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ELECTRICAL AND OPTICAL CHARACTERIZATION OF DIELECTRIC BARRIER DISCHARGE PRODUCED IN ATMOSPHERIC AIR

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ABSTRACT
This paper reports the results concerning the production of Dielectric Barrier Discharge (DBD) at atmospheric pressure air and its electrical and optical characterization. The discharge was produced by applying high voltage AC source of frequency (10-30) kHz and potential difference of (0-20) kV across the electrodes. The discharge was characterized by measuring current and voltage with a high frequency digital oscilloscope. The optical characterization was made by taking the spectrums of discharge by optical emission spectrometer. The optical spectra in the range of 200 nm to 450 nm have been analyzed in order to estimate the electron temperature by intensity ratio method. Results showed that the electron temperature is about 1.9 eV.

Key words: DBD, emission spectra, electron temperature, non-equilibrium plasma

INTRODUCTION
In recent years, non-equilibrium plasmas under atmospheric pressure have been developed as an effective means for surface modification of polymers (Shenton and Steven, 2001; Fang Qiu and Y Luo, 2003).These plasmas possesses unique features that have led to a number of important applications such as ozone production, pollution control by oxidation of volatile organic compound or nitrogen monoxide, bio-treatment of micro-organisms by oxidation, surface treatment (thin film deposition, surface modification), UV or VUV generation, aerosol charging and electro-filtration (Hammer, 1999; Kogelschatz *et al*., 1999; Tepper *et al*. 2000; McAdams, 2001; Fridman *et al*., 2005). They are rapidly being popular due to their many advantages, such as having no need for expensive vacuum equipment, being low cost and simple systems, and easy to operate (Bogaerts, 2002). The existence of the thermal non-equilibrium between the electron, the ions and the neutrals is the realm of non-thermal plasmas in which the electron temperature can exceed the temperature of the heavy particles (atom, molecules, ions) by orders of magnitude. Since the ions and the neutrals remain relatively cold, these plasmas do not cause thermal damage to surfaces they may come in contact with (Borcia, 2006). This characteristics provides the possibility of using these plasmas for low temperature plasma chemistry and for treatment of heat sensitive materials including polymers and biological tissues. Usually the DBD plasma consists of many tiny micro-discharges (or filaments) of nanosecond or microsecond duration. The homogeneity of the DBD is very desirable for industrial applications especially for surface treatment processes.
Atmospheric plasma source has been developed in a wide range of frequencies from DC to microwave, RF or in a short pulse (Moisan, 1992; Park, 2001; Simor, 2002; Moon,

2002; Guo, 2003; Moon and Choe, 2004). The characteristics of the discharges are controlled by the operating parameters voltage, frequency, gap width, nature of materials of reactor and nature and operating conditions like gas flow rate, temperature and moisture. In the present study, the discharge was produced by applying 10 –30 kHz, 0 –30 kV AC source. The details of the electrical system used in our experiment are also reported earlier (Shrestha, 2007).

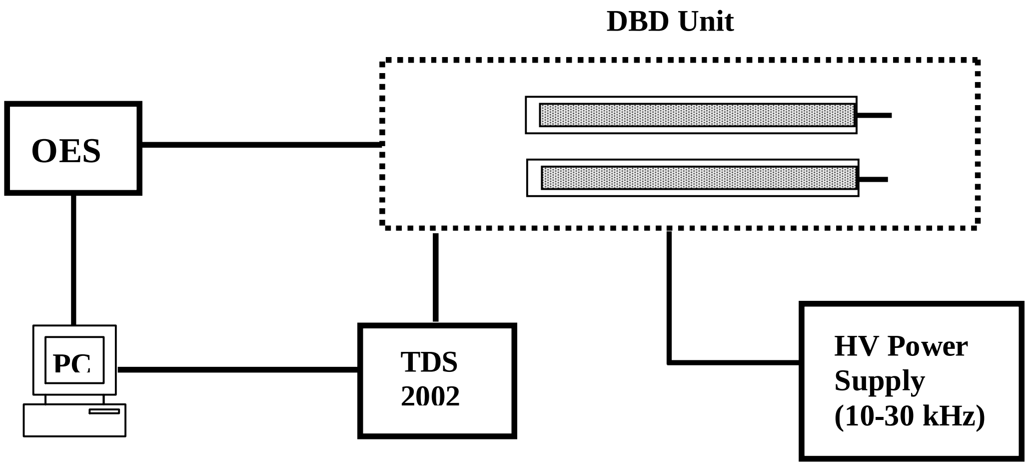

Fig. 1. Schematic diagram of the experimental set-up. OES: Optical Emission Spectrometer, TDS 2002: High Frequency Digital Oscilloscope.

EXPERIMENTAL PROCEDURE

Fig. 1 shows the schematic diagram of the experimental set-up used in our study. A high voltage power supply of frequency 10-30 kHz was used to generate the discharge in the air gap between two cylindrical electrodes covered by dielectric medium. The power supply was fabricated indigenously at the department of electrical and electronics engineering, Kathmandu University. The electrodes are made of brass and the dielectric material is glass of thickness 2mm. The current and voltage of the discharge were measured by high frequency digital oscilloscope (Tektronix TDS 2002). For optical characterization, the most commonly used method is optical emission spectroscopy (OES). For OES measurement, the light emitted by the discharge is detected by optical emission spectrometer via an optical fiber. The OES is connected to a personal computer where the corresponding spectra are recorded. The applied voltage, discharge current and spectrum are simultaneously measured and analyzed.

RESULTS AND DISCUSSION

Electrical Characterization

Figure 2 shows the voltage and current waveforms of the discharge when the peak voltage was 9.15 kV and peak current 0.28 mA. The DBD is characterized by a number of short life-time micro-discharges created over the surface of the dielectric material. The micro-discharges are generated when the applied voltage exceeds the breakdown voltage of the gas. These micro-discharges extinguish when the charge build-up on the dielectric reduces the local electric field. Numerous spiky current pulses of micro-discharges are superimposed on the positive and negative half-periods of current waveforms. Power consumed in the discharge corresponds to the product of current and voltage. In the present condition of the discharge the calculated power was found to be equal to 2.56 W. It is important to note that only the spiky parts of current waveforms are used for the formation of reactive species such as O, OH and O_3. The generation of OH free radicals in the discharge was indirectly observed by the increased hydrophilicity of a polymer sample treated in the discharge whereas the generation of O_3 was detected through the typical ozone odor. Our future work in DBD characterization will be extended to monitoring ozone concentration by chemiluminescene analyzer and a portable flue gas analyzer.

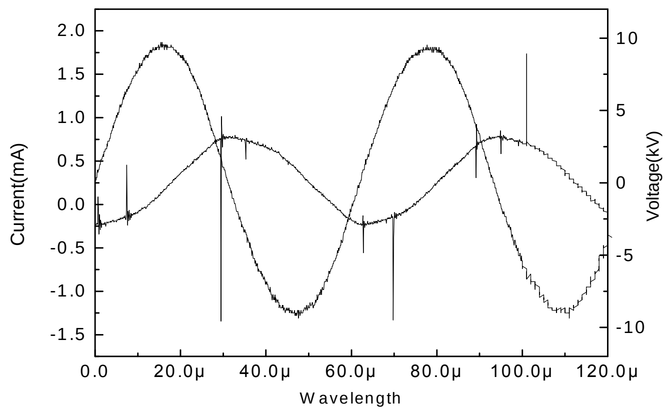

Figure 2: Current and voltage waveforms of a DBD in air with inter-electrode gap of 2 mm.

Optical Characterization

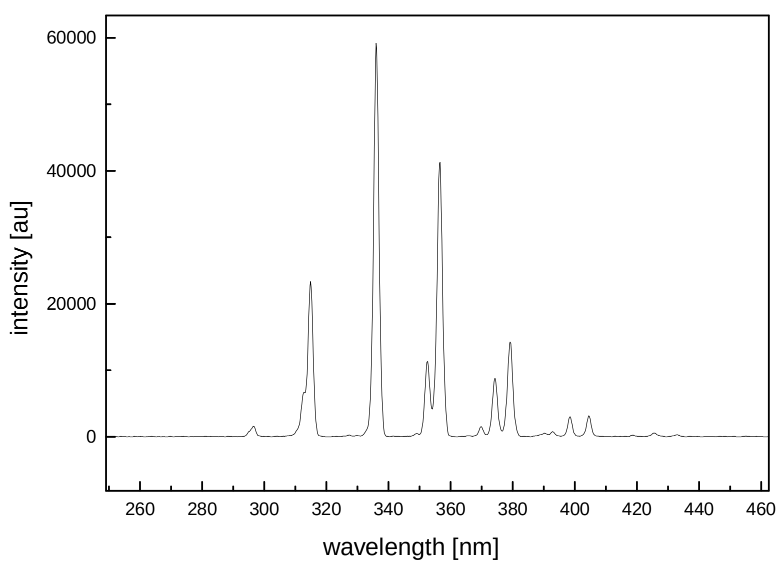

Figure 3 OES of DBD between 250 nm and 450 nm.

Figure 3 shows the OES from the discharge between 250 nm and 450 nm with 2mm electrode gap. Four suitable lines (two for NI and NII) are chosen and electron temperature is estimated using the line intensity ratio method. For the measurement of electron temperature, the following equation is used.

$$\frac{R_1}{R_2} = \frac{I_1/I_2}{I_3/I_4} = \left(\frac{A_{pq}}{A_{xy}}\right)\left(\frac{g_p}{g_x}\right)\left(\frac{\lambda_{xy}}{\lambda_{pq}}\right)\left(\frac{A_{uv}}{A_{rs}}\right)\left(\frac{g_u}{g_r}\right)\left(\frac{\lambda_{rs}}{\lambda_{uv}}\right)\exp\left[-\frac{E_p - E_x - E_r + E_u}{kT_e}\right]$$

where R is the ratio of intensity of two lines, I is the intensity of the spectral line, A_{ij} is the transition probability of transition $i \rightarrow j$, g_i is the statistical weight of the upper level, λ is the wavelength of line radiation, E_i is the energy of the upper level, k is Boltzmann constant and T_e is electron temperature. The value of λ and I are obtained from the observation, and the values of A_{ij}, g_i, and E_i are obtained from NIST atomic Spectra Database. Considering two NI lines with wavelengths 381.02nm and 426.9 nm and two NII lines with wavelengths 392.12 nm and 409.6 nm we obtain,

A_{pq}= A_{NI} (381.02 nm) = 8.95×10^5 s¯1, gp= 4, E_p= 13.92 eV
A_{rs}= A_{NI} (426.98 nm) = 2.26×10^6 s^{-1}, gr= 4, E_r= 14.92 eV
A_{xy}= A_{NII} (392.12 nm) = 7.99×10^6 s^{-1}, gx= 5, E_x= 28.34 eV
A_{uv}= A_{NII} (409.6 nm) = 8.05×10^4 s^{-1}, gp= 4, E_p= 15.03 eV

Using the above data we obtain, $\frac{R_1}{R_2} = 8.95 \times 10^{-5} \exp\left[\frac{14.31}{kTe}\right]$

Figure 4. shows the plot between R_1/R_2 and Te with different values of Te. This graph is used to determine the electron temperature using the value of R_1/R_2 obtained from the observation. From the observation, $R_1/R_2 = \frac{I_1/I_2}{I_3/I_4}$ = 10.8 which corresponds to electron temperature of 1.9 eV. From the observed values of R_1/R_2 it can be concluded that the electron temperature lies between 1 eV and 2 eV.

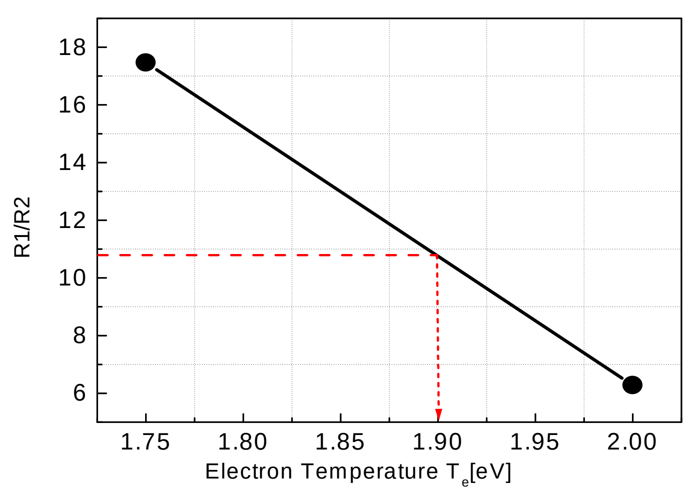

Figure 4. The plot between R_1/R_2 and Te with different values of Te.

Figure 5. shows the photograph of the glow like discharge produced between the electrodes when the applied voltage was 6.69kV at a frequency of 19.19 KHz. The inter-electrode gap was 2mm and the discharge current 0.36 mA. With the increase in frequency of the applied voltage to about 20 kHz the discharge appears to be similar to atmospheric pressure glow discharge (APGD). At lower frequency the discharge consists of several inhomogeneous filaments.

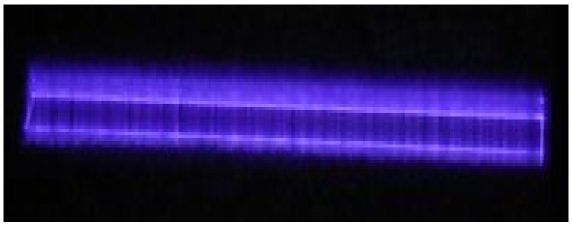

Figure 5: Photograph of the discharge. The Discharge conditions were: Frequency= 19.19 kHz, Voltage V_{rms}: 6.69 kV, I_{rms} = 0.36 mA. Electrode spacing d = 2mm

Cylindrical Electrode

CONCLUSIONS

Atmospheric pressure plasma which uses a dielectric barrier discharge has been developed indigenously in our laboratory. The general characteristics such as current in the discharge, discharge power and the optical emission spectra in our study has been found to be similar with APGD. The electron temperature of about 1.9 eV was determined. The discharge has been successfully applied for the hydrophilization of low density polyethylene. Investigation on water treatment by DBD is also in progress.

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