Characteristics Of A Dielectric Barrier Discharge In Atmospheric Air

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Abstract. Parallel plate dielectric barrier discharges consisting of two electrodes with glass (ε_r = 7.5) and alumina (ε_r = 9.0) as the dielectric barrier were constructed. The system is powered by a variable 20 kV high voltage supply which is capable of delivering unipolar voltage pulses at frequency of 0.1 - 2.5 kHz and sinusoidal voltages at 6.5 kHz and above. At atmospheric pressure, the discharges exhibit either diffuse or filamentary appearance depending on parameters which include the series capacitance established by the electrodes with the dielectric barrier and varying air gap, dielectric material, and frequency of the supply voltages. This DBD system is built for the study of bacterial sterilization.

Keywords: Dielectric barrier discharges, Atmospheric pressure, Bacterial sterilization.
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INTRODUCTION

Non-thermal plasma is gaining popularity recently because of its use in several key applications such as industrial ozone generation, pollution control of gaseous pollutants, surface modifications [1], lightings, and plasma displays [2]. Non-thermal plasma can be established at atmospheric pressure by using the dielectric barrier discharge (DBD) which consists of a dielectric layer in contact with either one of a pair of electrodes.

The electrical discharge characteristics of the DBD are dependent on several parameters such as the series capacitance contributed by the dielectric and varying air gap sandwiched by the electrodes, dielectric material, and frequency of the discharge voltages. At atmospheric pressure, DBD appeared either diffuse or filamentary depending on these parameters. By utilizing the low temperature plasma produced, sterilization of bacterial cell can be done [3,4].

EXPERIMENTAL SETUP

The DBD system is constructed with two flat circular brass plate electrodes. Dielectric materials used are (i) glass sheet (ε_r = 7.5) of thickness 2 mm, and (ii) alumina sheet (ε_r = 9.0) of thickness 1 mm. Air gap of widths 0.5 mm, 1.5 mm and 3 mm are selected to vary the effective capacitance of the DBD device as given in Table 1. All measurements are carried out in air under normal atmospheric pressure.

The DBD device is powered by a high voltage (H.V.) generator capable of delivering up to 25 kV peak-to-peak and output frequency of 0.1 to 12 kHz. Unipolar pulses are consistently produced at low frequencies (0.1 kHz to 2.5 kHz). Distinct sinusoidal output waveform is obtained at higher frequencies (6 kHz to 12 kHz), whose amplitude peaks at the resonance frequency of the DBD set-up.

TABLE 1. Calculated capacitances of the DBD device (without connecting to the circuit) using (i) glass and (ii) alumina sheets as the dielectric. Edge-effects are neglected.

Dielectric Material	(i) Glass			(ii) Alumina		
Air-gap width / mm	0.5	1.5	3.0	0.5	1.5	3.0
Air-gap capacitance / pF	20.1	6.7	3.3	20.1	6.7	3.3
Dielectric-gap capacitance / pF		37.7			90.4	
Effective capacitance / pF	13.1	5.7	3.0	16.4	6.2	3.2

The DBD voltage is monitored via the Tektronix P6015A H.V. probe connected to the powered electrode, and the current is measured by the Pearson current probe Model 4100. The physical appearance of the discharge is captured using Canon EOS 40D digital SLR camera.

For investigation of sterilization of bacterial cell, the *Escherichia coli ATCC 25922* is used as the disinfection target. The bacteria is placed on only the glass barrier between the electrodes and exposed to the plasma for durations of 0.5, 1, 2, and 3 minutes to investigate the effect of plasma exposure time to the bacteria.

RESULTS AND ANALYSIS

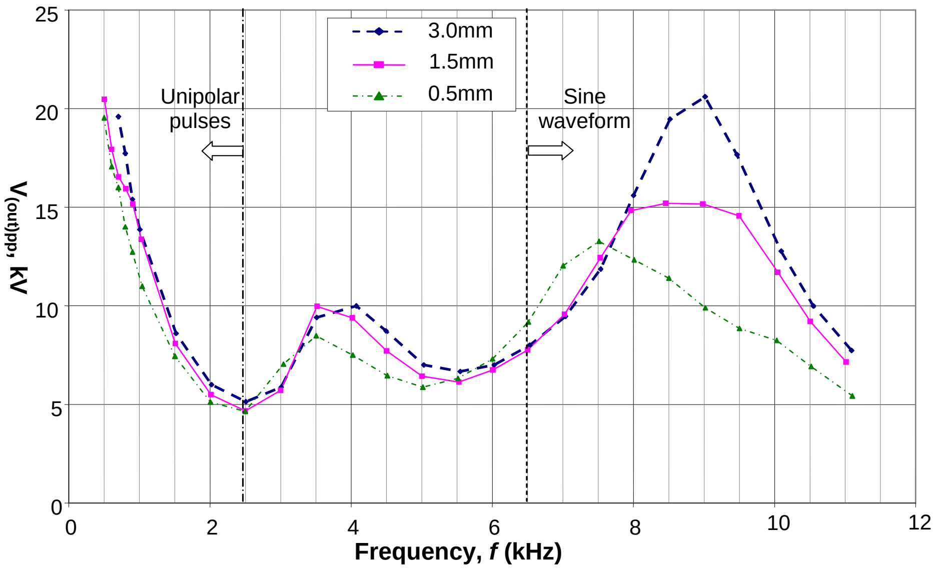
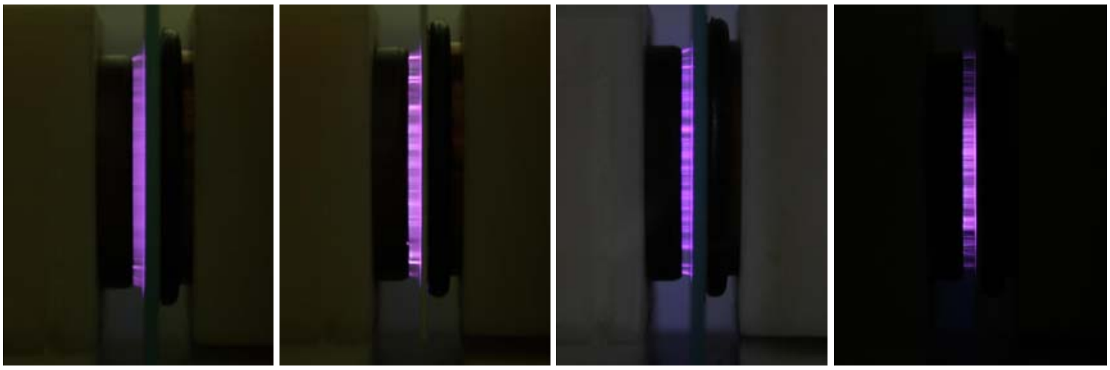


FIGURE 1. Discharge voltage (peak-peak) versus discharge frequency for all three 0.5, 1.5, 3.0 mm air-gap widths (Glass dielectric).

The breakdown across the DBD air-gap is observed to depend on the air-gap width according to Paschen's law (to the right of the Paschen's minimum) for electrical breakdown at constant pressure. For the glass barrier, at air-gap width of 0.5 mm, breakdown occurs at ~8.5 kV; at 1.5 mm gap, ~13 kV; and at 3.0 mm gap, ~21 kV. For the alumina barrier, breakdown occurs at approximately 1 kV lower for each gap.

Either uniform/diffuse or filamentary plasma can be formed in the gap after breakdown. After the discharge streamer has bridged the gap, the discharge voltage across the DBD is dependent on the driving frequency (at fixed power) due to charge deposition on the dielectric surface which is a dominant feature of DBD [2].

At sinusoidal waveform H.V. supply, with glass as the dielectric, resonance frequency f_{res} for the 0.5 mm air-gap is obtained at 7.5 kHz; for the 1.5 mm gap, f_{res} = 8.5 kHz; and for the 3.0 mm gap, f_{res} = 9 kHz (Fig. 1). The increase of the resonant frequency f_{res} with air-gap width is expected since the capacitance across the DBD electrodes decreases with increased air-gap width (Table 1) and $f_{res} = \left[2\pi\sqrt{LC}\right]^{-1}$, L being the inductance of the ignition coil.



(a) Glass dielectric, unipolar pulses (500Hz). Lens Aperture F/5.7 Shutter speed 1.0

(b) Alumina dielectric, unipolar pulses (500Hz). Lens Aperture F/5.7 Shutter speed 1.0

(c) Glass dielectric, sinusoidal waveform (8.5 kHz). Lens Aperture F/5.7 Shutter speed 1/6

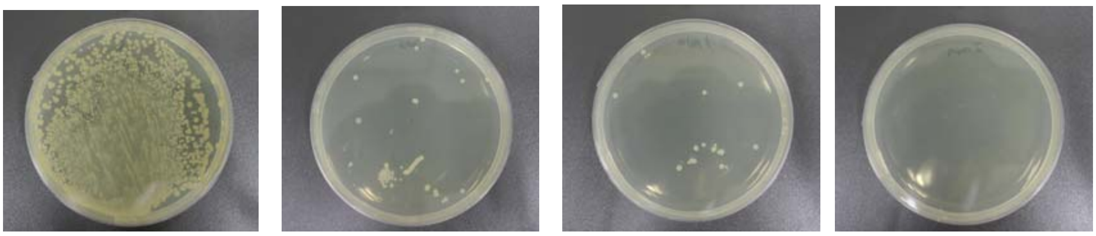
(d) Alumina dielectric, sinusoidal waveform (8.5 kHz). Lens Aperture F/5.7 Shutter speed 1/6

FIGURE 2 : Appearance of the DBD (1.5mm) at different dielectric material and driving waveforms.

Dielectric material influence on the discharge is expected. Discharges using glass dielectric barrier tend to distribute its microdischarges more evenly over the available surface, while alumina with higher dielectric constant (higher current insulation) has some strong streamers or filaments formed across the air-gap.

On another aspect, unipolar pulses powered discharge (high-voltage, low-frequency) exhibits more uniform and diffuse discharge; while sinusoidal discharge (lower voltage, high-frequency) is more filamentary in appearance due to the memory effect of the dielectric [2]. Since the number density of microdischarge rises with power density, which is a function of applied frequency and the peak voltage; high-voltage low-frequency DBD operates to distribute its microdischarges more evenly on the available dielectric surface, while low-voltage, high-frequency DBD tends to reignite the microdischarge channels at the previous positions every discharge cycle.

For investigation of the low temperature plasma produced by the DBD for sterilization capability, the *Escherichia coli ATCC 25922* in solution is exposed to the plasma for durations of 0.5, 1, 2, and 3 minutes. The *cfu (colony forming unit)* of the treated bacterial solution is determined after incubation for 24 hours on nutrient agar plates (Fig. 3). The number density of bacteria is reduced by few orders after treatment time of 30 s and totally disinfected within 2 minutes.



(a) Control (untreated sample) | (b) Treatment time of 30 second | (c) Treatment time of 1 minute | (d) Treatment time of 2 minutes - cleared

FIGURE 3. Photos of the nutrient agar plates cultured with untreated and treated bacterial solutions. One white dot represents one *cfu*. Complete disinfection is achieved within 2 minutes indicated by absence of *cfu* (the irregular white patch is due to reflected light in (d)).

CONCLUSION

DBD with glass sheet dielectric at 1.5 mm air-gap can produce more diffuse plasma with unipolar pulses of 500 Hz when compared to the alumina sheet as the dielectric. The series capacitance of the DBD, dielectric material, and operating frequency are major factors determining the electrical characteristics of the DBD.

The plasma produced by DBD is effective for bacterial sterilization purposes.

ACKNOWLEDGMENT

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