Atmospheric-Pressure Non-Thermal Plasma Jet for biomedical and industrial applications

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Abstract. In this work we present the development and evaluation of a low-cost DBD Plasma-JET reactor using Argon as carrier gas, this device is capable of generating a cold plasma plume several centimeters in length making it suitable for use directly in contact with objects and delicate materials, including living tissue.

1. Introduction

Recently Atmospheric-Pressure Non-Thermal Plasmas (APNTP) have become a topic of great interest for a wide range of applications in different branches of industry. In these plasmas the electron temperature is far higher than the temperature of the heavy particles [1]; elastic collisions of the electrons are not effective in contrast to collisions of heavy particles however it can transfer energy to other processes such as ionization, activation or dissociation of molecules This explains the great interest in this type of plasmas.

Over the past 20 years, there has been growing interest in developing this type of devices, particularly for biomedical applications such as bacterial inactivation [2, 3], wound healing [4], dental bleaching [5]; atmospheric plasmas are also of great interest in the industry, improve adhesion for inks, paints, and coatings are examples of plasma applications in order to improve surface properties, changes on the surface energy of any material is one of the purposes of applying plasma [6].

Various types of Atmospheric-Pressure Non-Equilibrium Plasma Jets (APNP-Js) with different configurations have been reported, most of the jets are working with noble gas mixed with a small percentage of reactive gases [1]. According to X. Lu et al. in their work “On atmospheric-pressure non-equilibrium plasma jets and plasma bullets”, plasma jets operating with noble gases can be classified into four categories, i.e. Dielectric-Free Electrode (DFE) jets, Dielectric Barrier Discharge (DBD) jets, DBD-like jets and Single Electrode (SE) jets

There are a number of strict requirements that a plasma jet reactor must meet to cover biomedical and industrial applications: low temperature, no risk of arcing, easy to repair, operation at atmospheric pressure, hand-held operation, low ozone generation, etc. [7]. These considerations have been taken into account for the development of reactor


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2. Methodology

2.1. Materials

The insulating material used in constructing of the device was Polyoxymethylene (POM), that is a thermoplastic for use in engineering parts that require high rigidity, and excellent dimensional stability, this material is capable of providing the required precision for building small pieces for the reactor.

POM also has also great thermal characteristics: coefficient of linear thermal expansion for most POM resins ranges from 10.4×10^{-5} to 13.5×10^{-5} m/m/°C, the specific heat has been determined as an average over a range from –18 to 100°C; The value is constant at 0.35. Thermal conductivity of the material is in range of 0.30 to 0.37 W/m·k. The melting temperature varies depending on the type of POM from 110 to 170°C degrees [8]. These characteristics make POM a good option for avoid heating problems in the device and also increasing the operating time of it.

The material used for electrical components was cooper.

2.2. Design

Figure 1 shows configuration chosen for reactor, this set-up allows the device work in two working modes depending if plume enters or not in contact with an object. The material for the main electrode and the ground ring was copper; POM was used for all dielectric materials in reactor.

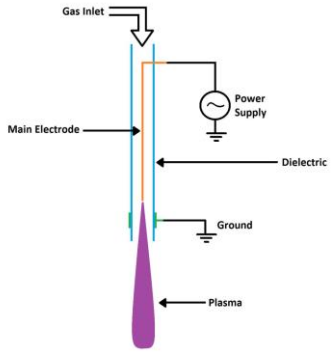


Figure 1. Experimental Set-Up: DBD-like JET

To ensure an easy operation of the device we design a cylindrical reactor with a length of 70.00mm and 25.40mm of diameter. On the top of the reactor there is a gas opening of 4.5mm diameter, at bottom: cooper ground ring with 3.5mm thickness and a dielectric tube of 1.75mm thickness between the electrode and ring. The main electrode consists in a copper wire of 0.8mm thick. Figure 2 shows in detail the design of the reactor and figure 3 shows an explosion view of the real devise and design.

Machining is performed by parts for easy assembly and also to facilitate the replacement of any parts if required. Gas is connected to the device using a tube 1/4OD a common adapter for this diameter was used in order to make the connection and prevent any leakage of gas. Exposed copper cables facilitate electrical connections.

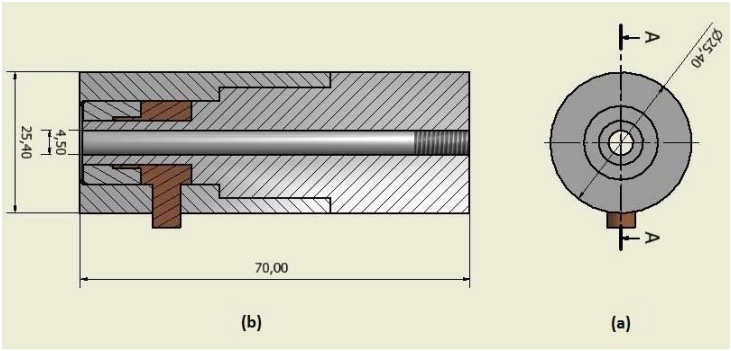


Figure 2. Detailed device design (all units in mm)

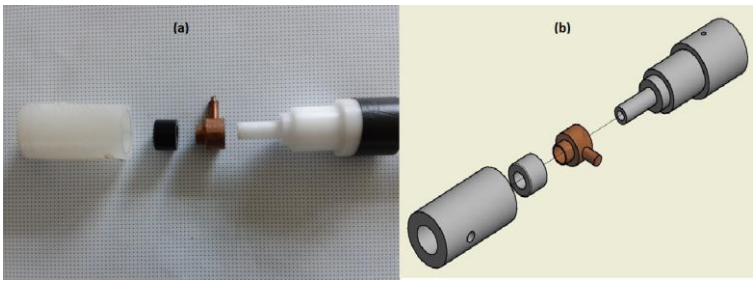


Figure 3. Explosion View (a) Real device (b) Design

Common kHz AC power was used to generate the plasma discharge. In the market there are several low-cost drivers that use a flyback transformer and allows user to control the voltage frequency and duty cycle in order to obtain different characteristics in plasma discharges depending on the application.

3. Results

3.1. Device Testing

For device test was used Argon as gas with flux of 10SCFH. In order to find the optimal discharge conditions according to the capabilities of the power supply, scans were performed at 100V from 20kHz up to 60Khz to locate the optimal discharge frequency which was 25KHz. Then proceeded to vary duty cycles from 50% to 90% for the same purpose, optimal working cycle was 50%

Is important to mention that the optimal point was established as the parameters which give us the longer plume in the reactor however the user can change some parameters depend on the applications needs

Once the optimum values are determined for the frequency and duty cycle several tests at different voltages were performed to observe the behavior of the reactor. Breakdown voltage was determinate at ~72VRMS which was the voltage at we see ionization of gas around main electrode.

Some tests at 100, 150, 200, 250 and 300 VRMS were performed to observe changes in plume length; results in Table 1 and Figure 4 shown us that there are no significant changes in the length of the plume voltages above 200VRMS . No arcs were observed during testing.

Table 1. Plume length at different voltages

Voltage (V_{RMS})	Plume Length (mm)
80V	0
100	18
200	24
250	36
300	39
350	39
400	39

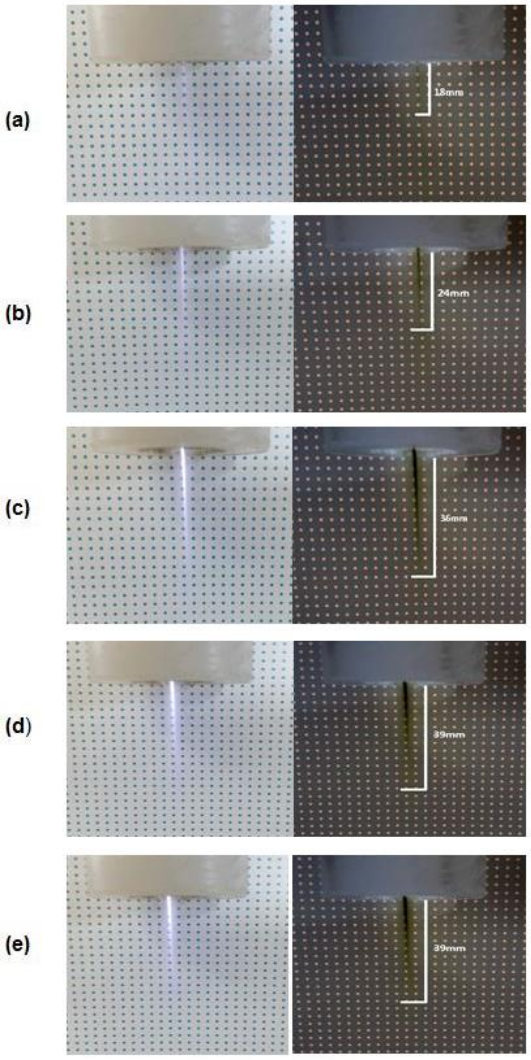


Figure 4. Device Tests (a) 100, (b) 150, (c) 200, (d) 250, & (e) 300 V_{RMS}

The waveform of the output signal was characterized using a digital oscilloscope and setting the power supply at the lowest possible voltage, Figure 5 shows the waveform obtained: the measured frequency was 24.98 kHz with a duty cycle of 50.2% rise time of 9.520 µs and fall time of 9.760 µs. For higher voltages the waveform of the signal remains unchanged.

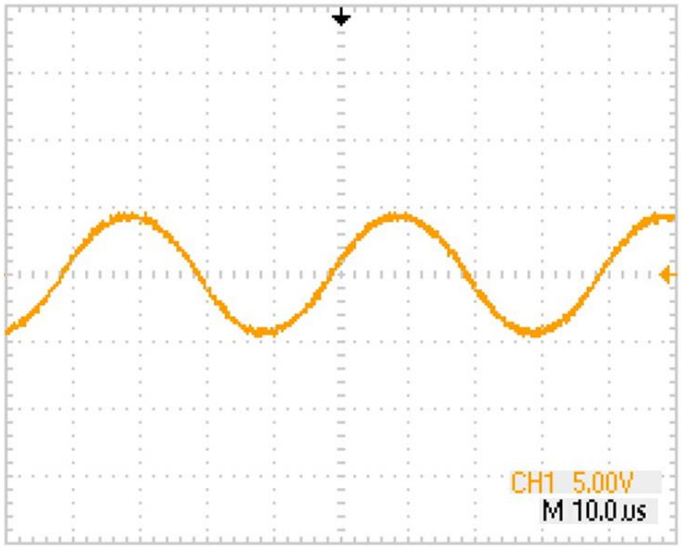


Figure 5. Output waveform from power supply

4. Conclusions

Small size of the reactor makes it suitable for operation in various applications including laminar flow chambers in which it can be used to study the interaction of the plasma with living tissues or bacteria.

Although no change was observed in plume length for voltages above 200VRMS is likely that if there is a change in the temperature of the plasma so in future is necessary to perform some plasma emission analysis to characterize plasma.

The most sensitive part of the device corresponds to the POM dielectric located between the hole for the gas and copper ring due to wear of the materials by the action of plasma, this is indeed the part that must be replaced more often.

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