

# SELECTION OF SUITABLE DIAGNOSTIC TECHNIQUES FOR AN RF ATMOSPHERIC PRESSURE PLASMA

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## 1 Introduction:

With their successful applications to many technologically important applications such as etching[1], deposition[2], surface modification[3], and sterilization[4], nonthermal gas discharges generated at atmospheric pressure have recently commanded much interest. Motivated by the considerable cost reduction afforded through the elimination of vacuum system and by the rich physics of these relatively new plasma systems, we have very recently started at Loughborough University a primarily experimental study of a capacitively coupled RF atmospheric pressure gas discharge system. Our study is in its first six months and one current objective is to identify and develop simple and low-cost diagnostic techniques that can adequately and effectively characterize major plasma properties. This would eventually allow the development of a cost-effective atmospheric pressure plasma system, simplistic not only in rig configuration (no vacuum system) but also in associated diagnostics techniques (for easy system integration at a future development stage).

As an early report of our study, this paper summarizes the RF atmospheric pressure plasma system we intend to characterize and a number of diagnostic techniques presently under assessment for our plasma rig. By discussing the advantages and disadvantages of these diagnostic techniques at this meeting, we hope to gain feedback and comments to improve our choice of appropriate diagnostic techniques as well as our subsequent application of these techniques to nonthermal RF atmospheric pressure plasmas.

## 2 Configuration of an RF Atmospheric Pressure Plasma Rig:

Our atmospheric pressure plasma rig consists of two parallel plates each of 15cm long and 10cm deep as shown in figure 1. The lower electrode is connected to an RF source of up to 800 watts and having two frequency settings, one at 13.56MHz and the other at 27.12MHz. The upper electrode is grounded with a hollow structure for water cooling. Neither electrode will normally be insulated with dielectric coating, and the gap between the two electrodes can be controlled between 1mm to 2cm by using different quartz spacers. The two gasfeed sides of the plasma generating area are sealed with insulating spacers (eg quartz) and the two sides (along the gas flow direction) are sealed with quartz sheets for visual inspection and possible optical emission measurement. We will use a mixture of helium and oxygen as the working gas for the majority of our experiments although other gas mixtures will also be considered at a later stage.

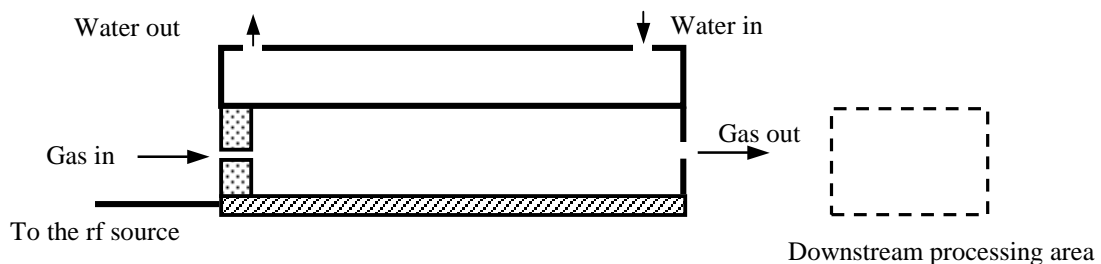


Figure 1 Schematic of an RF atmospheric pressure gas discharge system (not to scale)

The plasma configuration described above is designed for remote processing at a downstream point, and it is very similar to that studied by the UCLA/LANL group[1][5]. However both variation in excitation frequencies and modification to the electrode configuration are planned for the above-described basic configuration so that the gas temperature may be lowered from what is achievable at present (75°C – 200°C) for this type of nonthermal atmospheric pressure plasmas. In their recent experiments, the UCLA/LANL group was able to ignite a

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nonthermal gas discharge at around 130V of an applied 13.56MHz power supply and with a electrode gap of a few millimetres[1]. Therefore by choosing similar parameters for the RF source, the gap distance, and the gas flow rate, we should be able to generate a similar nonthermal plasma at atmospheric pressure. With a successful generation of a nonthermal atmospheric pressure plasma, we plan to increase the excitation frequency and/or modify the electrode configuration to obtain nonequilibrium atmospheric pressure plasma again but with a reduced rf power. This is to reduce the gas temperature to allow for a wider range of applications.

### 3 Assessment of Appropriate Diagnostic Techniques:

While different applications require different sets of excited species, free radicals, and charged particles, we restrict our study to applications that rely on production of reactive oxygen species such as oxygen atoms and metastable molecular O<sub>2</sub>, such as ashing of photoresist films[5] and biological sterilization[6]. To obtain basic understanding of plasma characteristics of our nonthermal atmospheric gas discharge and to indicate its efficacy for generation of reactive oxygen species, we assess various diagnostic techniques against the following physical quantities or relationships.

#### 3.1 Current-voltage relationship:

It is known that many nonthermal atmospheric pressure plasmas exhibit a current-voltage relationship very similar to that of low pressure DC glow discharges. Therefore it is useful to perform this relatively straightforward electrical measurement as an indicator of the nonthermal nature of the generated plasma. Many rf power supply manufacturers also provide associated voltage and current measurement modules for their power supplies, and so this measurement can be set up easily.

#### 3.2 Spatial uniformity of the plasma, electron temperature, and neutral temperature:

The plasma rig is configured to have quartz windows for visual inspection, and this is useful to obtain a simple indication of the spatial uniformity of the plasma. Although our intended processing is to be in a downstream area, this information would allow us to assess the possibility of in-plasma processing for the future.

Quartz windows also facilitate optical emission spectroscopic measurements of electron temperature. For a thorough understanding of plasma physics of the generated nonthermal atmospheric gas discharge, electron temperature is in general a very important quantity and ideally should be measured. However we do not at present have access to an optical spectroscopic measurement system nor can our budget afford this relatively expensive instrument. Given that electrons and ions have very low number densities in the gas effluent used for remote processing[5] and they are not considered to contribute significantly to our intended applications (ashing photoresistive films and sterilizing biological bugs)[5][6], we plan to postpone measurement of electron temperature until cheaper alternative methods are identified.

Gas temperature can be easily measured with thermal couples both within the plasma generating structure and at the downstream processing area.

#### 3.3 Number densities of charged particles:

Densities of charged particles within the plasma producing structure (the quartz sealed unit) are important to understand the discharge plasma, and their values in the downstream processing area are also crucial for assessing their roles in the plasma processing achieved. Langmuir probe techniques have been used to determine densities of charged particles for some nonthermal atmospheric pressure plasma systems[5], although no discussions have been provided so far to examine the applicability of Langmuir probe techniques for high pressure plasmas. We plan to employ the standard probe configuration with negative biasing so as to measure ion flux and so ion density, but will pay particular attention to its use for high pressure plasmas. To this end, we will also seek opinions and comments at the meeting. As a comparing technique, we plan also to use a generalized Ohm's law to estimate electron density from power density using

$$J = \sigma E = en_e \mu E \quad (1)$$

where  $\mu$  is the electron mobility. This technique has been used for microhollow cathode discharges at atmospheric pressure.

#### 3.4 Densities of excited species and radicals:

To relate processing efficiency to densities of excited species at the downstream processing area, we need to measure densities of ozone, O atoms, and metastable molecular O<sub>2</sub> (both <sup>1</sup>Δ<sub>g</sub> and <sup>1</sup>Σ<sub>g</sub><sup>+</sup>) as well as their dependence on distance from the gas exit point of the plasma producing structure. The amount of ozone generated may be measured using an electrochemical ozone detector. While this approach may be simple to

implement, we recognize that ozone concentration can also be measured using ultraviolet absorption spectroscopy[5]. Again this second method is not at present an option for us, and so it is useful for us to gain comments on the difference in their accuracy at the meeting.

With regard to metastable molecular O<sub>2</sub>, optical emission spectroscopy has been used to measure the concentration of singlet-sigma metastable oxygen and infrared emission spectroscopy has been employed to determine the concentration of singlet sigma metastable oxygen[5]. Similar to our previous standpoint, we consider these spectroscopy based techniques are not practical for us simply because we do not have access to relevant instruments. As a result, we are yet to identify techniques to determine densities of O atoms and metastable molecular O<sub>2</sub> for our planned study. As an alternative, we plan to carry out reaction chemistry modelling to provide us some indications of concentration of these excited species.

#### 4 Concluding remarks:

The experimental techniques considered and their intended plasma diagnostics will provide us some basic characterization of our RF atmospheric pressure plasma system, a very useful first step in our attempt to eventually gain a full understanding. Numerical modelling of the plasma physics is also underway and this theoretical work will further enhance our understanding. Nevertheless due to our present lack of experimental determination of concentrations of excited oxygen species, combinations of system parameters and modifications to the basic rig configuration cannot be confidently and purposely adjusted to optimize the application of these nonthermal atmospheric plasmas. To introduce an optimization mechanism, we plan to characterize the efficacy of our plasma system through their effects on sterilization of bacteria, which can be quantified using conventional microbiological techniques.

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