Development of plasma needle to be used for biomedical applications

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Abstract. Plasma needle is a novel design of a plasma source at atmospheric pressure to achieve a non-thermal plasma jet. The advantage of the plasma needle is that it can be operated in open air, outside a vessel. The plasma that is generated with the plasma needle is small (about one millimetre) and non-thermal, the temperature of the neutral particles and ions is in about room temperature and suitably can interact with living biological cell without damaging the cell. In this work, we report the development of a plasma needle, which is operated by a dc power source and produced a stable plasma jet on water surface. Argon gas is used to operate the plasma needle. The preliminary electrical diagnostics of the plasma needle shows that the discharge is filamentary in nature. For diagnostic of the plasma jet produced by the developed plasma needle, the produced plasma jet is directed to water surface and characterization are carried out by means of electrical discharge characteristics and optical emission spectroscopy. In this work, preliminary results of the diagnostic will be presented.

1. Introduction
The plasma needle is a type of non-thermal atmospheric glow discharge; it has a single-electrode configuration and it is a novel design of a plasma source at atmospheric pressure to achieve a non-thermal plasma jet[1]. The advantage of the plasma needle is that it can be operated in open air, outside a vessel. The plasma that is generated with the plasma needle is small (about one millimetre) and non-thermal, the temperature of the neutral particles and ions is in about room temperature and suitably can interact with living biological cell without damaging the cell. Important properties of this type of plasma are that it operates near room temperature, allows treatment of irregular surfaces and has a small penetration depth. These characteristics give the needle great potential for use in the biomedical field. Several experiments have shown that the plasma needle is capable of bacterial decontamination [2] and of localized cell removal without causing necrosis to the treated or neighbouring cells [3]. Areas of detached cells were made with a diameter of 0.1mm, which indicates...
that the precision of the treatment can be very high. It is believed that plasma particles, such as radicals and ions, and also emitted UV light, interact with the cell membranes and cell adhesion molecules and therefore cause detachment of the cells [3,4]. In this work, we report the development of a plasma needle, which is operated by a dc power source and produced a stable plasma jet which can interact with living cell. Argon gas is used to operate the plasma needle. The preliminary electrical diagnostics of the plasma needle shows that the discharge is filamentary in nature. For diagnostic of the plasma jet produced by the developed plasma needle, the produced plasma jet is directed to water surface and characterization are carrying out by the means of electrical discharge characteristics and optical emission spectroscopy. In this work, preliminary results of the diagnostic are presented.

2. Experimental setup
The plasma needle consist of a metallic needle covered by several well machined Teflon pieces for flow of argon and electrical connection. A photograph of the plasma needle along with the components are shown in figure 1. The current have been measured by a set of Tektronix current probes (CT1 and TCP 312A along with TCPA 300). The current have been also estimated by measuring the voltage drop across a 45 Ω resistance connected in series with the discharge. The discharge voltages at the electrode is measured by a Tektronix voltage probe (P6015A). The voltage and current data are recorded with the help of Tektronix oscilloscope (MDO 3034).

3. Result and discussion
A typical image of the plasma jet interacted with human hand is shown in figure 2. However, for details characterization of the plasma jet, the plasma jet is operated on the water surface to mimic the interaction of the plasma with living cell and stability of the plasma jet. The plasma jet operated on the water surface are shown in figure 3.
Figure 2. Photograph of the plasma jet interacted with human hand.

Figure 3. Photograph of the plasma jet operated on water surface.

Figure 4 shows the electrical discharge characteristics of the plasma needle operated over water surface at two different power supply voltage of 3 kv and 5 kV. From the preliminary electrical characteristics of the plasma needle, it have been observed that the discharge is filamentary in nature. It have been observed that the increased in the voltage of the power supply increases the frequency of the discharges without considerably affecting the discharge voltage and current. A typical optical emission spectra (OES) are shown in figure 5. Several prominent Ar lines are observed in the spectra.
Figure 4. Electrical discharge characteristics of the plasma needle for power supply voltage of (a) 3 kv and (b) 5 kv.

Based on the intensity of the emission spectral lines it is possible to estimate the excitation temperature of the plasma. The calculation of temperature can be made by either the intensity ratio of two lines or Boltzmann plot method. The error related to measurements can be reduced by considering several lines by Boltzmann plot method [5, 6].

Considering $I_1$ and $I_2$ as the intensity peaks at two different emissions at wavelength $\lambda_1$ and $\lambda_2$, the ratio is given by [5],

![Intensity vs Wavelength](image.png)

Figure 5. Photograph of the plasma jet operated on water surface.
Where, $A$ is the Einstein coefficient of spontaneous emission (transition probability), $g$ is the statistical weight of the upper level of transition, $E$ is the energy of the upper level of the transition, $k$ is Boltzmann’s constant and $T$ is the temperature. The plasma temperature can be calculated by above equation on the basis of line intensity ratio by measuring the spectral intensity of two lines. However, the Boltzmann plot method is more accurate and reliable than the line intensity ratio method since several spectral lines are involved in Boltzmann plot method.

In general, the intensity $I_i$ for a particular spectral line can be express as [5],

$$\ln \left( \frac{I_i}{g_i A_i} \right) = \ln \left( \frac{h c}{4 \pi \rho_0} \right) - \frac{E_i}{kT}$$

where $l$ is the path length, $h$ is Planck’s constant, $c$ is the light velocity and $\rho_0$ is the density of atoms. By plotting the term $\ln (I_i \lambda_i / g_i A_i)$ as a function of $E_i$, the slope $1/kT$ of which gives temperature, since the first term in the right hand side are constant and does not depend on the particular spectral line. A typical Boltzmann plot of the emission spectra of the plasma jet produced by the plasma needle is shown in Fig. 6. The excitation temperature calculated from the OES using Boltzmann’s plot method are found to be approximately 0.6 ev. It have been observed that the variation of the excitation temperature with changing the discharge voltages is almost negligible. However, details studies is underway.

![Figure 6. Typical Boltzmann’s plot for the plasma jet produced by the plasma needle.](image)
4. Conclusion
A plasma needle have been developed by using a dc power source. The plasma jet produced by the plasma needle can easily interact with human body. Preliminary characterization of the plasma needle by the means of electrical discharge characteristics and OES are carried out.

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