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Electrical Characterization of Dielectric-Barrier Discharge Reactor in Air and Argon

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Abstract— **Dielectric barrier discharge Plasma (DBDP) is a type of non-equilibrium plasma that operates at atmospheric pressure. Electrical breakdown happens in many independent thin current filaments which are called micro discharges. These short-lived micro discharges have properties of transient atmospheric glow discharges with electron energies ideally suited for exciting or dissociating background gas atoms and molecules (Air and Argon). The discharge parameters such as gas gap voltage, discharge current, discharge consumed power for both Air and Argon are studied. The effect of different flow rates of Argon gas on the intensity of plasma and current signals was studied. The effect of different charging voltages on Air as the plasma photo and current filaments was studied.**

Index Terms—: **Dielectric barrier discharge Plasma (DBDP), non-equilibrium plasma, Argon, current filaments**

I. INTRODUCTION

Dielectric-barrier discharge is a simple technique for generating non- equilibrium DBD plasma that operates at atmospheric pressure(1 bar). It is found out that the breakdown of atmospheric-pressure air between planar parallel electrodes covered by dielectric material always occurs in a large number of tiny short-lived current filaments. the generation of non-thermal or cold non-equilibrium plasma at atmospheric pressure and the strong effect of the local field breakdown caused by space charge accumulation.

The standard planar DBD configurations are drawn in Fig. 1[1]. As a result of the existence of at least one dielectric barrier, these DBD discharges require AC voltages for their operation. The dielectric, is an insulating material, cannot pass a DC. It has dielectric constant and thickness, in combining with the time derivative of the applied voltage, dV/dt, obtain the displacement current that can be passed through the dielectric(s). To transmit current in the discharge gap the electric field must be high enough to cause the gas breakdown. In most applications, the dielectric restricts the average current density in the gas area. Therefore it acts as a ballast which, in the perfect case, does not consume energy[1]. The favourite materials for choosing the dielectric barrier are perspex, glass or silica glass, ceramic materials, and polymer layers. In high frequencies, the current limitation is less effective by the dielectric. Therefore, the DBD is normally operated between line frequency and nearly 100kHz.

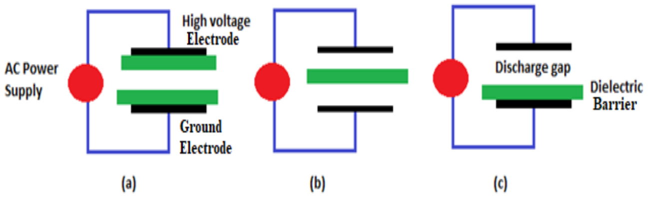

Fig 1. The DBD electrode configurations[1]

When the electric field in the discharge gap is high enough to cause a breakdown in most gasses, a large number of micro discharges are illustrated when the pressure is in order of 10^5 Pa. This is a good pressure range for ozone generation[2], excimer lamps[3], flue gas treatment, pollution control, and biomedical applications. In this filamentary mode, the plasma generates in the electrical conductivity is limited to the micro discharges. The gas in between is not ionized yet and acts as a surrounding medium to absorb the energy dissipated in the micro discharges and to collect and transmit the long-lived species[4].

The plasma concept is created by shedding high voltage energy to the gaseous state that atoms strike together and diminish their electrons [5]. The Plasma has a complicated structure, It contains a group of electrons, ions, excited and neutralization atoms, ultraviolet (UV), free radicals, thermal and infrared radiation, electric fields, and molecules [6].

From the year 2000 up till now, The Non-thermal DBD plasma is increasing attention all over the world in the biomedical field and it is presented for biomedical applications [5]–[8]. Non-thermal Plasma is a gaseous state of matter that has been ionized and considers a novel direction for the remediation of cancer, some diseases, and biomedical purposes [9]–[11]. This exciting gas contains a mix of free charges (ions, electrons), excited molecules, free radicals, and large amounts of visible, Ultraviolet (UV), and Infrared (IR) radiations and produces transient electric fields [12]. The working gas in the experiment is argon gas because it results in strongly OH emission comparing with Nitrogen.

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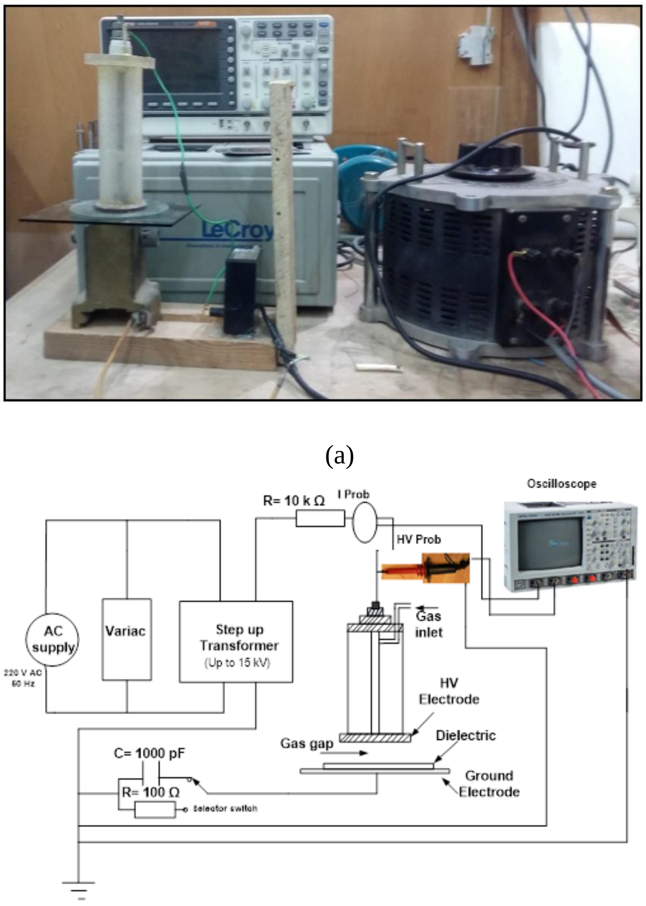
The plasma nonequilibrium in atomic argon gas is much greater than in diatomic nitrogen[13].

II. EXPERIMENTAL SETUP

The electrical circuit of the DBD plasma device consists of an HV power supply of voltage up to 15 kV AC, a frequency of 50 Hz is connected to a variable resistance controller to adjust the input voltage and a charging resistor of 10 kΩ. The input voltage is connected to the HV electrode (anode) via the HV probe of attenuation ratio 1000:1 linked to a digital oscilloscope[14]



(a)

(b)

Fig 2. The Experimental setup of the DBD reactor. (a) the DBD reactor photograph, (b) the DBD reactor arrangement

Figure 2 illustrates the experimental setup of the DBD reactor which is used in this work to generate the DBD plasma and investigate the electrical characteristics and show how it works.

The DBD is generated between two parallel plane electrodes, one of them is 6 cm in diameter which is made of iron material (HV electrode) and the other is a stainless steel sheet of dimensions 18x15x1 mm (cathode electrode). the dielectric material covers the cathode electrode in a 12 mm diameter of a circular glass plate. The air gap distance is 3 mm.

The HV power supply is a step-up transformer of 15 kV of 50 Hz in frequency. an autotransformer variac to control the applied voltage and a ballast resistance of 10 kΩ for protection.

The diagnostic techniques which are used in this experiment are a 1000:1 HV probe to measure voltage, a Rogowiski coil to measure current, a digital oscilloscope of bandwidth 200MHz, an IR thermometer to measure the plasma temperature.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The voltage V(t) is measured using a HV probe which records the temporal variation in voltage on a digital oscilloscope. The current I(t) measured current using a Rogowski coil. Fig. 3, Fig. 4 shows the oscillograms of the applied voltage to the DBDP reactor using the gases of air and argon at a discharge gap distance of 3 mm.

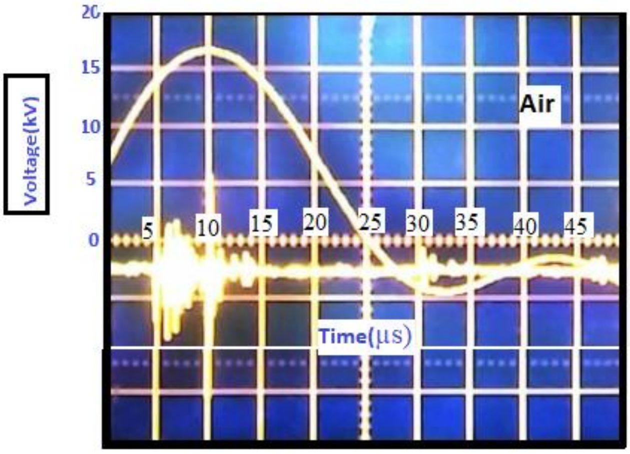


Fig. 3. The waveform of the voltage of the DBD reactor changes with time For air.

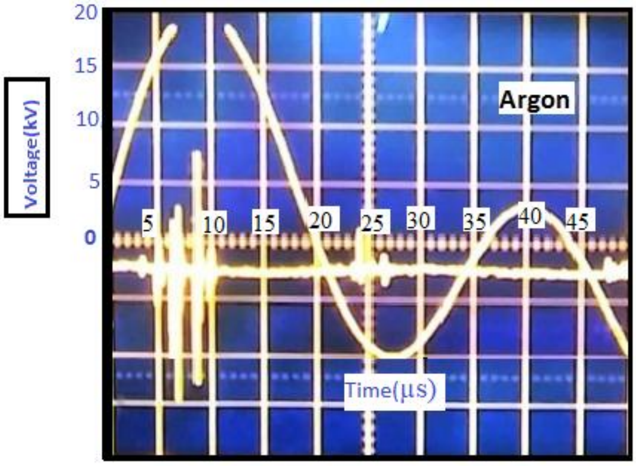


Fig. 4. The waveform of the voltage of the DBD reactor changes with time For Argon.

When the ac applied voltage of the DBDP reactor reaches the starting value, the DBD begins in the air gap inside the reactor and appears as streamers. The observed filaments are distributed randomly on the surface of the entire electrode. The streamers pass the discharge gap and diffuse on the dielectric barrier surface, generating surface charges that produce an electric field opposite to that of the applied field. Thus, after a short time (ns), the streamer action in this spot is extinguished, followed by steamers starting in another site.

At the peaks values of ac applied voltage, where dv/dt =0, the displacement current on the dielectric is zero, and streamer actions stop to exist. The applied voltage connected to the anode electrode has a maximum value of 15 kV.

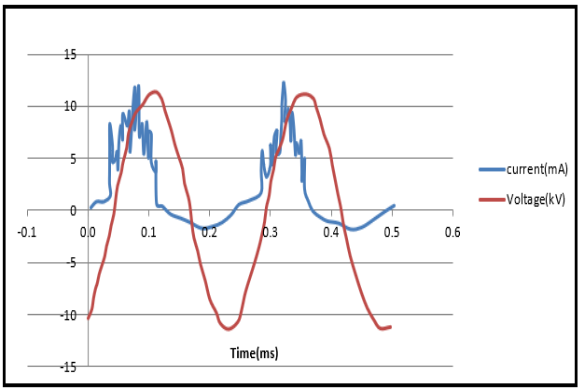


Fig. 5. Applied voltage and discharge current graphs at atmospheric pressure.

The applied voltage and discharge current are sinusoidal signals, but there are some filaments superimposed on the discharge current signal. There are current filaments for both positive cycles of the current signal. In the plasma development, the current filaments occurred at positive cycles of applied voltage, see Fig. 5. There are no filaments at a minimum of discharge current amplitudes.

Fig. 5. Applied voltage and discharge current graphs at atmospheric pressure are illustrated that every current filament corresponds to a series of micro discharges on the dielectric barrier material [15]. From Fig. 5, it could be summarized that the series of micro discharges was liberated from a circular anode electrode at every half positive cycle of the applied voltage. The area of Lissajous figures always changes with the time of the discharge. Therefore, it was very difficult to record it and to find a stable area during the experiment for both gases. The power of the plasma discharge is given by(1).

$$P=\int_0^T v(t)\times i(t)dt \quad (1)$$

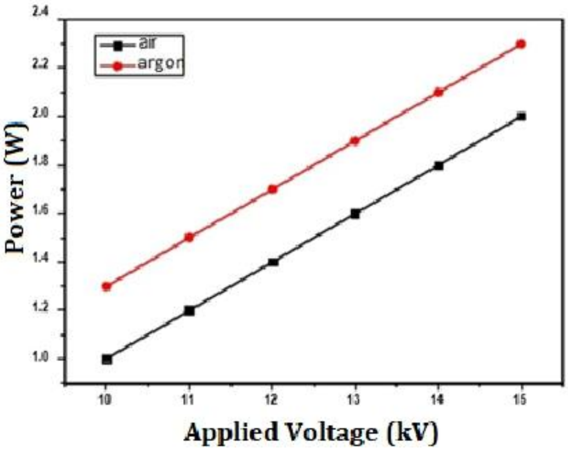


Fig. 6 Discharge power (W) to the applied voltage (kV) for Air and Argon.

Fig. 6 shows the average discharge power versus the applied ac voltage for air and argon which illustrated that as the applied voltage increases, the discharge power increases in a linear relationship.

Also, the photographs for the corresponding generated DBDP are shown in Fig. 7.

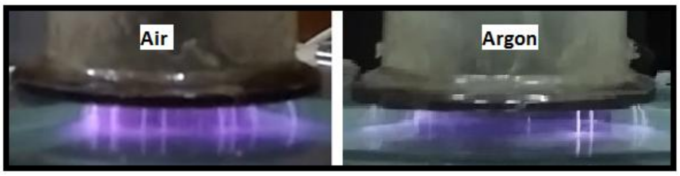
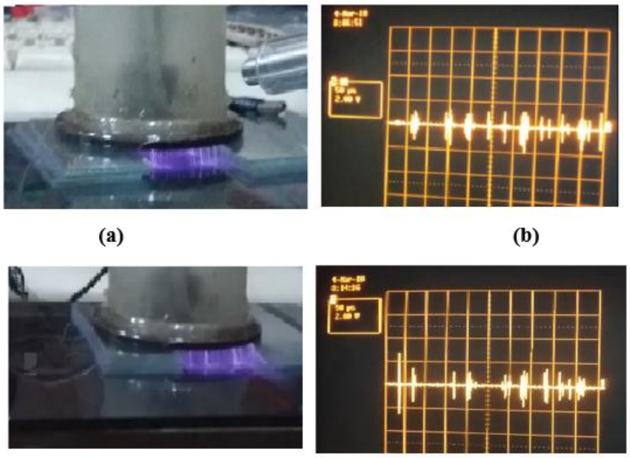


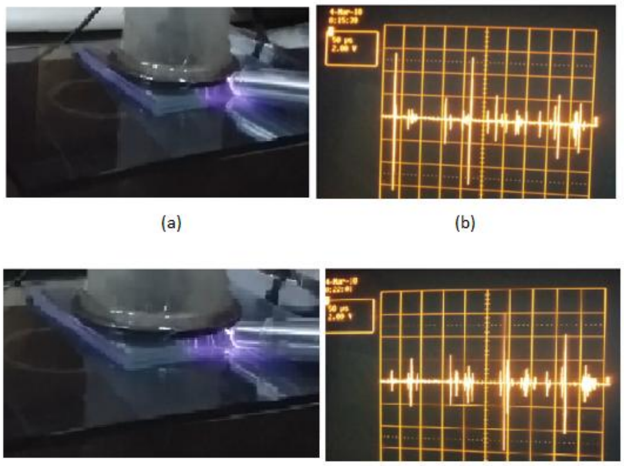
Fig.7. DBDP photographs with air and argon gas at a voltage 12 kV.


(a) (b)

(c) (d)

Fig.8. DBDP photographs and current signals at fixed voltage(5.6 kV) at Argon flow rates(5,10) SCFH.

In Figure 8, the effect of different flow rates of Argon gas on the intensity of plasma and current signals has been studied and illustrated that as increasing the Argon flow rates, the plasma intensity increased and the current filaments increased. In Figure 9, the effect of different charging voltages on Air as the plasma photo and current filaments has been studied and illustrated that as increasing the charging voltage at atmospheric pressure, the plasma intensity increased and current filaments increased.


(a) (b)

(c) (d)

Fig.9. DBDP photographs and current signals of Air at voltages (5.6 kV) and (6.4 kV).

IV. CONCLUSIONS

- The air gap gas required a higher applied voltage at the breakdown more than that required for argon gas.
- The charge transferred per half cycle is less for air gas and highest for argon gas.
- The electrons in the DBD gas region dissipate rapidly $\cong 30\ ns$, while the heavy ions remain several μs which can be attributed to its low speed (electrons $10^5\ m/s$, but ions $\cong \frac{1}{100}$ $of\ electron\ speed$).
- It was confirmed that the micro-discharges channels spread from the positive electrode toward the ground electrode and did not shift to an arc discharge.
- The conventional DBD using AC high voltage has a relatively low instantaneous energy input, but by using high-frequency Ultra- Short pulses to obtain highly energetic electrons, which results in an efficient formation of key radical species.
- There are many current filaments in the current waveforms. These filaments showed that the micro discharges produced on the dielectric barrier and superimposed on the current signal. The micro discharges happened before each positive half cycle of the applied voltage.
- The DBDP phenomena have been observed more luminous, clearer, and more homogenous as increasing the flow rate of gas.

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