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DESIGN AND CONSTRUCTION OF A PEN PLASMA DBD FOR USE BIOMEDICAL

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Abstract. *In this work was designed a pencil, designed and constructed a plasma DBD pen for biomedical use. Studies showed that Dielectric Barrier Discharge (DBD) produces a plasma in temperature range that is suitable for biomedical applications. The cold plasma is characterized mainly by the generation an ionized gas at room temperature and Atmospheric Pressure Plasma Jet (APPJ). Thus, this technology is interesting because it is inexpensive, environmentally friendly and very efficient. This technique has been applied to surface modification of biocompatible polymers. Moreover, the researchers have been using this technology to conduct a study to develop a device configured in the best condition to modify PCL for potential tissue-engineering applications. This device consists basically of a glass tube, two electrodes in a ring and rod and an insulating material. In this device, a source of high voltage and a compressed gas were used. This study showed the possibility of using this device for biomedical applications. To identify the jet length, a camera was used and to identify species produced during the discharge Optical Emission Spectroscopy (OES) was used. The intensity and length of the torch were also analyzed regarding the settings adopted. The results showed that variations of these parameters influence the formation of plasma jet. To ensure greater flexibility, a bench trial was designed to support the equipment. In this work, the optimal settings for the formation of jets to conduct effective on surface of polymers used in biomedical applications were determined.*

Keywords: *cold plasma, atmospheric pressure, plasma DBD, tissue-engineering.*

1. INTRODUCTION

Lately, atmospheric-pressure non-thermal plasmas have received much attention as a promising source in numerous applications. They can be used as analytical tools (Franzke *et al.*, 2003), photonic devices(Chen, 2005), for surface treatment of vulnerable materials(Laroussi e Lu, 2005), in bacterial inactivation processes(Uhm, Lim e Li, 2007), in thin films deposition (J. Benedikt *et al.*, 2006) and tissue-engineering applications. Particularly, the jet configuration in the generation of atmospheric non-thermal plasmas has become a key issue to attain high plasma stability during plasma chemistry reactions (Hong e Uhm, 2007). The reactive species produced from the plasma jets are blown out to a separate region for surface modification, obtaining plasma stability and an active plasma chemistry reaction (Hong. Yong Cheol, Uhm. Han Sup e Yi. Won Ju, 2008). These processes have been shown to alter surface functionality and topography including the wettability, adhesion properties, permanency, roughness, and have an effect on physical modifications such as cross-linking, chain scission and ablation (Paynter, Ménard e Benalia, 2004). Therefore, there is increasing interest in the biomedical applications of plasma processing. Investigations in this area have so far been aimed towards using plasma treatment to modify surface properties such as hydrophobicity/hydrophilicity ratio (Webb, Hlady e Tresco, 1998), surface energy (Daw *et al.*, 1998), surface charge (Shelton, Rasmussem e Davies, 1988) and surface roughness (Bos, Van Der Mei e Busscher, 1999), and towards improving the cell affinity of the polymer.

The plasma can be used to activate, sterilize, promote adhesion, improve biocompatibility and provide a friction barrier coating on medical polymers (Hegemann, Brunner e Oehr, 2003). Plasma treatment of polymer surfaces not only causes a modification during the treatment process but also leaves active sites at the surface which are subject to subsequent reactions, a process termed ageing (Guruvenket *et al.*, 2004).

If a polymer that has been treated with an inert gas plasma is exposed to atmospheric air after treatment for any time, the plasma-activated surface readily absorbs the moisture that is present in the environment, and long-living radicals, which exist on the surface after plasma treatment, react with oxygen species and ageing commences (Yang *et al.*, 2002).

In the ever-expanding field of tissue engineering, bioresorbable polymers have become more frequently used. Polycaprolactone (PCL), a bioresorbable polymer, offers certain advantages for tissue engineering applications, including cost, biocompatibility, processability and non-toxicity. However, one significant disadvantage is the surface hydrophobicity (Hirotsu, Ketelaars e Nakayama, 2000). The hydrophobic surface restricts cell interactions such as adhesion, proliferation and differentiation into mature cell and tissue types, thus limiting the range of applications of PCL in vivo.

Widespread use of plasma processing of polymers is still being impeded by difficulties in achieving permanent surface modification and in identifying, optimizing and controlling the effective plasma–surface interactions and their role in the modification of surface properties (Little *et al.*, 2009).

The use of such plasmas could eliminate the problems associated with use of heat and antibiotics. Therefore, the present work aims in designing an equipment with the similar a pen to create a cold plasma for be used in application biomedical. Thus, we briefly describe the effects of non-thermal plasmas to assess the feasibility of non-thermal plasmas to application biomedical. Therefore, the results showed this works has more potential for be used in biomedical applications.

2. MATERIALS AND METHODS

In this work we designed an atmospheric pressure pencil plasma to biomedical applications. An argon plasma jet source at atmospheric pressure was fabricated in a pencil-type design (Plasma Pencil Jet) to generate cold plasma and a plasma jet device driven by a microsecond pulsed dc voltage (HV source). To be possible to measure the high voltage we used a HV Probe of 1000:1 (Agilent: N2771B). Additionally, the characteristics of the argon plasma jet source were investigated based on electrical (Oscilloscope – Agilent: MSO-X 2002 with 2 canals) and optical emission measurements (Spectrometer and a computer together for look the Optical emission spectrum of Argon) that are shown schematicly in the experimental setup (figure 1).

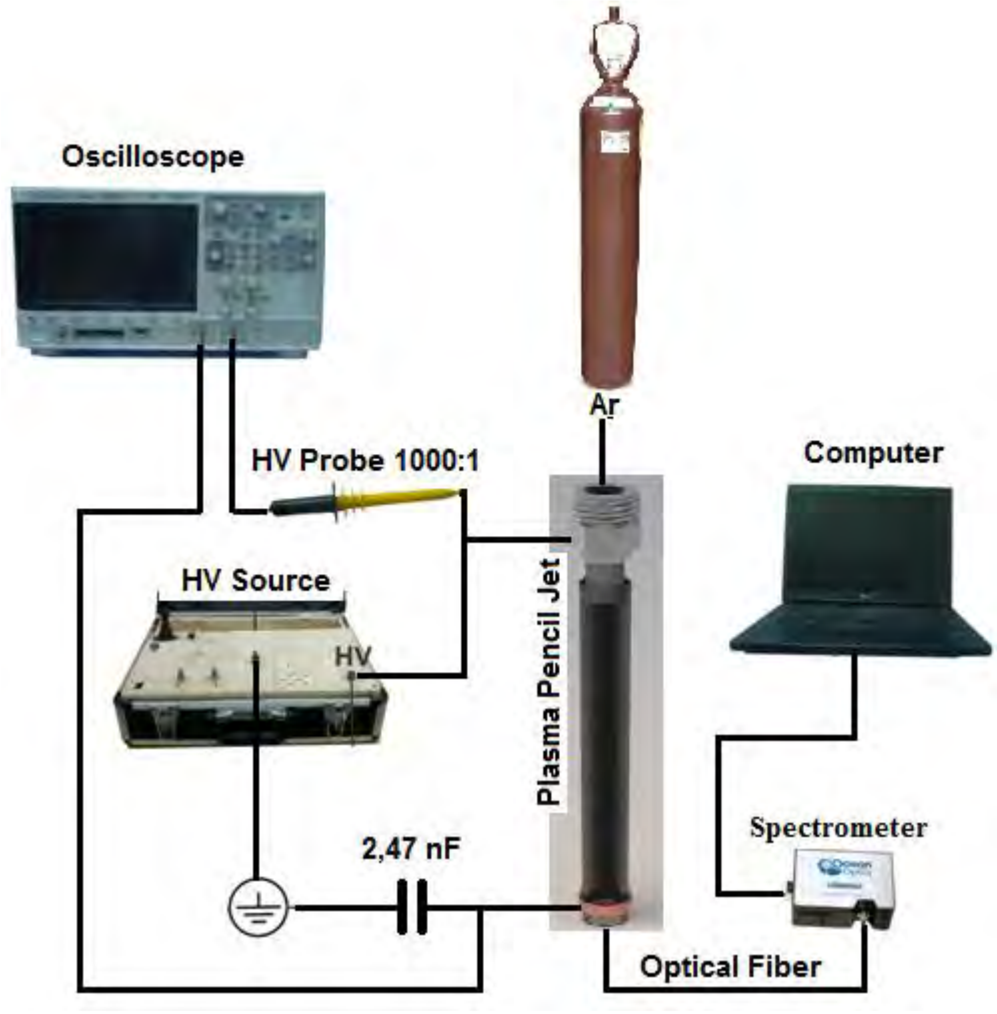

Figure 1. Schematic of the experimental setup

Figure 2 (a) shows schematic of a DBD-like plasma and figure 2 (b) shows a CAD presentation of the plasma jet device at atmospheric pressure used in this work. The pulsed dc voltage is connected to the inner electrode of stainless steel. The voltage controller regulates the primary voltage of the high-voltage transformer. There are two electrodes in this device. The first inner electrode is a hollow made of stainless steel with an inner diameter of 4,2 mm and a thickness of 1mm. The second is a copper ring electrode connected to the ground source. And between both electrodes there is a glass tube (dielectric tube) with an outer diameter of 12,1 mm and a thickness of 9mm. To secure the glass tube on the stainless steel electrode a rubber ring was used.

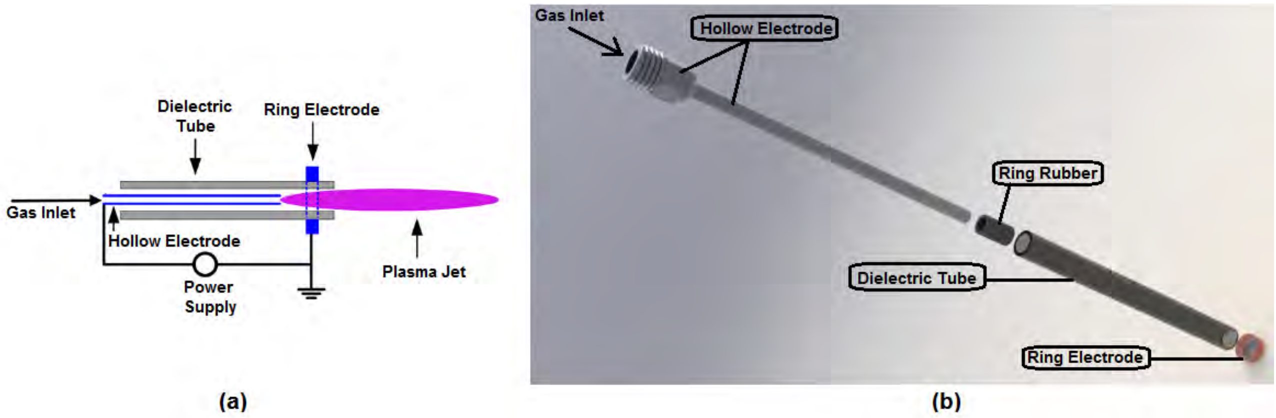

Figure 2. (a) Schematic of a DBD-like plasma jet and (b) CAD of the plasma jet device used this work

Once argon is injected into the hollow electrode and the dielectric tube, and high-voltage dc power is applied, a discharge is fired in the gap between the electrodes and 5 l /min is ejected to the open air, as shown in the inset of figure 3.

3. RESULTS AND DISCUSSION

When argon with a flow rate of 5 l /min is injected into the hollow barrel and the HV pulsed dc voltage amplitudes up to 50 kV and repetition rate up to 600 Hz are applied to the HV electrodes, a homogeneous plasma is generated in front of the end of the glass tube, along the nozzle, and in the surrounding air, as shown in Figure 3. The length of the plasma plume can be adjusted by the gas flow rate and the applied voltage amplitude and frequency. Besides argon, gases including helium, nitrogen, or even air could be used as the operating gas.

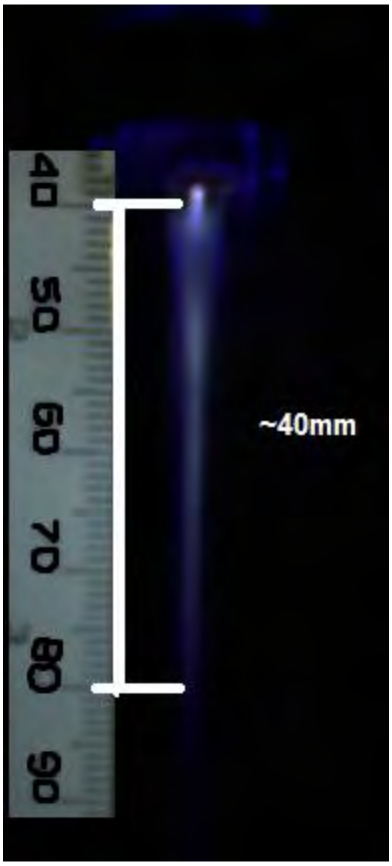

Figure 3. Photograph of the plasma plume with argon flow rate of 5 l /min.

When argon flows through the glass tube and the HV power supply is on, a cold plasma plume (about 35ºC) is generated in the surrounding air with a length of up to about 40 mm approximately as shown in figure 3.

When the plasma plume is not in contact with any object, the discharge like a DBD. However, when the plasma plume is in contact with an electrically conducting (a non-dielectric material) object, especially a ground conductor, the discharge is actually running between the HV electrode and the object to be treated (ground conductor) (Lu, Laroussi e Puech, 2012).

It is known that very small electrode structures combined with very high gas flow rates help reduce gas temperature in atmospheric plasmas, but this approach tends to result in variation in cycle-to-cycle plasma properties. The pulsed atmospheric Ar plasma jet does not rely on high flow rates of the background gas, and its electrical and optical properties have an excellent cycle-to-cycle repeatability (Walsh e Kong, 2007).

Figure 4 displays an optical emission spectrum that helps to identify various excited plasma species produced from the argon plasma jet. The optical emission spectrum was obtained from the plasma jet shown in Figure 3. The emission spectrum was dominated by the presence of excited nitrogen species. It contained excited nitrogen molecules N2 2nd positive system in a range of 337–405 nm and for the four strongest Ar lines at 696, 750, 763 and 772 mm. In previous articles, equidistantly spaced striated discharges were observed in monatomic gases with increasing powers.

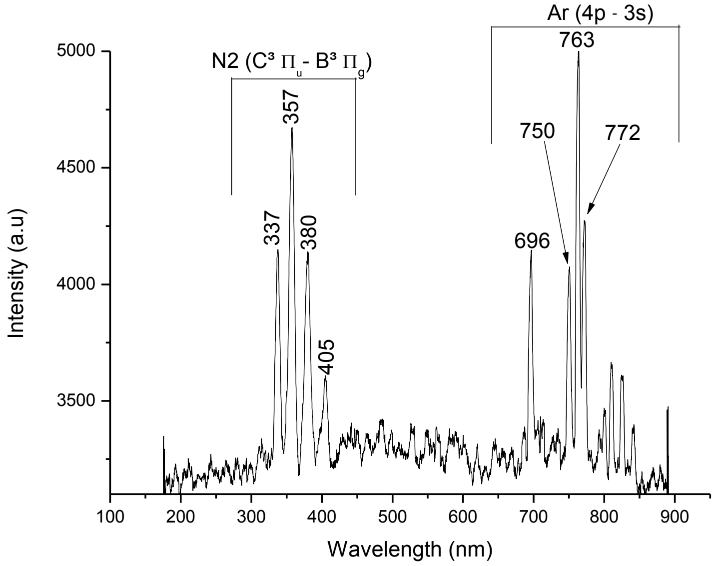

Figure 4. Optical emission spectrum of the microplasma jet at 5 l /m of Argon

Atmospheric pressure plasmas in DBD and APGD modes have been widely used for polymer surface modification (Janca *et al.*, 2001; Subedi *et al.*, 2008). In both cases, the treatment increases the hydrophilicity of polymers. Therefore, the discharge described in this paper can be used efficient for the treatment of poly(e-caprolactone) PCL. An increase in hydrophilicity of the sample is evident from review. For example, according to (Tyata *et al.*, 2013) the contact angle of a water droplet on untreated sample is 90° and after 6 s of exposure in the discharge the contact angle decreases to 45.5º. The decrease in contact angle can be attributed to the increase in surface roughness and incorporation of hydrophilic functional groups.

Several studies underline the effectiveness of the current DBD system, operating in an APPJ mode, for modifying PCL for potential tissue-engineering applications. Hydrophilic materials are particularly required for tissue engineering because they permit cell adhesion, and subsequent proliferation and differentiation into mature cell and tissue types. Several works showed that plasma discharge caused a significant reduction in contact angle, thus rendering the surface more hydrophilic. Optimum performance enhancement was achieved when the system was operating in a spatially uniform glow discharge mode. Previous papers demonstrated that the reduction in contact angle, and subsequent increase in wettability, is due to the cumulative effect of chemical (functionalization) and roughening alterations of the substrate surface properties (Little *et al.*, 2009) .

Plasma treatment has been shown by other authors to increase roughness, which causes an increase in surface area of the substrate surface. The increase in surface area increases the area of contact between aqueous solutions and the substrate surface, increasing binding sites, and hence improving hydrophilicity (Hegemann, Brunner e Oehr, 2003) .

The species showed in the spectrum (fig. 4) were also found by others authors (Janca *et al.*, 2001; Subedi *et al.*, 2008). Therefore, this device can be used to reach the same surface modification, because the equipment produces species that increase surface roughness and incorporation of hydrophilic functional groups.

4. CONCLUSION

In this work, a pen plasma DBD was designed and constructed for biomedical use**.** The device made jet with a length of up to about 40 mm and displayed an optical emission spectrum that helps to identify various excited plasma species produced from the argon plasma jet. The optical emission spectrum was obtained from the plasma jet. The emission spectrum was dominated by the presence of excited nitrogen and argon species. These characteristics can be used in biomaterials, because these species can increase the hydrophilicity of biopolymers. Therefore, the discharge described in this paper can be used efficient for the treatment poly(e-caprolactone) PCL. Several studies underline the effectiveness of the current DBD system, operating in an APPJ mode, for modifying PCL for potential tissue-engineering applications. Therefore, this device can be used to reach the same surface modification, because the equipment produces species that increase in surface roughness and incorporation of hydrophilic functional groups.

5. ACKNOWLEDGEMENTS

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