltage and discharge current wave form are symmetrical for both polarities of applied voltage. The discharge current waveform shows only few pulse of current on the positive half cycle andnegative half cycle which indicates the plasma is glow like type.

Analysis of Lissajous figure is carried out in order to estimate the energy consumed per cycle in the discharge. The plot of the charge transferred (*Q*) during the discharge vs.the voltage applied (*V*) is used to calculate the energy injected into the gas. Figure 3(a)correspondsto appliedvoltage and discharge current wave form and figure 3(b) corresponds to the Lissajous figure of the discharge in Ar with the applied voltage 2.86kV. Figures 4, 5, 6, 7 and 8 correspond to thecurrent wave form and Lissajous figure of atmospheric pressure plasma jet withapplied voltage 3.86kV,4.7kV, 5.86kV,6.75kV and 7.8kV respectively. The shapes of the Lissajous figures are not exactly parallelogram because of the differencein ‘on time’ and ‘off time’ of discharge.

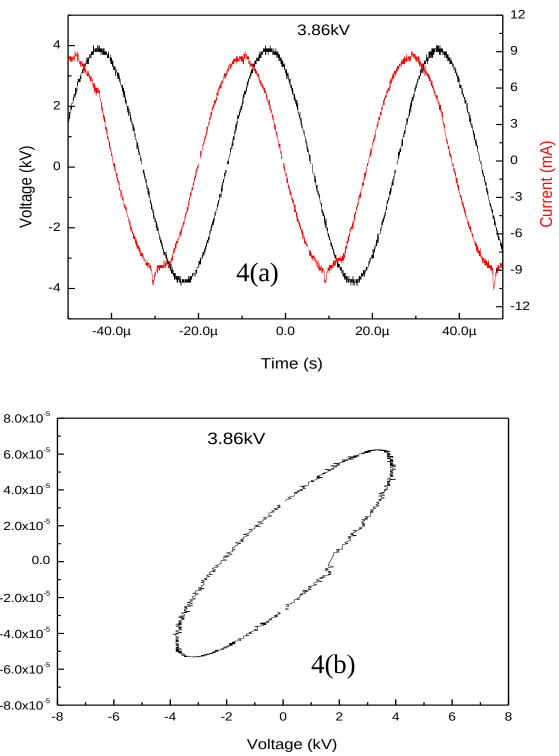
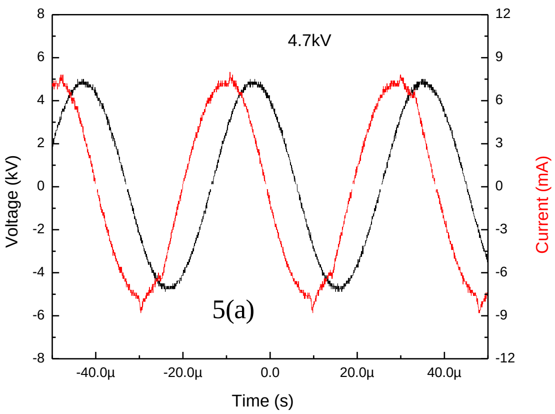


Fig: 4: a) Time evolution of discharge current applied voltage b) Charge voltage curve for APPJ Conditions:V_{peak}=3.86kV,Frequency = 27kHz, flow rate =2Lmin^{-1}



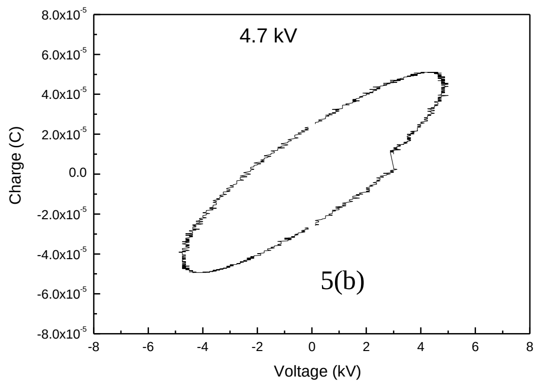
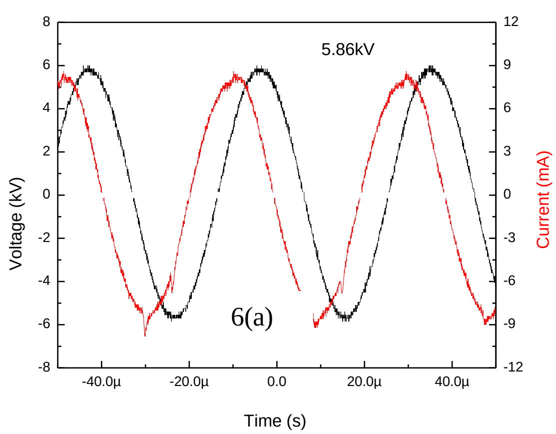


Fig: 5: a) Time evolution of discharge current applied voltage b) Charge voltage curve for APPJConditions:V_{peak}=4.7kV, Frequency= 27kHz, flow rate =2Lmin^{-1}



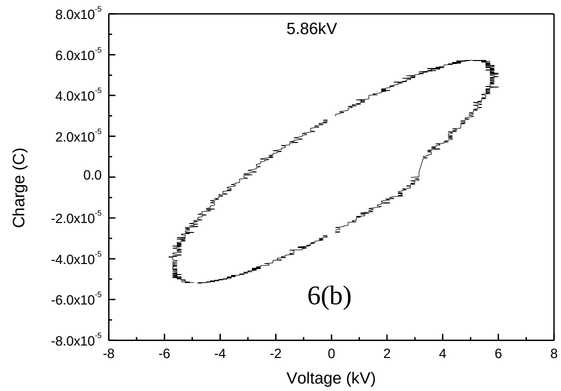
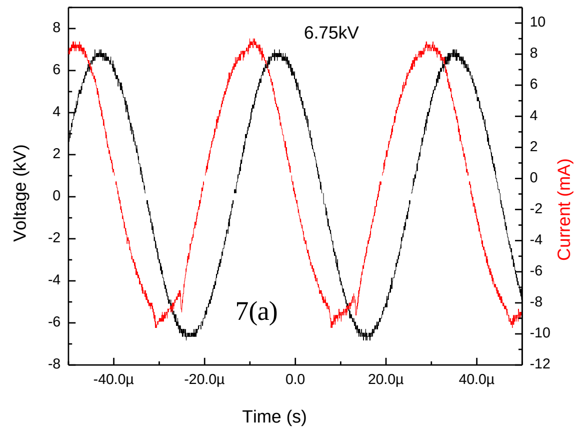


Fig: 6: a) Time evolution of discharge current applied voltage b) Charge voltage curve for APPJ Condition: V_{peak}=5.86kV, Frequency = 27kHz, flow rate =2Lmin^{-1}



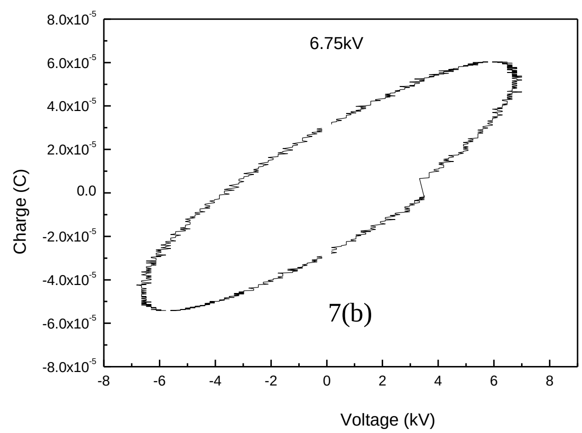


Fig: 7: a) Time evolution of discharge current applied voltage b) Charge voltage curve for APPJ Conditions: V_{peak}= 3.86kV, Frequency = 27kHz, flow rate =2Lmin^{-1}

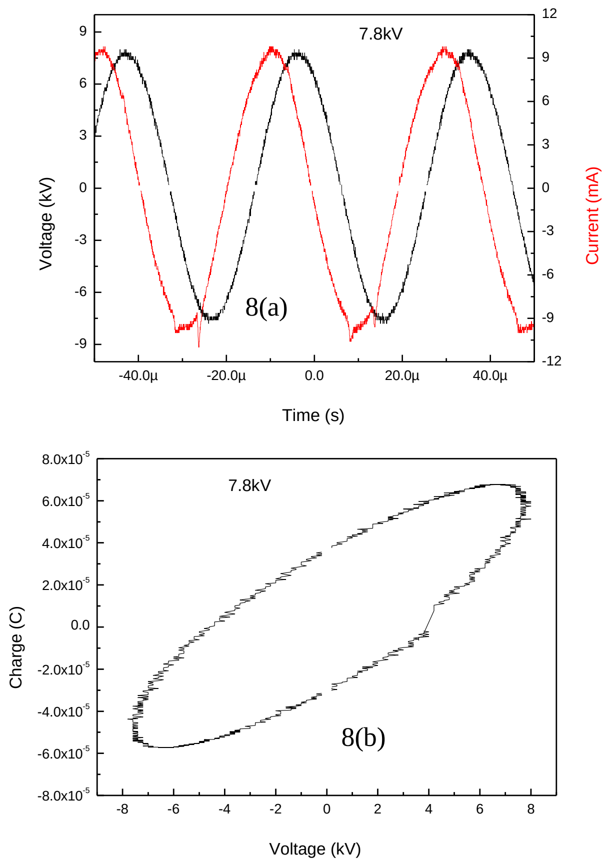


Fig: 8: a) Time evolution of discharge current applied voltage b)Charge voltage curve for APPJ Conditions: V_{peak}=7.8kV, Frequency = 27kHz, flow rate =2Lmin^{-1}

From the voltage and current waveform analysis of figures3-8, data of voltage and current for two positive and two negative half cycle and the calculated values of electron density in atmospheric pressure plasma jet by using equation (1) for different applied voltage and power consumption are shown in Table 1.This value clearly showed that electron density depends on the applied voltage.

Figure (9) and figure (10) shows the discharge power and discharge current of APPJ as a function of applied voltage between two electrodes. The discharge power and discharge current increases with increasing applied voltage.

Table 1: Calculated values of electron density for different applied voltage

Applied voltage (kV)	**Current (mA)**	**Power consumption (W) From VI product**	**Electron density $10^{13}cm^{-3}$**
2.86	6.685	19.119	1.08
3.86	7.679	29.641	1.63
4.7	8.14	38.258	2.17
5.86	8.875	52.007	2.85
6.75	9.177	61.945	3.46
7.8	10.235	79.833	4.38

Figure (11) and figure (12) shows the electron density in APPJ as a function of applied voltage and electric field between two electrodes respectively. The electron density increases with increasing applied voltage and electric field. The variation of electron density with power consumed in discharge is shown in figure (13). Figure (13) clearly showed that electron density depends on power.

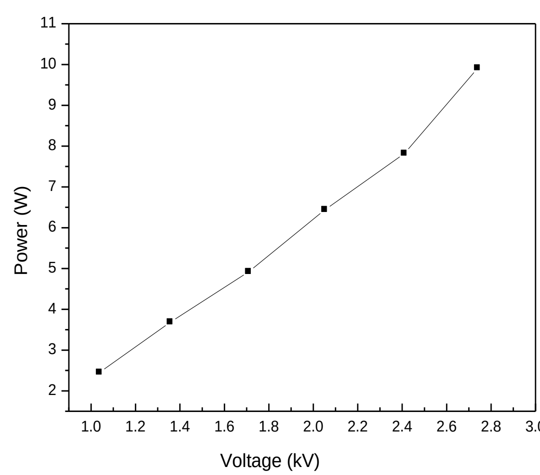


Fig.9: Discharge Power as function of applied voltage

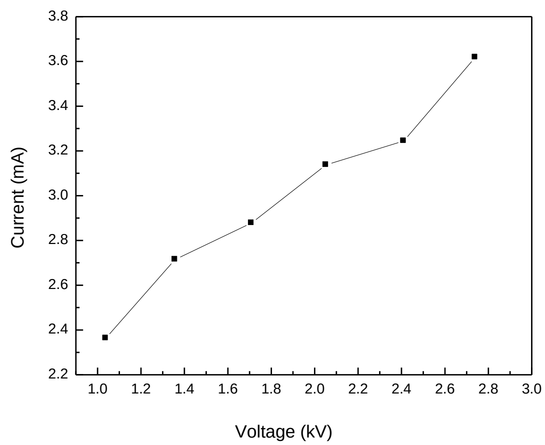


Fig.10: Discharge current as function of applied voltage

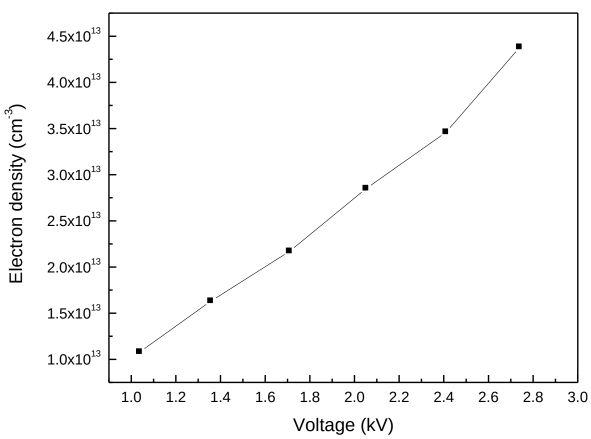


Fig. 11: Electron density as function applied voltage

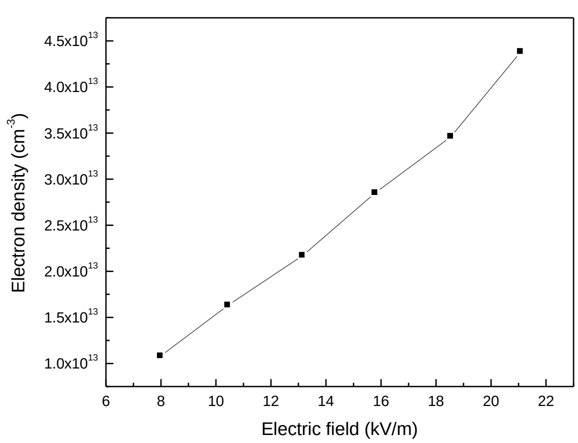


Fig. 12: Electron density as function of electric field

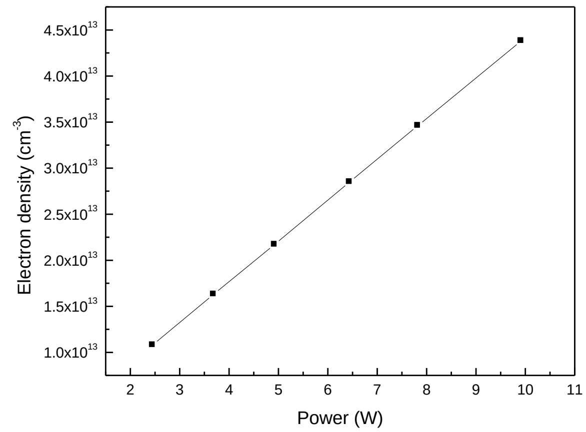


Fig. 13: Electron density as function Discharge power

V. CONCLUSION

Atmospheric pressure plasma jet generated in argon was investigated and its electron densities were estimated by employing the power balance equation. It is found that the electron density of the cold argon plasma jet at atmospheric pressure generated by means of the high voltage AC source of frequency 27kHz is of the order of 10^{13} cm^{-3}. The power dissipation of the plasma was measured with electrical probes the power dissipation ranged from 19.119W to 79.833W for the APPJ in argon.The influence of applied voltage on its discharge characteristics was also studied experimentally.

VI. ACKNOWLEDGEMENT

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