

GENERATION OF HOMOGENEOUS GLOW DISCHARGE USING A
COMBINATION OF FINE WIRE MESH AND PERFORATED ALUMINIUM
ELECTRODE

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ABSTRACT

Nowadays, a gas discharge plasma applications has rapidly extended due to the greatest chemical freedom offered by the non-equilibrium aspects of the plasma. Among the applications of gas discharge plasma are surface treatment, air pollution control, lasers, lighting, plasma displays, ozone generation and biomedical applications. The most commonly used in plasma industry is the glow discharge plasma. It is known to be generated under high vacuum condition. At low pressure glow discharge plasma, the producing of surfaces and thin films are more effectives and good quality. But, this technique gives disadvantages due to the large cost to maintain at low pressure condition. However, there were many researches that have been done to produce glow discharge at atmospheric pressure. This glow discharge can be stabilize at atmospheric pressure if three simple requirements are fulfilled: (i) use of source frequency of over 1 kHz, (ii) insertion of a dielectric plates between the two metal electrodes, (iii) use of helium dilution gas. Used of helium gas is impractical due to its high cost. In order to generate glow discharge at atmospheric pressure in any gases, it was found that fine wire mesh and perforated aluminium can maintain a stable glow discharges. This thesis focus on the production of homogeneous glow discharge by using a combination of fine wire mesh and perforated aluminium as electrodes. A study was also made to determine the effect of a frequency and gap spacing on the stability of glow discharge.

ABSTRAK

Pada masa kini, penggunaan penyahcasan gas plasma telah berkembang pesat disebabkan aspek bebas kimia yang terdapat pada plasma tidak-seimbang ini. Antara penggunaan penyahcasan gas plasma adalah rawatan permukaan, kawalan pencemaran udara, lazer, pencahayaan, tatapan plasma, penghasilan ozon dan penggunaan perubatan. Kebanyakan plasma yang digunakan dalam industri plasma adalah penyahcasan plasma pijar. Ia dikenali untuk dihasilkan dibawah keadaan vakum yang tinggi. Pada tekanan yang rendah, penghasilan permukaan dan filem nipis adalah lebih efektif dan mendapat kualiti yang bagus. Tetapi, teknik ini tidak memberi faedah kerana ia memerlukan kos yang tinggi untuk kekal pada keadaan tekanan yang rendah. Walaubagaimanapun, banyak kajian telah dijalankan untuk menghasilkan plasma gas ini pada tekanan atmosfera. Penyahcasan gas ini boleh kekal dalam keadaan stabil sekiranya tiga syarat-syarat ini dipenuhi: (i) penggunaan sumber frekuensi melebihi 1 kHz, (ii) penggunaan lapisan dielectric diantara elektrod, (iii) menggunakan gas helium. Penggunaan gas helium tidak praktikal kerana kosnya yang tinggi. Untuk menghasilkan penyahcasan gas ini pada tekanan atmosfera dalam apa jua gas, ia telah dijumpai bahawa penggunaan wayar 'mesh' and aluminium yang berlubang boleh mengekalkan kestabilan penyahcasan gas ini. Tesis ini fokus kepada penghasilan penyahcasan gas yang seragam menggunakan gabungan wayar 'mesh' dan aluminium yang berlubang sebagai elektrod. Kajian juga dibuat untuk menentukan kesan frekuensi dan jarak elektrod pada kestabilan penyahcasan gas ini.

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LIST OF ABBREVIATIONS

Hz	-	Hertz
ICP	-	Inductive Coupled Plasma
RF	-	Radio Frequency
DC	-	Direct current
CO ₂	-	Carbon dioxide
H ₂	-	Hydrogen
N ₂	-	Nitrogen
He	-	Helium
Ar	-	Argon
DBD	-	Dielectric Barrier Discharge
APGD	-	Atmospheric Pressure Glow Discharge
SED	-	Silent electric discharge
Al ₂ O ₃	-	Alumina Ceramic
CRT	-	Cathode Ray Tube
PDP	-	Plasma display panel
PALC	-	Plasma addressed liquid crystal
LC	-	Liquid crystal
PP	-	Polypropylene

LIST OF SYMBOLS

E	-	Electric field
V	-	Voltage
d	-	distance
i_0	-	low initial current
μ_e	-	electron mobility
α	-	Townsend coefficient
λ	-	secondary emission coefficient
cm	-	centimetre
A	-	Ampere
kW	-	kilowatt
x	-	thickness of dielectric
p	-	power dissipated
f	-	frequency
C_D	-	dielectric capacitance

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CHAPTER 1

INTRODUCTION

1.1 Research background

In recent years, a gas discharge plasma applications has rapidly extended due to the great chemical freedom offered by the non-equilibrium aspects of the plasma. Gas discharge plasma present considerable interest for a wide range of applications such as surface treatment, air pollution control, lasers, lighting, plasma displays, ozone generation and biomedical applications [1].

The most commonly used in plasma spechrochemist is the glow discharge plasma. Glow discharge plasmas are known to be generated under a so-called high vacuum condition. The producing of surfaces and thin films are more effectives and relatively good quality under low pressure glow discharge plasma technique. However, this technique gives disadvantages in its production process since it is necessary to maintain at low pressure condition and therefore, a large amount of cost is necessary to keep the system air-tight.

In general, the glow plasma is thought to be stable only in a low pressure discharge. This is because the discharge concentrates on one point a pressure of about 100 Torr. When the pressure is rising, the discharge shifts to sparks and arc at about atmospheric pressure and thus, making it impossible to uniformly process an object [2]. But, glow discharge is possible to stabilize at atmospheric pressure if three simple requirements are fulfilled: (i) use of source frequency of over 1 kHz, (ii)

insertion of a dielectric plate (or plates) between the two metal electrodes, (iii) use of helium dilution gas [3,4]. Used of helium as dilution gas is able to produce a stable and homogeneous glow discharge at atmospheric pressure is due to its low breakdown stress and thus, makes it easy to produce the small avalanches that are required [5]. On the other hand, the use of helium as dilution gas is impractical due to its high cost. It is increases in interesting of researchers to use other low-cost of gases. In this field, a new technique of stabilizing the homogeneous glow discharge at atmospheric pressure in any gases by a 50 Hz source is proposed [6]. This method used a fine wire mesh as a discharge electrodes and it is found that fine mesh electrodes can maintain a stable glow discharges in any type of gases. In [7], it has been confirmed that wire mesh is very important in increasing the possibility of the existence of glow discharge plasma at atmospheric pressure. They also suggested that the mesh could influence the discharge by its electrical resistance which is higher than metallic electrodes. Besides fine mesh wire, perforated aluminium sheet electrode is introduced for comparison with the well-known fine stainless steel wire mesh. From this work, it was found that perforated material electrode can produce a homogeneous glow discharge as an alternative of the well established fine steel wire mesh [8].

This thesis focuses on the production of homogeneous glow discharge by using a combination of fine wire mesh and perforated aluminium as electrodes. A study of the relevant literature has confirmed that uniform and stable glow discharge also dependent on the material of electrodes used. Uniformly distribution of the electric field strength throughout the electrode surface may be due to the shape and size of the holes, as well as the material used. However, the reason why glow discharge has different stability when different configuration of material used as electrodes is not clear. For this reason, further study on the effect of material used as electrodes is proposed in this project. Combination of these two materials as electrodes is introduced instead of using these two materials as electrodes separately. A study was also made to determine the effect of a frequency and pulse of the input voltage on the stability of glow discharge.

1.1 Problem Statement

Nowadays, the use of plasma which is generated by discharge has widely applications including surface treatment of semiconductor, formation of thin films, ozone generation, biomedical applications etc. Glow discharge is well-known generated under low-pressure condition but it is costly in order to maintain at low-pressure state. Thus, many researchers have worked out to introduce techniques which can generate glow discharge plasma under atmospheric pressure to replace the conventional low pressure glow discharge method. In order to achieve a stability of glow discharge at atmospheric pressure, it depends on the feed gas, the dielectric barrier material, the discharge electrode structure, the pulsed supply frequency, the gap spacing and the humidity of the gas.

Homogeneous glow discharges can be established at atmospheric pressure by using special kinds of electrode material and configuration. In [6], it has shown that with wire mesh as electrodes behind the dielectric barriers homogeneous discharge can be obtained with any gas at atmospheric pressure. This result also has been confirmed by [7], and it has also been found that fine mesh electrodes produce a more stable glow than coarse mesh electrodes.

Furthermore, for comparison with well established fine wire mesh, perforated aluminium electrode was introduced into reaction chamber [8]. It has been found that perforated aluminium with small holes can generate a homogeneous glow discharge compared to fine wire mesh electrode. Initially, perforated aluminium is expected to produce higher electric field strength than fine wire mesh due to its sharp edges holes. Higher electric field strength can cause ionization that will produce more micro-discharges near the electrodes. It further, will give a discharge that fills up the whole volume of the discharge chamber.

Nevertheless, simulation results on the observation of electric field strength between these two materials showed that wire mesh configuration produced higher electric field strength than perforated aluminium. This result proved that electric field strength does not influence the stability of the glow discharge. Thus, it makes

the reason why the glow discharge produced by the configuration with perforated aluminium has better stability than the wire mesh is unclear.

In this present study, production of glow discharge by using a combination of fine wire mesh and perforated aluminium as electrodes will be investigated. In addition, the effect of frequency and pulse supply on the stability of glow discharge also will be studied.

1.2 Objectives

The aim of this project is to study on the effect of new configuration and combination of two materials on the generation of glow discharge. This aims will be met through these objectives:

1. To develop glow discharge chamber which having different configuration consist of a combination of fine wire mesh and perforated aluminum electrodes.
2. To develop input driver of pulsed voltage that will be used as a supply for the chamber.
3. To conduct an experiment to study the effect of each discharge configuration on glow discharge characteristics.
4. To study the effect of glow discharge stabilization when frequency and gap distance of electrode is varied.

1.4 Scope of work

The scope of this project in generating a stable glow discharge is stated as follows:

1. Several glow discharge chamber with different configuration of a combination of fine wire mesh and perforated aluminum electrodes will be developed.

2. Input driver of pulsed voltage will be developed.
3. An experimental work will be conducted to study the effect of each discharge configuration on glow discharge characteristics.
4. The glow discharge generated will then be detected and then will be analyzed in order to identify the homogeneity of the discharge.

1.5 Methodology of Project

This project is done in sequence in order to ensure that the project will be done in a specific time. The flow of this project is as shown below:

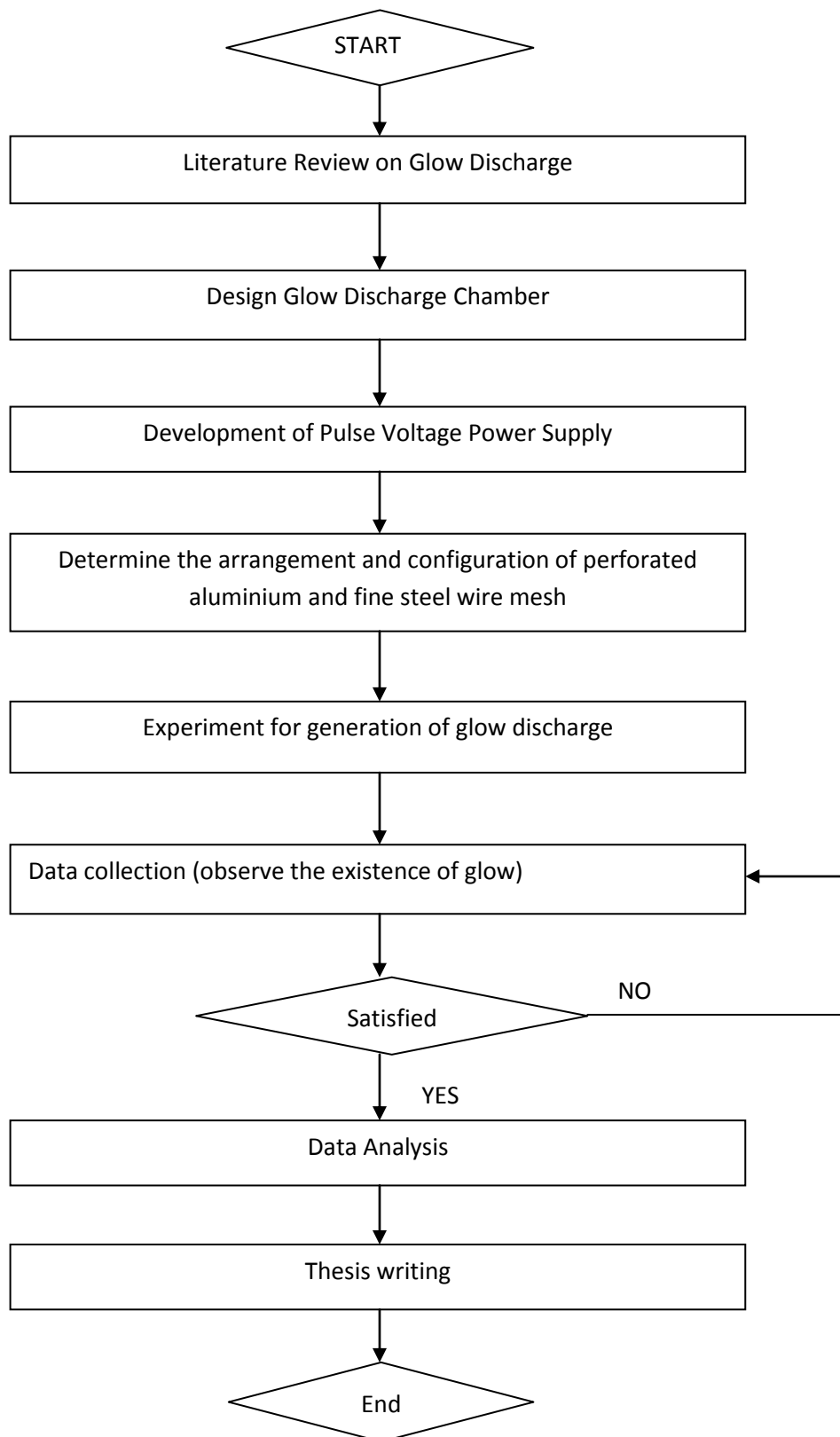


Figure 1.1 Flow chart of the project

1.6 Thesis Outline

This thesis is divided into five chapters. Each chapter is briefly described as below:

Chapter 1 is the introduction of this project including brief description on background of study, problem statements, objectives, scopes of work and methodology of this project.

In chapter 2, the literature review on glow discharge is being discussed. Several sources of information consist of research papers, journal and reference books that help the implementation of this project are further elaborated.

In chapter 3, the methodologies and apparatus of the project are being discussed. It consists of two main parts, the high frequency power supply and the glow discharge chamber.

The results and analysis of the project are discussed in chapter 4. Two types of results are covered in this chapter which are influences of frequency and influences of gap spacing.

Chapter 5 is the conclusion and future development of this project. Some suggestions are provided in this chapter for further improvement of this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to glow discharge plasma

Glow discharge is a process occurs when an adequately high potential difference is applied between two electrodes. The gas between these two electrodes will break down into positive ions and electrons. This process of breakdown giving rise to a gas discharge. Electrons emitted from the cathode are not able to maintain the discharge without applying a potential difference. In the presence of voltage difference, electrons near to the cathode are accelerated by the electric field and have a collision with the gas atoms. The collision between electrons and atoms will give rise to an inelastic collisions and leading to excitation and ionization process. The characteristics name of the 'glow' discharge are responsible by the excitation collisions that normally followed by de-excitation which can cause emission of radiation. The process of ionization can create new electrons and ions. The latter can cause secondary electrons emission at the cathode and give rise to new ionization collisions. Therefore, the glow discharge in the plasma is self-sustaining plasma due to the process of electrons emission at the cathode and ionization in the plasma.

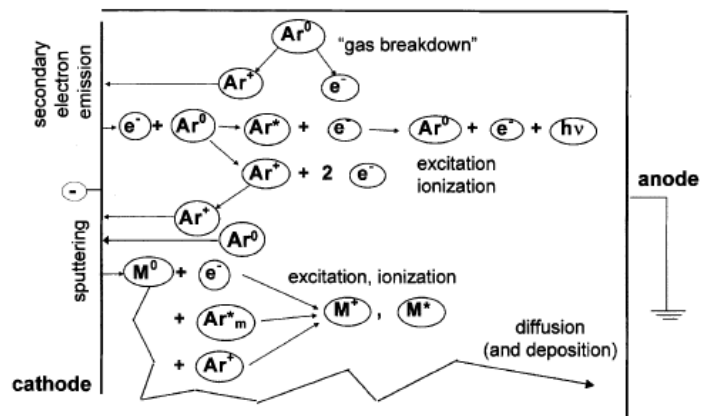


Figure 2.1 Schematic overview of the basic plasma processes in a glow discharge

Basically, plasma-chemical systems are divided into two major categories which are thermal and non-thermal. It is characterized by their specific advantages and disadvantages. Thermal plasma is associated with thermal ionization, Joule heating and able to deliver high power up to 50 Megawatts per unit at high operating pressures. Thermal plasma usually an arcs or Radio Frequency Inductively Coupled Plasma (ICP) discharges. However, thermal plasma sources have limit energy efficiency and applications due to the low excitation selectivity, very high gas temperature, electrode problem result and serious quenching requirements. At low pressure glow, RF and microwave discharge it is called non-thermal plasma. Non thermal plasma presents high selectivity and energy efficiency of plasma chemical reactions. It has advantages than does thermal plasma where it is able to operate effectively without any special quenching and at low temperature. Due to its advantages, non-thermal plasma atmospheric pressure has been studied for variety industrial applications such as removal of volatile organic compounds, control the car exhaust emission, a pollution control and treatment of surface polymer. Non-thermal plasma also widely used to generate ozone for water purification.

Non-thermal plasma may be generated by using electrical discharge or beams of electrons. They produce plasma when electrical energy goes into the production of energetic electrons besides of heating the entire as stream. These energetic electrons create excited free radicals, ion and additional electrons through dissociation, excitation and ionization of gas molecules. All these excited species reduce the pollutant molecules in the applications of pollutions control. On the other hand, in thermal process such as plasma-torches or furnaces and some chemical techniques

require heating the whole gas stream for the purpose to destroy the pollutants. Non-thermal plasma has widely used in industry also due to the low temperature plasma technologies and have relatively low maintenance requirements resulting in relatively low energy costs.

2.2 Electrical Breakdown of Gases

2.2.1 Townsend mechanism of electric breakdown of gases

The electrical breakdown is a process of formation conductive gas which occurs when electric field exceeds some critical value. Different kind of plasma will be generated as a result of the breakdown different. The breakdown mechanism starts with the electron avalanche which is multiplication of some primary electrons in cascade ionization [14].

This mechanism can be described by considered the simplest breakdown in a plane gap of spacing d between electrodes. It connected to a DC power supply which provides the homogeneous electric field $E = V/d$. By providing the very low initial current i_0 , some primary of electrons are formed near the cathode. Each primary electrons that formed at the cathode drift to anode to ionize the gas and therefore generates an avalanche. This is the procedure of emission of secondary electrons. Due to the multiplication of electrons proceeds along with their drift from cathode to anode, the avalanche develops both in time and in space (see figure 2.2). The ionization avalanche is by the Townsend ionization coefficient, α and not by the ionization rate coefficient. It is shows the electron production in per unit length or the multiplication of electrons. The Townsend ionization coefficient is related to electron drift velocity v_d and ionization rate coefficient $k_i(E/n_0)$:

$$\alpha = \frac{\nu_i}{v_d} = \frac{1}{v_d} k_i(E/n_0) n_0 = \frac{1}{\mu_e} \frac{k_i(E/n_0)}{E/n_0} \quad (2.1)$$

Where,

ν_i = ionization frequency with respect to one electron

μ_e = electron mobility

The breakdown starts at room temperature and the mobility of electron is inversely proportional to pressure.

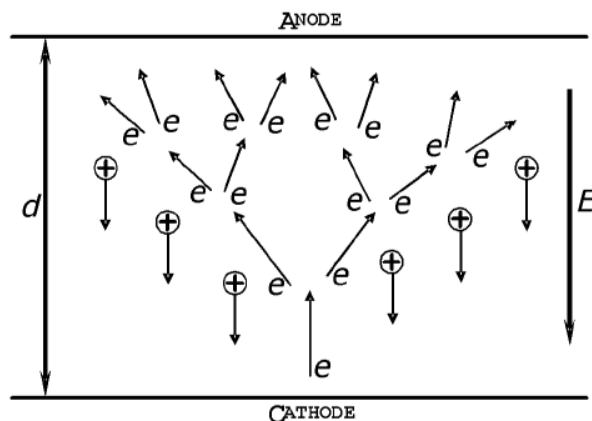


Figure 2.2 Illustration of the Townsend breakdown mechanism

From the definition of the Townsend coefficient α , each one primary electron created near the cathode produce $\exp(\alpha d) - 1$ positive ions in the gap as shown in figure 2.2. In electronegative gases, the attachment processes are most important and will be discussed below.

All the positive ions created in the gap per one electron are moving back to the cathode and the $\gamma (\exp(\alpha d) - 1)$ electrons are knocked out from the cathode in the process of secondary electron emission. γ is the secondary emission coefficient also called third Townsend coefficient and depends on cathode material, state of surface, type of gas and reduced electric field. It is defined as probability of a secondary electron generation on the cathode by an impact. The usual value of γ is 0.01-0.1 in electric discharge. It is depends on effects of photons, meta-stable atoms and molecules on the secondary electron emission.

Table 2.1 : Numerical parameters A and B for calculation of Townsend coefficient

Gas	A, 1/cm Torr	B, V/cm Torr
Air	15	365
CO ₂	20	466
H ₂	5	130
N ₂	10	310
He	3	34
Ar	12	180

When the electric field and Townsend α coefficient becomes high enough, transition to self-sustained current takes place. This is actually the breakdown mechanism. Therefore, the simplest breakdown condition in the gap can be shows as:

$$\gamma[\exp(ad) - 1] = 1, ad = \ln(1/\gamma + 1) \quad (2.2)$$

2.3 Dielectric Barrier Discharge

2.3.1 Overview of the dielectric barrier discharge

Dielectric barrier discharge (DBD) is a discharge system formation when dielectric barrier is placed inside the discharge gap. It then will stop the electric current and avoid spark formation which is from streamer to spark transition. This discharge system usually operates at frequencies between 0.05 and 500 kHz. In other words, DBD also called silent discharges due to the nonexistence of spark which are accompanied by generation of local shock waves and noise.

Dielectric barrier discharges have largely applications in industry because they operate under non-equilibrium conditions at atmospheric pressure and high power levels without using complicated pulse power supplies. This discharge is widely used in generation of ozone, CO₂ lasers and as a UV-source in lamps. DBD also applied in air and it is normally used in the web conversion industry where it is known as corona discharge treatment. Corona discharge treatment is used to treat polymer outside in order to support printability, wettability and adhesion [15]. DBD application also used in pollution control but the largest application of DBD is on the production of plasma display panels for large-area flat television screens.

Kogelschatz, Eliasson and their group [16] has gives important contributions in fundamental understanding and industrial applications of DBD. However, this DBD actually has a long history. Essential steps in understanding the physical structure and nature of the DBD were made by Klemene in 1937 [17].

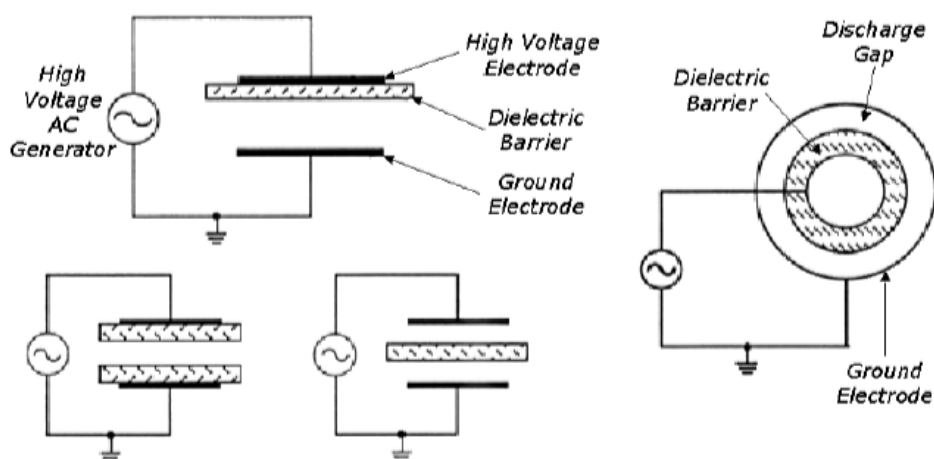


Figure 2.3 Common dielectric-barrier discharge configuration [22]

2.3.2 Properties of the dielectric barrier discharges

The dielectric barrier discharge gap normally contains one or more dielectric layers. It is located in the current path between metal electrodes. As illustrated in figure 2.3, there are two specific DBD configurations which are planar and cylindrical form. Typical gap distance between these two electrodes varies from 0.1 mm to several centimetres. The dielectric barrier can be made from mylar, glass, ceramics, quartz or other materials that has low dielectric loss and high breakdown strength.

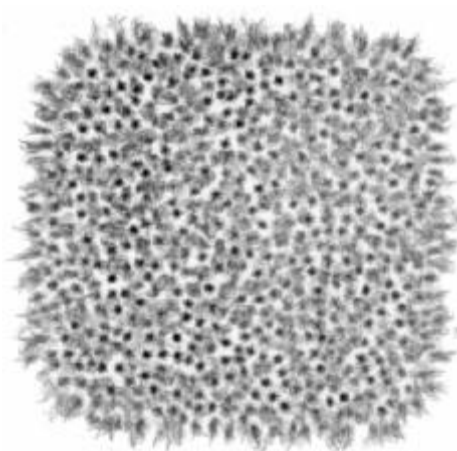


Figure 2.4 The storage phosphor image of filaments in the dielectric barrier discharge gap in air

Usually, dielectric barrier discharges are not evenly distributed and contain of plentiful microdischarges in the discharge gap as can be seen in figure 2.4.

It is important to distinguish and clarify the terms streamer and microdischarge. An initial electron starting from cathode or dielectric that covers the cathode and produces secondary electrons by direct ionization and electron avalanche is developed. If the electrons avalanche is big enough than cathode, direct streamer is initiated. Streamer forms a conducting channel of weakly ionized plasma and bridges the gap in few nanoseconds. Inside the plasma channel, the intensive electron current will flow until local electric field is collapse. Electric field collapse is due to the charges accumulated on dielectric surface and ionic space charge. The ions are too slow to leave the gap for the duration of this current peak. Group of local

processes in the discharge gap are developed and initiated by avalanche until the termination of electron current. This is usually called microdischarge. There is no more electron-ion plasma in the main part of micro-discharge after electron current termination. However, this region is separated from the rest of the volume due to high level of vibrational and electronic excitation in channel volume. This process is called microdischarge remnant. Microdischarge remnant will produce new microdischarge in the same spot as the polarity of the applied voltage changes. This phenomenon give cause the possibility to see single filaments in DBD.

2.3.3 Atmospheric pressure glow discharge

Dielectric barrier discharge (DBD) can display two major discharge mode which are filamentary mode and homogeneous or glow discharge mode. The filamentary mode has been discussed previously and widely utilized in industrial applications. Nevertheless, for deposition of thin films or treatment of surfaces, the glow discharge mode has clearly advantages over the filamentary one.

Glow discharge can be occurred at either atmospheric pressure or low pressure. Since the last century, many research projects on glow discharge at low pressure were developed and it is well established. It is widely used in many applications such as surface treatment, light sources and thin film coating. Yet, it is costly in order to maintain at low-pressure condition. Due to this limitation, many researches had been implemented on stabilization of glow plasma at atmospheric pressure. Several researchers [3,4] claimed that glow plasma is possible to stabilize at atmospheric pressure if three simple requirements are fulfilled: (i) source of frequency is over 1 kHz, (ii) dielectric plate is inserted between the two metal electrodes, (iii) helium is used as a dilution gas.

Typically, in APGDs, dielectric is covered at least one of the electrodes and the discharge operates at alternating voltage. In addition, the stability of the glow discharge is also determined by the type of gas discharge used. For example, helium gas can produce a stable homogeneous glow discharge, but nitrogen, oxygen and

argon can easily cause the transition into a filamentary glow discharge. However, since the helium gas is costly, it is still possible to let other gases operate in a homogeneous glow discharge by changing the electrode configuration [3,6].

A new technique to produce a stable homogeneous glow discharge at atmospheric pressure by a 50 Hz source in any gas is proposed [6]. This paper also consists a method of distinguishing between a glow discharge and a filamentary silent electric discharge. This work used atmospheric air, nitrogen, argon and oxygen as dilution gas which is easily produce an silent electric discharge (SED).

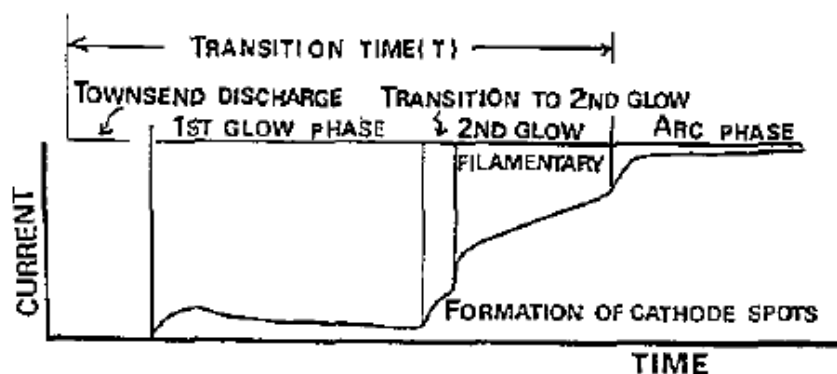


Figure 2.5 Transition from a glow discharge to an arc discharge

The discharge at atmospheric pressure starts from the Townsend discharge, as shown in figure 2.5. It then changes to a glow discharge (first glow), filamentary glow (second glow discharge) and finally to an arc discharge. The transition time from Townsend to arc discharge is depends on the gas pressure, the kind of gas, discharge gap length and state of the over-voltage. The discharges will show the homogeneous normal glow if the discharge stops before arriving at the second glow. In order to bring a stable glow discharge in pure argon, nitrogen, oxygen and air at atmospheric pressure, metal wire mesh which has a specified wire radius is used as electrodes. The monitoring method of distinguishing between stable and filamentary glow discharge has to use two figures which are the Lissajous figure of voltage-charges and the single pulse current shape. This new method is introduced because the previous work [10] has distinguished these two discharges by appearance of the cathode spots and by the increase in current. However, the current value changes continuously.

In [4], they succeeded in avoiding a conversion to an arc discharge at atmospheric pressure by using two electrode styles. Firstly, an insulating plate was set on the lower electrode plate or on the bottom of the upper electrode as shown in figure 2.6(a). Other configuration is shown in figure 2.6(b) which is by using a brush-style electrode which consists of sharp pointed fine tungsten wires. These two electrode styles result in large differences in the samples. APGD plasma with a brush-style electrode could not treat electrically conductive substances such as metal because the discharge would change to an arc style. Therefore, a metal sample has to be treated by a plate-style electrode.

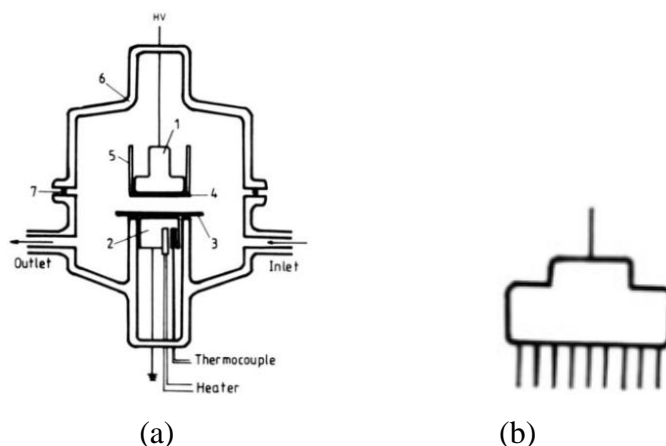


Figure 2.6 (a) A schematic representation of the apparatus: 1. Upper electrode; 2. Lower electrode; 3 and 4. Glass plates; 5. Pyrex tube; 6. Pyrex bell-jar; 7. O-ring (b) The brush style electrode.

Instead of using well-established fine wire mesh, perforated material as electrodes also has been introduced [8]. Perforated aluminium has been selected in this investigation is due to its arrangement of small holes with sharp edges. This special arrangement is expected to produce higher local electric field strength than fine wire mesh where higher electric field in the gap may be sufficient to cause ionization of the gas. Ionization in gas will create more micro-discharge near the electrodes which will provide a discharge that fills the whole volume of the discharge chamber.

Nevertheless, simulation results on the observation of electric field strength between these two materials showed that wire mesh configuration produced higher electric field strength than perforated aluminium. This result proved that electric field

strength does not influence the stability of the glow discharge. Thus, it makes the reason why the glow discharge produced by the arrangement with perforated aluminium has better stability than the wire mesh is unclear. Uniformly and stable glow discharge on the dielectric surface may be due to the shape, size of the holes and material used which helps to distribute homogeneously the electric field strength throughout the electric surface [8]. This author also claimed that a better stability of the glow discharge can be achieved with smaller diameter perforated holes of different shape. This claimed is based on the preliminary experimental results which indicated that with small diameter holes of perforated aluminium, the glow discharge generated is more stable than with bigger holes of perforated aluminium.

2.4 Pulsed glow discharges

The glow discharge voltage can also be applied in the form of discrete pulses normally with lengths of milli-to microseconds. Pulsed glow discharge has better efficiency and better sensitivities for analytical spectrochemistry. It is because a pulsed discharge can operate at much higher peak current and peak voltages for the same average power, hence can give higher instantaneous sputtering, ionization and excitation. Recently, more investigations have focused mainly on microseconds discharges because it is expected that even higher peak voltages and currents are applied, better sensitivities can be obtained [9]. Typical analytical microsecond pulsed conditions has a voltage of 2 kV, which is applied during a pulse of 10 μ s, with a pulse repetition frequency of 200 Hz. It giving rise to a peak currents of 1 A and powers of 2 kW approximately [9]. This authors claimed that the typical duty cycle is very short due to the ratio of 'pulse-on' period compared to 'pulse-off' period is very small. The average electrical power is relatively low, so that the sample will not excessively be heated.

The glow discharge in air at atmospheric pressure simply transition into spark discharges that significantly heat the gas. Thus, in order to control efficiently the glow-to-spark transition, nanosecond repetitively pulse discharge is used [12]. In these discharges, the application of high voltage nanosecond duration pulses generate

a strong electric field that accelerates electrons to the high energies required for efficient ionization, whereas the short pulse duration prevent spark formation.

2.4.1 Pulsed and RF glow discharge in Helium atmosphere

The optical and electrical characterization of sinusoidal and pulse glow-discharge plasma in helium can be obtained. In previous work [19] the dependence of different discharge parameters on the operating conditions has been illustrated. Figure 2.7 illustrates the average image of discharge that was taken by using digital camera. The image shows that the glow discharge covers the whole surface of the electrodes. Figure 2.8 (a) and (b) show the total current mark out together with the applied voltage using pulse and sinusoidal waveform respectively. Both the image and total current confirm the glow type discharge in helium dielectric barrier discharge. As shown in figure 2.8, it gives an explanation that even for same applied potential more current have been observed in case of pulse waveform.

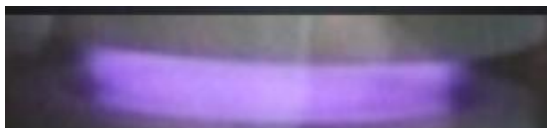


Figure 2.7 Diffused discharge in between the gap

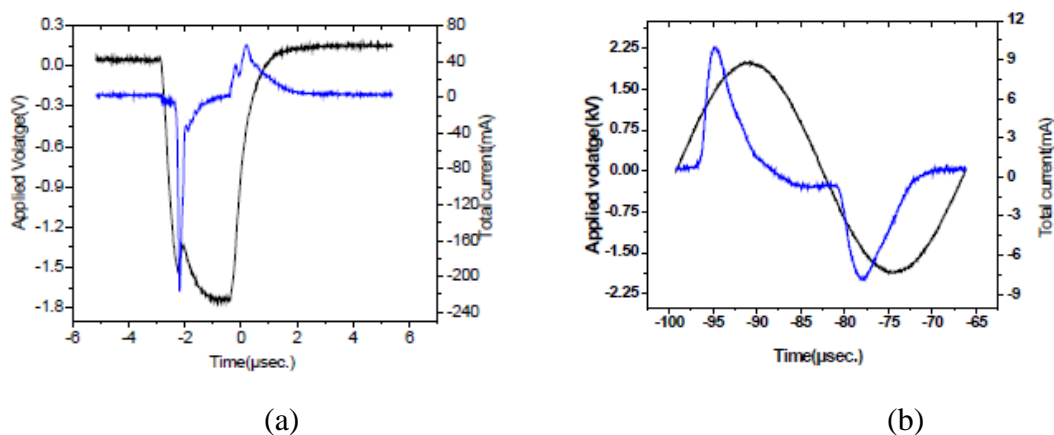


Figure 2.8 V-I waveform (a) pulse at 600mbar and 30 kHz (b) sine wave at 600mbar and 30 kHz

Figure 2.9 (a) and (b) demonstrate the several emissions spectral lines for various applied potential using pulse and sinusoidal supply respectively.

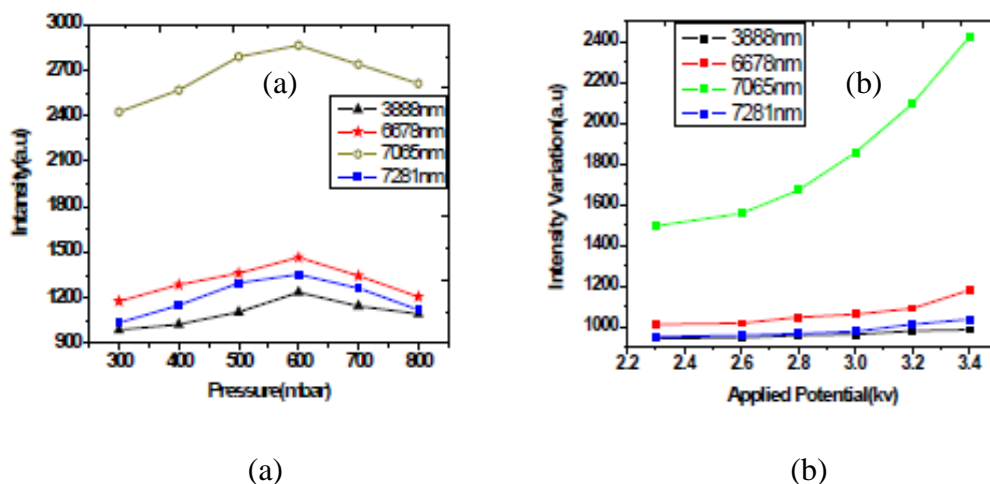


Figure 2.9 (a) intensities of different emission lines vs. Pressure using pulse waveform (b) intensities variation of emission lines vs. Applied potential sinusoidal waveform

The pulse excitation is found to be more stable and more efficient compared to sinusoidal waveform for the same operating conditions by the confirmation of kinetic simulation. Electron concentration is continuously increasing with the increased as pressure for the same simulation time. It is shows that pulse excitation gives more power so the more current and highly intense spectral lines of helium discharge for the same repetition rate as for the sinusoidal waveform.

2.5 Effect of Principal Parameters on Glow Discharge Generation

Generally, in order to achieve high stabilization on the production of glow discharge, it must be generated under low pressure of less than a few mbar [6]. Even so, it is costly to maintain the pressure at low condition. As pressure increase to atmospheric condition, the glow discharge is usually unstable and started to change to a filamentary discharge [13]. At atmospheric condition, glow discharge can be stable dependent on the specific gas dilution, the composition of the dielectric

barrier, the arrangement of the discharge electrode, the applied frequency, the gap spacing between electrodes and the gas humidity [3,4,6,8].

2.5.1 Gas Dilution

Normally, glow discharge is only visible at the voltage where the ionization point is occurred. There is no glow under ionization voltage or breakdown voltage. The occurrence of small avalanches under low field is necessary to obtain a glow discharge at atmospheric pressure. Thus, in order to produce glow discharge easily, it is related to low breakdown voltage of dilution gas. Helium is well known as a gas that has the ability to produce a stable glow discharge at atmospheric pressure. It has very low breakdown voltage at 1 atm which is only about 300 V/mm, some 10 times lower than air. In contrast, helium is not practical in used due to its high cost even though it is good for generating a homogeneous glow discharge at atmospheric pressure. In [13], other low cost gases have been found to replace the helium dilution gas. They used pure argon and pure nitrogen instead of helium due to conveniently low in cost. However, these two gases cannot stabilize the glow discharge and they will produce a silent electric discharge in form of filamentary.

2.5.1.1 Helium Gas

In [20] the experimental work has been done to investigate the Lissajous figure of glow and pseudoglow homogeneous glow discharge in helium under an 11.8 kHz voltage at atmospheric pressure. The experimental set-up for the measurement of the discharge current and Lissajous figure for this work is shown in figure 2.10:

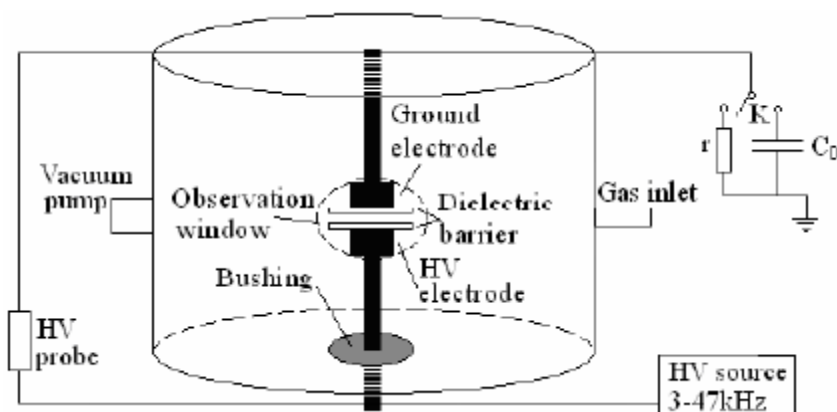


Figure 2.10 Schematic diagram for the measurement Lissajous figure of glow discharge in Helium

The homogeneous glow discharge was generated under the applied voltage with peak-to-peak amplitude of 1.01 kV. It is characterized by one discharge current pulse per one half cycle of the applied voltage as shown in figure 2.11 (a). From figure 2.11 (b), the glow discharge also can be characterized by only one step on the left-hand and right-hand sides of the Lissajous figure parallelogram.

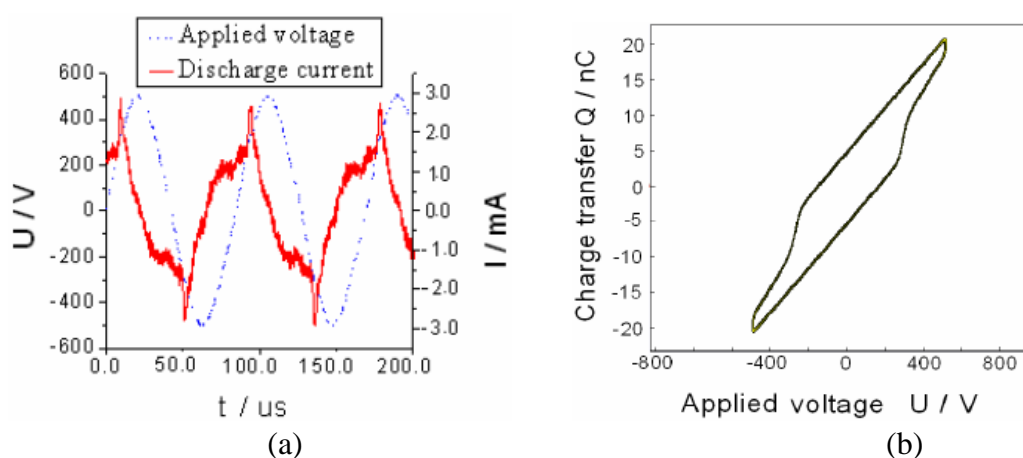


Figure 2.11 Glow discharge at 1.01 kV peak-to-peak and 11.8 kHz frequency at 2.5mm gap distance under atmospheric pressure. (a) Discharge current waveform, (b) Lissajous Figure

As applied voltage is increases to 2.39 kV peak-to-peak, the current pulse in discharge waveform is increases to 3 pulses per each half cycle of applied voltage as shown in figure 2.12 (a). The Lissajous figure (figure 2.12 (b)) is characterized by three steps on left and right hand side of parallelogram. This state is called as pseudoglow discharge.

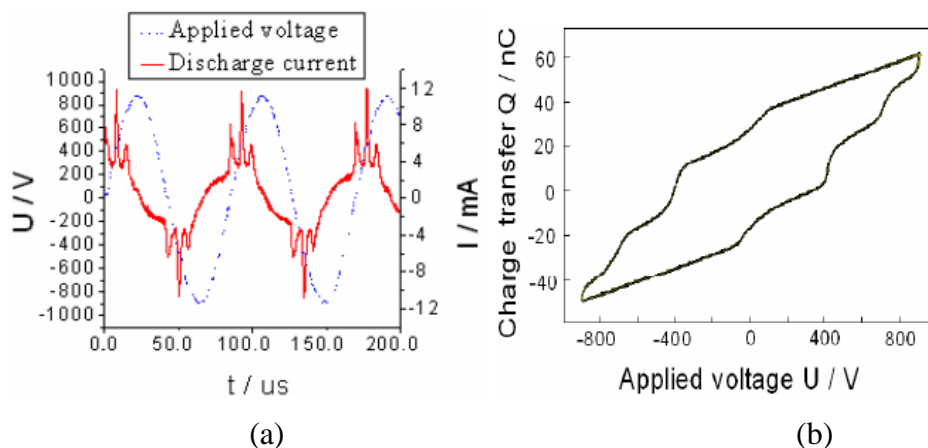


Figure 2.12 Pseudoglow discharge at 2.39 kV peak-to-peak and 11.8 kHz frequency at 2.5mm gap distance under atmospheric pressure. (a) Discharge current waveform, (b) Lissajous Figure

Figure 2.13 (a) and (b) show the discharge current waveform and Lissajous figure respectively when the applied voltage is increased to 20.09 kV under frequency of 11.8 kHz. These figures show that the discharge is at filamentary mode since there are too many pulses in current discharge waveform. For Lissajous figure, it is regular parallelogram because many steps are too little to display.

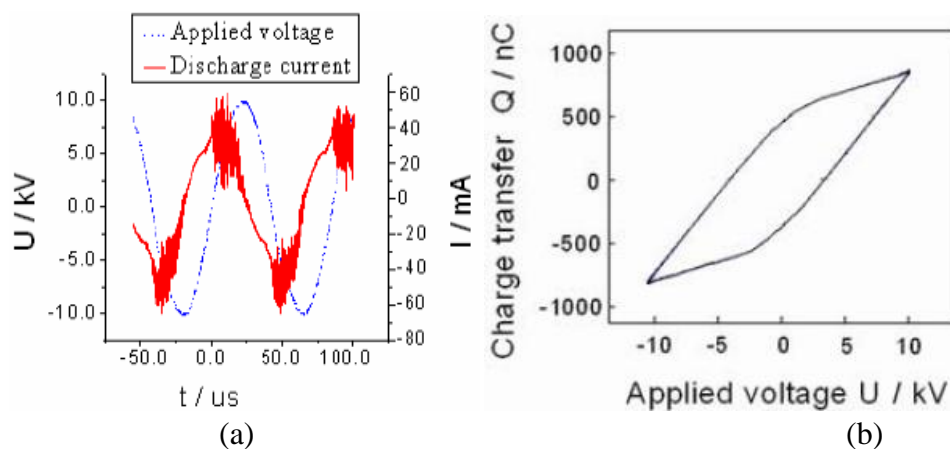


Figure 2.13 Filamentary discharge at 20.09 kV peak-to-peak and 11.8 kHz frequency at 2.5mm gap distance under atmospheric pressure. (a) Discharge current waveform, (b) Lissajous Figure

2.5.1.2 Neon Gas

A diffuse discharge in neon at atmospheric pressure was investigated in [21] with electrical dimension and rapidly photography. It was found that with a gap space from 0.5-6mm, an even diffuse discharge can be easily generated and it is

known as glow discharge. The experimental setup for this work is shown in figure 2.14.

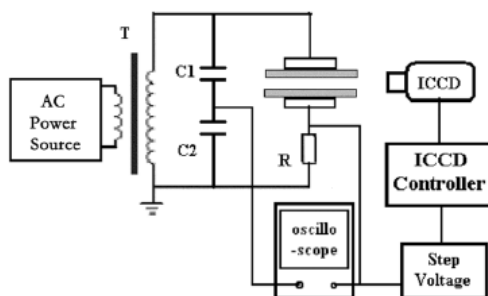


Figure 2.14 Experimental set-up

From figure 2.15 (a), the first breakdown occur at 1000 V at gap spacing of 6mm. Small discharge current peak is place over the displacement current. Then, by slowly increasing the applied voltage, the result shows a transition of the discharge from the first breakdown to a stable discharge as shown in figure 2.15 (b).

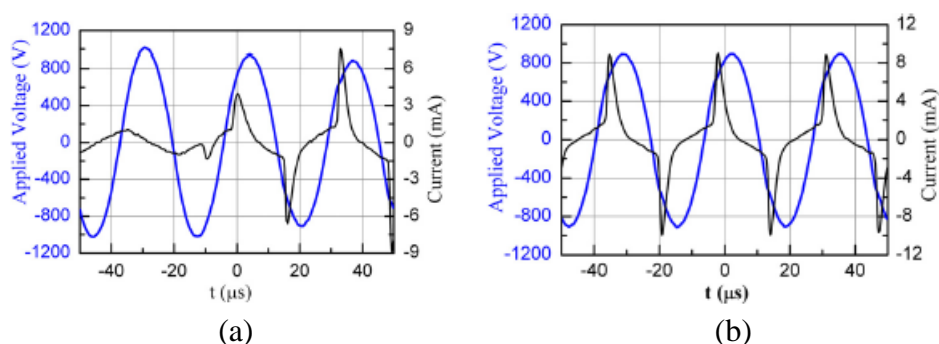


Figure 2.15 (a)Typical waveform of the first breakdown (b)Typical waveform of stable diffuse

2.5.1.3 Nitrogen Gas

In [22] a homogeneous dielectric barrier discharge in nitrogen at atmospheric pressure was investigated. From this work, it was proved that by including of a nitrogen as a gas flow, a stable homogeneous discharge only can be produced in a gap not longer than 3mm spacing. The experimental set-up is shown in figure 2.16 where the electrodes were made of stainless steel plates and both electrodes were covered by a quartz plate of thickness 1mm. A conducting glue called high purity silver paint was used on the metal and dielectric interface in order to make a good contact between these two materials.

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