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Generation and Characterization of Atmospheric Pressure Air Plasma and Finding its Applications

By M.A. Rahman, M.K. Saha, M.K. Alam & M.R. Talukder

University of Rajshahi

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GENERATION AND CHARACTERIZATION OF ATMOSPHERIC PRESSURE AIR PLASMA AND FINDING ITS APPLICATIONS

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Generation and Characterization of Atmospheric Pressure Air Plasma and Finding its Applications

M.A. Rahman [α], M.K. Saha [σ], M.K. Alam [ρ] & M.R. Talukder [ω]

Abstract - A high voltage RF plasma source is designed to produce atmospheric pressure air plasma. The plasma is produced at different electrode configurations. Properties of such plasma depend on several parameters such as frequency of the plasma generating source, input power and gas flow rate. The produced plasma is characterized by different diagnostic techniques in order to determine gas temperature, electron temperature, and electron density. It is desired to find out applications of such atmospheric pressure air plasma in food processing, surface modification, and material processing. One of the most fascinating applications of atmospheric pressure plasmas is its use for biomedical applications because of its capability of producing various biocidal agents including reactive species, UV radiation, and charged particles [1].

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I. Introduction

Plasma is a more or less ionized gas. It is the fourth state of matter and constitutes more than 99% of the universe. As temperature increases, molecules become more energetic and transform in the sequence: solid, liquid, gas, and plasma. In the latter stages, molecules in the gas dissociate to form a gas of atoms and then a gas of freely moving charged particles, electrons, and positive ions. This state is called the plasma state. It is characterized by a mixture of electrons, ions, and neutral particles moving in random directions that, on average, is electrically neutral ($n_e = n_i$) [2].

Plasma is created by applying energy to a gas in order to reorganize the electronic structure of the species (atoms, molecules) and to produce excited species and ions. This energy can be thermal, or carried by either an electric current or electromagnetic radiations. Due to a large diversity of possible applications [3–7], development of the devices aimed to generate atmospheric pressure plasmas have attracted a significant research effort in recent years. In order to ignite an electrical discharge at atmospheric pressure and maintain the plasma in a regime appropriate to a specific application, various electrical supply schemes, including superposition of a time varying periodic voltage to a dc voltage, have been developed. For the atmospheric pressure plasma source presented in this paper, the high voltage pulses produced by a self-oscillating fly back converter (FBC) are superimposed to a relatively low dc voltage. A FBC is very simple and has a good efficiency because it can be connected to the load without a ballast resistor. These devices require a high voltage pulse to initiate an arc discharge between the electrodes. Once the arc discharge has been ignited, another electrical circuit supplies the proper voltage and current for the discharge to run. Depending on the way they are activated and their working power, they can generate low or very high ''temperatures'' and are referred correspondingly as cold or thermal plasmas. This wide temperature range enables various applications for plasma technologies: surface coatings, waste destruction, gas treatments, food processing, chemical synthesis and also for biomedical application.

II. Design of Plasma Source

Figure 1 shows a schematic of the experimental set-up for optical emission spectroscopy (OES) measurements. The electrical circuit of the electrodes consists of two voltage sources in parallel connection. One of them is a low-power self-oscillating FBC able to produce negative high voltage pulses necessary to initiate an electrical discharge between electrodes. The second one is a conventional dc source which is used to sustain the electrical discharge. The FBC consists of the transformer, bipolar junction transistor and bias resistors. Discharge chamber is constructed from 0.35 inch (9 mm) ID stainless steel tube. The body of the chamber is grounded. There are gas inlet, view port and pressure gauge (HISCO, 131P30A) on one end plate and vacuum pump inlet, probe placing inlet and electrode placing on the other end plate. A transparent 4 mm width glass has been used for end view photos. Two copper electrode of cross section 2.6268 mm2 and the spacing ranging 0.5 to 3.00 mm are inserted through the electrode placing inlet in the chamber. We use spectrophotometer (Ocean Optics USB2000+XR1) and interface it with a computer to record the data.

Author α : Lecturer Dept. of Applied Physics & Electronic Engineering, University of Rajshahi, Rajshahi 6205
E-mail : arifour_rahman@yahoo.com
Author σ : M.Sc. Applied Physics & Electronic Engineering, Rajshahi University, Rajshahi, 6205.
Author ρ : Asst. Professor, Dept. of Physics, Pabna University of Science and Technology, Pabna 6600.
Author ω : Professor, Dept. of Applied Physics & Electronic Engineering, Rajshahi University, Rajshahi, 6205.

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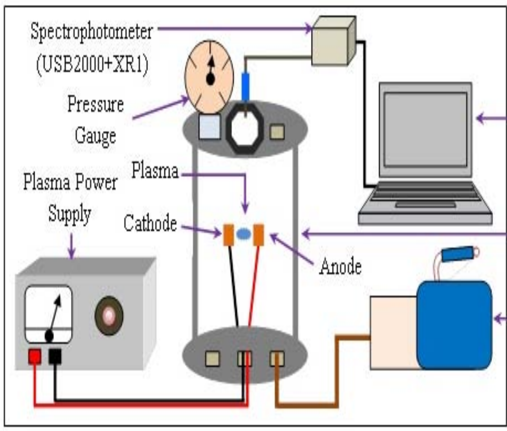

Figure 1 : schematic of the experimental set-up for optical emission spectroscopy (OES) measurements

III. Plasma Source Operation

In this paper we use 220 V AC of frequency 50 Hz. This AC voltage is converted to 24 V DC. We have been used 8200 μF 50V capacitor for dc filter. This supply is capable of supplying 3.0 A current. We have designed flyback converter circuit according to our requirements and secondary voltage and current are 5 KV and 50 mA, respectively at frequency 20 KHz. Discharge chamber has been used to reduce dust, water molecules etc from the air used to produce plasma. The geometrical structure and visible light emission distribution of the plasma are found to strongly depend on the applied power. Especially, the volume of the generated plasma is directly dependent on the magnitude of the applied voltage and frequency. Plasma is generated as long as the applied electric field across the discharge gap is high enough to initiate a breakdown. As expressed in Paschen's law (Eq. (1)),

$$V_b = \frac{B\,(p.d)}{\ln[A\,(p.d)] - \ln[\ln(1+1/\gamma_{se})]} \qquad (1)$$

the breakdown voltage [Vb] required to ignite the discharge is dependent on the process pressure [p] and the gap distance [d] between the electrodes, given that the discharge is confined between two electrodes, and [γ_{se}] is the secondary ionization coefficient for air. Constants A and B depend on the composition of the gas, their values for air are A=15 cm^{-1} Torr^{-1} and B= 365 V cm^{-1} Torr^{-1} [8]. Figure 2 shows the breakdown voltage of parallel plates in gas as a function of pressure and gap.

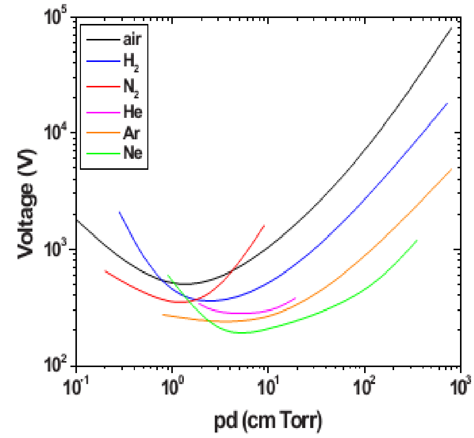

Figure 2 : Breakdown voltage of parallel plates in a gas as a function of pressure and gap distance for various gases [9]

As depicted in Figure 2, under atmospheric pressure conditions the electric field required to initiate the discharge is quite high because air is used as reactant gas. For example, atmospheric and higher pressure breakdown in dry air requires more than 30 KV with a 1 cm gap between electrodes. Even when the gap distance is shortened to d ≈ 1 mm it still requires about 3 KV at 1 atmospheric pressure. That is why the discharge gaps for most atmospheric pressure discharges are from mm to few cm. On the other hand, from the applications point of view, the short discharge gaps signficantly limit the size of the objects to be treated if direct treatment (when to the gaps and the active radicals of the plasma reach the object byflowing with the gas) is applied, active radicals with short lifetimes and charged particles may already disappear before reaching the sample to be treated. the object is placed between the gaps) is desired [10]. If indirect treatment (the object is placed next To overcome the shortcomings of the traditional atmospheric pressure non-equilibrium plasmas, plasmas generated in open space rather than in a con fined dischage gap are needed.

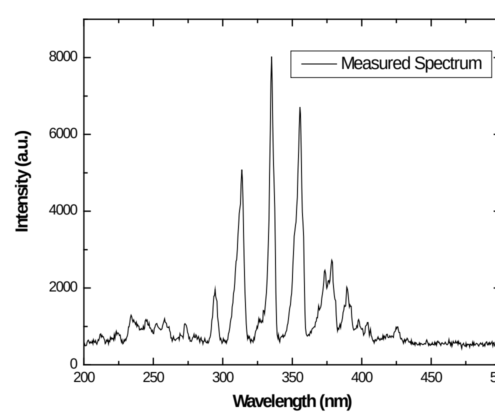

Figure 3 : Significant part of the observed spectrum of air plasma at atmospheric pressure (760 Torr)

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Figure 3 shows significant part of the observed spectrum of air plasma at atmospheric pressure (760 Torr). The spectral range of the spectrograph is from 200 to 500 nm. We have employed Stark broadening to calculate electron density and the electron density is 6.4×10^{22} m^{-3}. In addition, we have also calculated (using air spectra) Electron temperature 9500K, Rotational temperature 4500K, Translational temperature 4000K and Vibrational temperature 5000K.

IV. Areas of Application

Our investigations are aimed at air plasma discharges at atmospheric pressure. Plasmas generated in atmospheric pressure have attracted increasing attention in recent years since they do not require vacuum chambers or pumping systems, and are capable of continuous plasma processing. Atmospheric pressure plasma devices developed and made available commercially thus far can generate plasmas from room temperature helium, argon, or air. The atmospheric pressure discharge plasmas afford new parameter regions, for example, (i) high density, (ii) minute scale, and (iii) non-equilibrium, which are different from the conventional plasma regions [11]. Atmospheric pressure air plasma sources are widely used for numerous diversified applications such as air pollution control, bio-decontamination, material processing, plasma-assisted combustion, aerodynamic flow control, and electromagnetic wave shielding [12]. In many cases atmospheric pressure air plasma sources have certain limitations and cannot compete with low pressure plasma. At the same time they have a very promising unique potential for a number of new non-conventional applications, including new surface treatments and processing of materials. The atmospheric pressure air plasma sources also have low maintenance requirements resulting in relatively low energy costs.

V. Conclusion

In this paper a plasma source, operating at atmospheric pressure, supplied practically at a relative low dc voltage by means of a simple and inexpensive electrical circuit, is presented. Circuit topology enables a high efficiency of the electrical energy to plasma energy conversion. The plasma parameters that we have calculated (electron density, electron temperature, rotational temperature, vibrational temperature, transitional temperature) indicates that this designed plasma source can be used for various eco-friendly industrial applications as it can produce substantial amount of reactive species and avoid thermal damage. Such a source can be used to break down hazardous & toxic compounds to elemental constituents by high temperatures. Air plasma, which breaks down the surrounding air rather than an external fed noble gas, is also attracting attention because it has great potential in various biomedical applications and it is highly portable as it only requires a handy discharge device and a power source [13].

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