ANKARA YILDIRIM BEYAZIT UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

OPTICAL EMISSION SPECTROSCOPIC INVESTIGATION OF THE MILLIMETER/THZ WAVE AND MAGNETIC FIELD COMBINED EFFECT ON THE COLD PLASMA ABNORMAL REGION

M.Sc. Thesis by

Abdusalam Abdulmajed FKEREEN

Department of Electrical and Electronics Engineering

May 2017

ANKARA

OPTICAL EMISSION SPECTROSCOPIC INVESTIGATION OF THE MILLIMETER/THZ WAVE AND MAGNETIC FIELD COMBINED EFFECT ON THE COLD PLASMA ABNORMAL REGION

A Thesis Submitted to

The Graduate School of Natural and Applied Sciences of

Ankara Yıldırım Beyazıt University

In Partial Fulfilment of the Requirements for the Degree of Master of Science in Electrical and Electronics Engineering, Department of Electrical and Electronics Engineering

by

Abdusalam Abdulmajed FKEREEN

May 2017

ANKARA

M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"OPTICAL EMISSION SPECTROSCOPIC INVESTIGATION OF THE MILLIMETER/THZ WAVE AND MAGNETIC FIELD COMBINED EFFECT ON THE COLD PLASMA ABNORMAL REGION"** completed by **Abdusalam Abdulmajed FKEREEN** under the supervision of **Assoc. Prof. Dr. Asaf B. SAHIN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

....

Assoc. Prof. Dr. Asaf B. ŞAHIN

(Supervisor)

....

Assoc. Prof. Dr. Enver ÇAVUŞ — Assoc. Prof. Dr. Mehmet ÜNLÜ

(Jury member) — **(Jury Member)**

....

Assoc. Prof. Dr. Hakan ALTAN — Assoc. Prof. Dr. Barış BAYRAM

(Jury member) — **(Jury Member)**

....

Prof. Dr. Fatih V. ÇELEBİ

(Director)

Graduate School of Natural and Applied Sciences

ETHICAL DECLARATION

I hereby declare that, in this thesis which has been prepared in accordance with the Thesis Writing Manual of Graduate School of Natural and Applied Sciences,

- All data, information and documents are obtained in the framework of academic and ethical rules,
- All information, documents and assessments are presented in accordance with scientific ethics and morals,
- All the materials that have been utilised are fully cited and referenced,
- No change has been made of the utilised materials,
- All the works presented are original,

and in any contrary case of above statements, I accept to renounce all my legal rights.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisor, **Assoc. Prof. Dr. Asaf B. SAHIN**, for his tremendous support and motivation during my study. His immense knowledge and precious recommendations constituted the milestones of this study. His guidance assisted me in all the time of my research and during the writing of this thesis.

I would like to thank **Assoc. Prof. Dr. Sinan KIVRAK**, for his understanding and endless support.

I am grateful to my friends for their superior contribution and great effort while preparing the coils for my dissertation. Also, they provided me enormous support during my study and always trusted on me. I am very pleased to have such friends.

Also, I must express my profound appreciations to my parents and my wife for providing me endless support and continuous encouragement throughout my years of study and through the period of writing this thesis. This accomplishment would not have been possible without them. Thank You.

Finally, I am very grateful to my large family "Libya" for giving me the opportunity to complete my master degree.

2017, May **Abdusalam Abdulmajed FKEREEN**

OPTICAL EMISSION SPECTROSCOPIC INVESTIGATION OF THE MILLIMETER/THZ WAVE AND MAGNETIC FIELD COMBINED EFFECT ON THE COLD PLASMA ABNORMAL REGION

ABSTRACT

Based on the growth of terahertz detection techniques, this study goal to investigate experimentally the impact of the terahertz radiation and magnetic fields on the glow discharge detectors GDDs (cold plasma) using plasma spectroscopy techniques (optical emission spectroscopy methods), which gave for more details via different techniques. that can be supported the neon indicator lamps GDDs as inexpensive detectors for terahertz radiation. Where interaction the glow discharge detectors GDDs with the magnetic field and THz radiation were studied by optical emission spectroscopy.

The experiment setup contains a plasma source which is the glow discharge detector GDD. Also, the electromagnetic field was generated by two EM coils. And the THz radiation was generated by the THz system which designed via Schottky Terahertz Diodes. While the results were collected by AvaSpec-ULS3648 Star-Line High-resolution Fiber-optic Spectrometer. The analysis methods that have been utilised are the ratio method and subtraction method.

At the end of the examination, the results were very encouraging, represented by the effect of terahertz radiation and magnetic field on GDD was clearly. Where the THz radiation works to suppress the light intensity of the GDD, reverse magnetic field effect. While the magnetic field works to support the light intensity of the GDD. Therefore, this study supports the other researchers which utilised the inexpensive tool GDDs to detect the THz radiation. And, the optical emission spectroscopy is very useful to examine the GDDs than using the light intensity measurements of the GDDs.

Keywords: THz radiation, glow discharge detectors GDD, electromagnetic field, optical emission spectroscopy OES, plasma spectroscopy.

ANORMAL ALAN SOĞUK PLAZMA ÜZERİNDE THZ DALGASI VE MANYETİK ALAN BİRLEŞİMİNİN ETKİSİ/ MİLİMETRİK OPTİK EMİSYON SPEKTROSKOPİK ARAŞTIRMASI

ÖZET

Terahertz görüntüleme tekniklerinin değerlendirilmesi temeline bağlı olarak,bu çalışma ve farklı tekniklerle daha detay sağlayan plazma spektroskopi teknikleri (optik emisyon spektrometre yöntemleri) kullanarak akkor boşalımlı detektörler GDDs(soğuk plazma) üzerindeki manyetik alanları ve terahertz radyasyonun etkisini deneysel olarak araştırmayı amaçlamaktadır. terahertz radyasyonu için pahalı olmayan detektörler olduğu için neon gösterge lambaları desteklenmektedir. THz radyasyonu ve manyetik alan etkileşimli akkor boşalımlı detektörler GDDs optik emisyon spektrometresi ile keşfedilmiştir.

Deney kurulumunda akkor boşalımlı detektör GDD olan plazma kaynağı bulunmaktadır. Ayrıca,elektromanyetik alan iki EM bobin ile oluşturulmuştur.THz radyasyonu ise Schottky Terahertz Diodes aracılığıyla tasarlanmış THz sistem ile oluşturuluştur.Sonuçlar, AvaSpec-ULS3648 Star-Line yüksek çözünürlüklü Fiber-optik Spektrometre ile toplanmıştır.Kullanılan analiz metotları ölçek ayarlama usulü ve çıkarma yöntemidir.

THz radyasyonu, GDD üzerindeki düşük yoğunluğu bastırmaya çalıştığı araştırma sonunda ,GDD üzerindeki manyetik alan ve terahertz radyasyonunun etkisi ile yansıtılan sonuçlar cesaret vericiydi.Bu yüzden,bu çalışma THz radyasyonunu tespit etmede kullanılan pahalı olmayan GDDs aracını kullanan diğer araştırmacıları desteklemektedir.Optik emisyon spektroskopisi,GDDs düşük yoğunluk ölçümlerini kullanmak yerine GDDs yi incelemek için çok kullanışlıdır.

Anahtar kelimeler: THz radyasyonu,akkor boşalmalı GDD,elektromanyetik alan,optik emisyon spektroskopisi OES,plazma spektroskopisi

CONTENTS

NOMENCLATURE

Roman Letter Symbols

A_{pq}	Transition probability
B	Magnetic field
c	Speed of light

d	Distance between electrodes
e	Charges of electron
E_p	Upper energy level
E_q	Lower energy level
E	Electric field
F	Electric field force
f	Frequency
g	Statistical weight
g_p	Statistical weight of upper energy level
h	Planck constant
I	Intensity
I_b	Non-effected spectrum
I_f	Effected spectrum
i	Electric current
I_{pq}	Intensity of specific energy levels
I_Z^*	Ionisation energy of the species in ionisation stage (z)
k	Boltzmann constant
L	Length of the coil
m	Mass of electron
N	Local of electrons density
n	Number density of emitting species
N_e	Density of electron
n_i	Number of ions
n_e	Number of electrons
n_s	Number of species. Plasma Density
p	Pressure
q	Quantity of charge
q_e	Charge of electron
R	Radius of coil
T	Excitation temperature
T_e	Plasma temperature
V_d	Breakdown voltage
V	Voltage
V_j	Velocity of electron before collision
V_i	Velocity of electron after collision
X_Z	Line intensity for transition from upper level-j to lower level-i

Greek Letter Symbols

α	First *Townsend's coefficient*
γ	Second *Townsend's coefficient*
ϵ_0	Permittivity constant
λ_i	Mean free path
λ	Wavelength
λ_{pq}	Wavelength of specific energy levels
$\Delta\lambda_{1/2}$	Full-Width Half Maximum
$\lambda_{pq,Z}$	Corresponding wavelength of transition from level-p to level-q
λ_D	Debye length
μ_0	Permeability constant
ρ	Density of charges
ν_{pq}	Frequency of specific energy levels.
ν	Velocity of electrons
ν_d	Drift velocity
ϕ	Electrical potential
$\emptyset$	Thickness
ω	Electron impact parameter

Subscripts

b	Base
d	Distance
e	Electron
i	Ion
p	Upper level
pe	Electrons of plasma
q	Lower level
s	Species
z	Ionization stage
Δ	Difference
∇	Derivative
1, 2	Refer to the spectral lines

Acronyms

AC	Alternative current
CCRF	Capacitively Coupled Radio-Frequency Glow Discharges
CW-THz	Continuous-Wave Terahertz
DC	Direct Current

DCPs	Direct Current Plasmas
EM	Electromagnetic
FWHM	Full-Width Half Maximum
GDDs	Glow Discharge Detectors
GHz	GegaHertz
ICPs	Inductively Coupled Plasmas
LTE	Local Thermal Equilibrium
MHz	Megahertz
Non-LTE	Non-Local Thermal Equilibrium
OES	Optical Emission Spectroscopy
RF	Radio Frequency
OR	Optical Rectification
THz	Terahertz
THZ-TDS	Terahertz Time-Domain Spectral

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The electromagnetic range between 100 GHz to 10 THz are called Tera-Hertz radiation discern to be extremely inviting for applications in space technology, medication, communications and etc. The terahertz radiation (THz) has gotten impressive consideration lately, due to their broad logical and mechanical applications. Regardless of the colossal significance of terahertz radiation, the propagation qualities of THz waves have not yet been contemplated in detail, particularly THz waves proliferation in plasma. However, the interaction of the THz radiation with plasmas was investigated by the transmission, reflection, and absorption of the THz radiation crossed the plasmas [1, 2]. Otherwise, the impact of the magnetic field on the plasmas was examined.

The plasma phenomenon occurs when applying enough energy (electrical field) on a neutral gas to reject an electron or more from the atom of gas, to get an ionising medium with parameters, plasma density, plasma frequency, collision frequency and plasma temperature [3]. Where, those parameters effect on the transmission, reflection, and absorption of the terahertz THz radiation crossed the plasmas. Therefore, the terahertz radiation can cross a dense plasma with high collision frequency close to THz repetition, without noticeable absorption power and reflection [4, 5]. Terahertz radiation sensors are finding a key part in a different scope of uses, for example, communication, identification of the materials, imaging, quality control or biochemical. At present time there exist an extensive assortment of the conventional profoundly stayed millimetre and sub-millimeter wavelength detectors and also new suggestions based on various standards and materials, which show up amid most recent years [6]. In addition, there is a broad field of measurement equipment, such as Detectors with direct and heterodyne detection, Electromagnetic coupling, Photoconductive broadband THz antenna sensors, Thermal sensors, Schottky barrier diodes, Transition edge sensors, Field−effect transistor detectors, Pair braking detectors [7] and chemometrics [8]. As well as, The glow discharge detectors GDDs are utilised as a sensor for terahertz radiation THz can be employed them in applications like THz imaging [9]. Where the responsivity of glow discharge detectors GDDs dependent on the polarisation of the THz radiation [10]. Therefore, it can be utilised the neon indicator lamps GDDs as inexpensive detectors for terahertz radiation THz [11].

The plasmas can be assorted into high-temperature plasma and low-temperature plasma. Where low-temperature plasma can be reached in a laboratory plasma. In addition, the latter group can be divided to local thermal equilibrium LTE, and non-local thermal equilibrium non-LTE. Wherever, LTE means all species of plasma medium have the equal temperatures, such as electrons, ions and neutral particles. Moreover, the non-LTE refers to the temperature of plasma species much different [12]. Optical Emission Spectroscopy OES is usually used in the diagnosis of laboratory plasma. For Ex, gas discharge plasma such as inductively coupled plasma ICP, direct current plasma DCP, etc. Plasma diagnosis is a technique for finding information about plasma characteristics [13], such as plasma density, electron temperature and electron / ion energy distribution, etc.. In most cases, the spectral diagnosis method attempts to establish a selection relationship between plasma parameters and radiation characteristics, such as an emission or an absorption intensity and spectral line expansion or displacement [13, 14]. However, the analytical methods of optical emission spectroscopy OES are divided dependent on target parameter, where, the temperature of electron analysed by methods differs the density of electron methods. The temperature of ions and electrons is proportional to the average random kinetic energy. In the heat balance, the velocity distribution of each particle is determined by the Maxwell distribution [15].

The improvement of new sources of the terahertz radiation THz spectral field has pulled in much consideration during recent years. The terahertz radiation can be generated by lots of sources. Solid-State electronic sources, Lasers, Mechanical Excitation Sources impelled by lasers Continuous, Optical Rectification etc. the solid-state electronic source (Schottky Terahertz Diodes) was utilised in the experiment of the dissertation. Where the Schottky terahertz diodes are working as frequency multiplier to generate high-frequency signal [16]. Considering the THz radiation as the main term into the experiment that effects on the GDD. The magnetic field strength B is the main component in the experimental setup of the thesis. Consequently, there are two ways to get a magnetic field B either by a permanent magnet or an electromagnetic coil. Considering the experiment setup, the permanent magnet couldn't use, due to several considerations; the permanent magnet has constant and weak magnetic field and inflexible tool. Furthermore, the electromagnetic coils have more advantages than the permanent magnets, due to the fact to create a DC magnetic field by just pass an electric current through a coil and it is an adjustable tool, to control the DC magnetic field strength via controlling the electric current.

Based on the development of terahertz detection techniques, this study goal to investigate experimentally the impact of the terahertz radiation and magnetic fields on the cold plasma GDDs using plasma spectroscopy techniques (optical emission spectroscopy methods), which gave for more details via different techniques. that can be supported the neon indicator lamps GDDs as inexpensive detectors for terahertz radiation.

The scope of the thesis

The dissertation contains four chapters. The chapter one will be the Introduction. That has the general information, goals of the examination and the scope of the thesis. After that, the chapter two will talk onto the literature survey, which separated into four parts: Glow discharge plasmas, plasma spectroscopy, Terahertz radiation, interaction plasmas with THz radiation and flux distribution of a magnetic field by the coil. Then, the chapter three will be about the Methodology and implementation, contains experimental methods, experiment apparatus, experimental setup, and experimental procedure. Thereafter, the chapter four will show and discuss the results and follow them the conclusion and future work. Also, there are references, a list of figures.

CHAPTER 2

LITERATURE SURVEY

2.1 GLOW DISCHARGE PLASMAS

2.1.1 Introduction

Plasmas are ionised gases; it can be formed by Theta pinches, Tokamaks and Glow discharge tube etc. We can present the plasma state as the fourth state of matter, in addition, the plasma distinguishes two main groups the high temperature or fusion plasma and low-temperature plasma or gas discharge [17, 18]. Generally, we can partition the plasma, which is in thermal equilibrium and non-thermal equilibrium. Thermal equilibrium means that temperature of all species (electrons, ions and neutral species) are similar. Commonly, the local thermal equilibrium (LTE) used which denotes that the temperatures of all plasmas species are the equal in localised areas in the plasma. Otherwise, non-local thermal equilibrium (non-LTE) means that the temperature of the plasma species is not the same [12, 19]. Properly; the electrons are much higher temperature than other particles (ions, neutral species and molecules). We can classify the gas discharge plasma into LTE and non-LTE plasma; this subdivision is usually related to the pressure in the plasma. High gas pressure means that many of the collisions in the plasma due to the presence of so many particles (the average free path of the short collision compared to the discharge length). Otherwise, a low gas pressure has a few collisions in the plasma (A long collisions mean free path compared to discharge length) [3].

2.1.2 Fundamental Equations

The charge is the source of the electric field through which each charge exerts a force on any other charge by inverse square separation (r).

$$\boldsymbol{F} \propto \frac{\mathbf{1}}{\boldsymbol{r}^{\mathbf{2}}} \qquad \textbf{(2.1)}$$

Where r is the distance between two charges.

An externally applied electric field will exert strength on any cost of entering it.

$$\boldsymbol{F = Eq_0} \tag{2.2}$$

Where the charges can generate the electric field. The Poisson's equation.

$$\boldsymbol{\nabla . E = \frac{\rho}{\epsilon_0}} \tag{2.3}$$

For slow time variations like DC and RF

$$\boldsymbol{E = -\nabla\phi} \tag{2.4}$$

From, (2.3) and (2.4) we will have,

$$\boldsymbol{\frac{\partial^2\phi}{\partial x^2} = -\frac{\rho}{\epsilon_0}} \tag{2.5}$$

The electric field is generated at the x-axis by electrical potential (ϕ).

The charge near the magnetic field also tests the force. Lorentz forces are easily combined with charge and electromagnetic effects

$$\boldsymbol{F = q(E + v * B)} \tag{2.6}$$

Where q is the quantity of charge, E is an electric field, v is velocity and B is the flux density. Can be generated an electric field by using an induced magnetic field and conversely. The Faraday's Law gives us the relation between the electric field and the magnetic field.

$$\boldsymbol{\nabla * E = -\frac{\partial B}{\partial t}} \tag{2.7}$$

If applying an electric field on a charge, it will gain kinetic energy.

$$\boldsymbol{\frac{1}{2}mv_d{}^2 = eV = \int_0^x eE.dx} \tag{2.8}$$

In which, (v_d) is a drift velocity. The energy (eV) can be gained by moving a given distance (x), in the trend of an electric field [18].

2.1.3 Fundamental Parameters of plasma physics

2.1.2.1 Plasma temperature (T_e)

If the electron accelerated by an electric field, imply it gains kinetic energy by velocity (v).

$$\boldsymbol{E = \frac{1}{2} m_e \langle v_e^2 \rangle} \tag{2.9}$$

Here, the angular brackets to v means the average of electron velocity. In plasma physics is denoted *the kinetic temperature* of electrons related to Plasma Temperature [12].

$$\boldsymbol{T_e = \frac{1}{2} m_e \langle v_e^2 \rangle} \tag{2.10}$$

Temperature unit is kelvin (K) Often use equivalent voltage of the temperature:

$$T_e(electron - volts) = \frac{kT_e(kelvins)}{e}$$

Where $k = Boltzmann's\ constant = 1.38 * 10^{-23}\ J/K$

2.1.2.2 Plasma Density (n_s)

In the quasi-neutral situation, the number of ions (n_i) and electrons (n_e) are approximately equal, $n_e \approx n_i \equiv n_s$. Number of species, $n_s = 10^7 - 10^{20}\ cm^{-3}$. Typical glow discharges and arcs have an electron and ion density ~ $10^8 - 10^{14}$ [12].

2.1.3.3 Electron plasma frequency (ω_{pe})

In physics of plasmas, there is the most important term. The plasma frequency ($\boldsymbol{\omega_{pe}}$), where, the electron frequency is faster than ion frequency, dependent on the mass. In textbooks. The electron plasma frequency it is same "*The Plasma Frequency*" [12, 17].

$$\boldsymbol{\omega_{pe} = \sqrt{\frac{e^2\, n_e}{\epsilon_0 m_e}}} \tag{2.11}$$

2.1.2.4 Debye length (λ_D)

In physics of plasmas, the Debye length is the effective distance between two oppositely charged particles. In which, each charge particles have electric field radius called Debye shielding distance [3, 12, 17, 20].

$$\lambda_D = \sqrt{\frac{\epsilon_0 kT}{n_0 . e^2}} \quad \textbf{(2.12)}$$

2.1.2.5 Elastic and inelastic collisions

Heretofore, the most joint encounter in gases is among pairs of particles (dual collisions). When particles react, (collide) energy and momentum must conserve. There are two events [12, 17].

I. ***Elastic***: momentum is propagated between particles and the total kinetic energy does not modify.

II. ***Inelastic***: momentum is propagated between particles but a part of the primary kinetic energy is imparted to inner energy in one or more of the particles.

2.1.2.6 Mean free path (λ_i)

In plasma bulk, where, there are many collisions between charged particles, here, the mean free path is the average distance crossed between collisions by particles [12, 17].

2.1.2.7 Townsend's coefficient (α)

The first *Townsend's coefficient*, that refers to the rate of ionisation events to unit distance for electrons having a drift energy in the trend of the electric field E.

$$\alpha = \frac{1}{\lambda_i} . exp\left(-\frac{V_i}{eE\lambda}\right) \quad \textbf{(2.13)}$$

Since the mean free path is inversely proportional to pressure(p), we can write the coefficient as.

$$\boldsymbol{\alpha = Ap\, exp\left(-\frac{Bp}{E}\right)} \quad \textbf{(2.14)}$$

Where, the constants A and B are properties of the gas [12, 17].

2.1.2.8 Paschen's law

After one mean free path for ionisation (λ_i), an electron produces binary of electron of ions on average. Therefore, after a few (λ_i) the electron ions increase. The number of ions can be estimated for slab of gas dx by;

$$\boldsymbol{dN = N\left(\frac{dx}{\lambda_i}\right)} \quad \textbf{(2.15)}$$

Where, N is local of electrons density, here, the charged particles (n_e, n_i) grows exponentially with distance of parallel gap

$$\boldsymbol{N = N_0 . exp\left(\frac{x}{\lambda_i}\right)} \quad \textbf{(2.16)}$$

Now, combining Townsend's coefficient (α) function with the previous function.

$$\boldsymbol{Apd\, exp\frac{-Bp}{E} = ln\left(1+\frac{1}{\gamma}\right)} \quad \textbf{(2.17)}$$

For planar geometry, the breakdown voltage ($V_d = E.d$).

$$\boldsymbol{V_d = \frac{Bpd}{ln(Apd) - ln[ln(1-\gamma^{-1})]}} \quad \textbf{(2.18)}$$

Where, $A \; and \; B$ are private constants for each gas, and p is the pressure at the breakdown. Here we see the breakdown-voltage (V_d) dependent on the pressure (p) and length of the gap (d). However, (γ) is the second *Townsend's coefficient* that is the probability of an ion creating one secondary electron ion near the cathode, this is common dependent on the gas [12, 17, 21].

2.1.2.9 Paschen curve

The Paschen curve is commonly relation between the voltage which produces an electric field to ionise a gas, and pressure (P) with the length of gap (d) in parallel plate system. To find the minimum breakdown-voltage to each gas [12, 17].

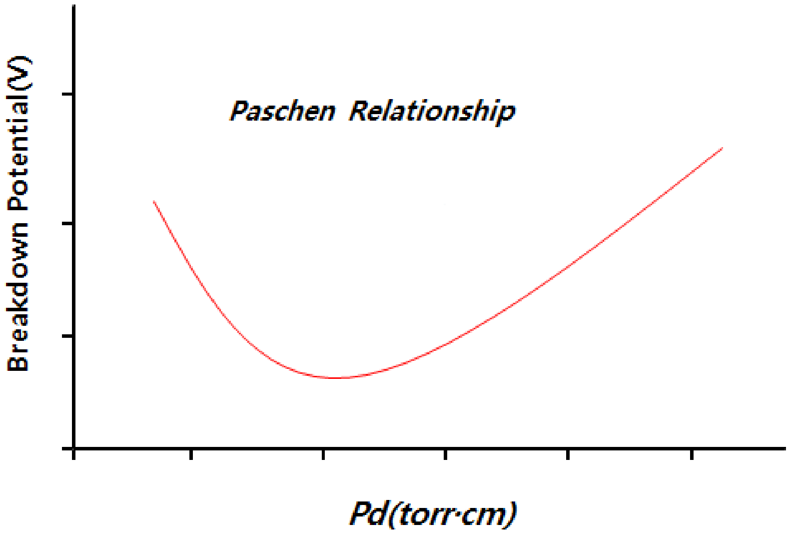

Figure 2.1 The Paschen curve.

2.1.2.10 Breakdown

In this section, taking into account the process of electrical collapse. If an electric field is applied on a parallel gap containing the width d of the gas, the gas is suddenly formed from the insulating medium to the conductive gas at a sufficiently high field. Assuming that several electrons are always in a vacuum, or due to cosmic rays, the field emission near the surface is strongly enhanced near the electric field. The above is assumed to be a DC state. RF breakdown is similar, except that high-frequency surface treatment is not so important: electrons are field oscillation limits multiplied by additive diffusion

As with DC and RF a low-frequency breakdown and higher pd values requires some larger voltages in order to achieve a breakdown, and at lower pd, the breakdown voltage rises sharply again [17, 21, 22].

2.1.4 The Glow Discharge Plasmas Generation

The glow discharge is a plasma produced by a path of the electric field through a low-pressure gas to atmospheric pressure. Therefore, the mechanism of the glow discharge is started by applying a DC voltage on a gas discharge using electrodes under vacuum.

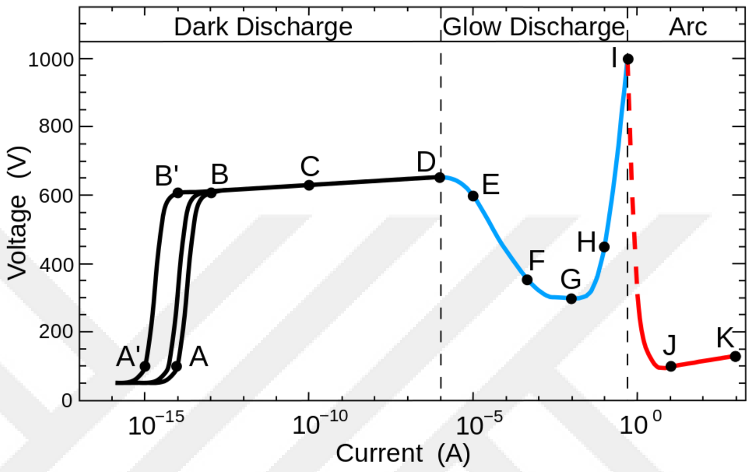

Figure 2.2 The relationship between Current and Voltage of Discharge Plasmas.

Thus, allowing increase the voltage (apply an electric force onto the particles of gas) from (A) on the plot until (B). When a basic estimation of electric field quantity is reached, the atomic gases will collapse (D). Suddenly, the glow discharge will occur (G) called normal glow discharge. If the voltage increases, the discharge gas will follow an ohmic behaviour (H) called abnormal glow discharge. If the voltage increase more, the gas discharge will fall into the electric arc (J) [3, 12]. whereas, there are different methods to get a glow discharge.

2.1.4.1 Direct Current Glow Gas Discharges

If we apply a sufficiently high voltage difference between two electrodes positioned in a gas, the gas will break down to ions and electrons. So, that the mechanism of gas collapse can be explained; due to the ubiquitous cosmic radiation, several electrons are released from the electrodes. In the case where no voltage difference is applied, the electrons emitted from the cathode cannot maintain the discharge. However, when the voltages difference is used, the electrons are accelerated by an electric field opposite to the cathode and collide with the neutral particles. Here, the inelastic collisions here are most important, which leads to excitation and ionisation. Excited collisions, followed by the de-excitation of the radiation, responsible for the name of the "glow" discharge. Ionisation collisions produce new electrons and ions. In addition, the electric field accelerates the ions to the cathode, where they release new electrons by ion-induced secondary electron emission. The electrons produce new ionisation collisions that produce new ions and electrons. Electron emission processes at these cathodes and ionisation in the plasma causes luminescence [19, 23].

2.1.4.2 Capacitively Coupled Radio-Frequency Glow Discharges (CCRF)

Radio Frequency plasma sources use high power AC sources to generate a plasma. RF discharges generally operate in the frequency range $f = \omega/2\pi \; 1 - 100 \; MHz$ to produce a non-thermal plasma with $\boldsymbol{n_e} = 10^{10} \; cm^{-3}$ and $\nu = 10^{9} \; s^{-1}$ yields a skin depth of 0.25 m at frequency of 13.56 MHz. The container of a capacitively coupled discharge might have some interior circular disc-shaped parallel electrodes, which are separated by a distance of a few centimeters. They may be in contact with the discharge or they might be isolated from it by a dielectric. In the situation where insulating chamber walls, outer electrodes, i.e. electrodes on the outside of the vessel, are sometimes utilized. Gas pressures are commonly in the range $1 – 10^{3}$ Pa [19, 22, 24].

2.1.4.3 Pulsed Glow Discharges

In addition, the RF voltage is applied to the glow discharge, the voltage can be used in the form of separate pulses, the length of which is about nanoseconds. The peak current can be operated at higher peak voltages due to pulsed discharges and at the same average power, ionisation, excitation and higher sputtering, and thus are the preferred efficiency [19].

2.1.4.4 Atmospheric Pressure Glow Discharges

As mentioned before, the gas discharge can be operated at a large pressure. The typical pressure range is about 100 Pa, and the operation at higher pressure is (for atmospheric pressure), but it is easy to cause the arc and the heating of the cathode. According to the law of the classical theory, if the linear dimension of the device (d) decreases, the variable of the product (pd) remains constant during the downscaling, and the gas pressure (p) can be increased. Therefore, the miniaturized discharge device is expected to produce glow discharge at atmospheric pressure [19].

2.1.4.5 Corona Glow Discharges

In addition to the gas discharge through the electrode, there is another pulse DC discharge with the cathode wire. Use a high negative potential on the cathode, and discharge at atmospheric pressure. "Corona discharge" the name appears in such a fact that the discharge around the wire is like a crown of illumination. The mechanism of negative corona discharge is like that of DC glow discharge. The ions are increased towards the wire and which in turn causes a secondary electron emission. The electrons are increased into the plasma. This is referred to as a streamer [19].

2.1.4.6 Magnetron Glow Discharges

In addition, a magnetic field may be applied in order to apply a DC or RF voltage difference (electric field) to the glow discharge. The most famous type of discharge, characterised by crossover electric field and magnetic field, is called the magnetron discharge. Three different kinds of magnetron arrangements can be featured, circular, cylindrical and planar magnetrons. It called 'balanced planar magnetron', which is a magnetic field symmetrical about the axis, applying a permanent magnet magnetic field behind the cathode so that the magnetic field path begins and returns to the magnet. Thus, a "magnetic ring" is created on the surface of the cathode, with an average radius R and a domain w, which "catches" electrons, which are paths that accelerate from the cathode by an electric field. The electrons will travel along the magnetic field path along the helix, which will move on longer path lengths in the plasma than in the normal glow discharge [19].

2.1.4.7 Low Pressure, High-Density Plasma

In recent years, some low-pressure and some high-density plasma glow discharges have been developed, fundamentally, as an alternative to capacitive RF discharge and magnetic development variants for deposition and etching applications. In fact, one of the drawbacks of RF diodes is that current and voltage cannot be independently planned. Thus, bombardment energy and ion bombardment fluxes cannot be diversified independently of each other, unless the application of different frequencies, which is not always very useful [19].

2.1.5 The Glow Discharge Plasmas Applications

In this dissertation, will briefly introduce the applications. Subsequently, the glow discharge plasmas have many application fields; industrial applications [25] (e.g. Etching , Deposition, Sputtering, etc.), environmental applications (e.g. wastewater treatment [26], etc.), Plasma displays (e.g. TV, plasma display panel, etc.), Lamps (e.g. fluorescence lamps, neon lamps or glow discharge detectors GDDs, etc.) [19]. The latter tool of glow discharge plasma (GDDs) is the tool which was utilised in the dissertation.

2.2 PLASMA SPECTROSCOPY

2.2.1 Introduction

In this part of literature review, we will talk about plasma spectroscopy. The plasmas can be classified into high-temperature plasma and low-temperature plasma. Where low-temperature plasma can be achieved in a laboratory plasma. In addition, the latter group can be divided to local thermal equilibrium (LTE), and non-local thermal equilibrium (non-LTE). Wherever, LTE means all species of plasma medium have the same temperatures, such as electrons, ions and neutral particles. Moreover, the non-LTE refers to the temperature of plasma species much different [12]. Optical Emission Spectroscopy (OES) is generally used in the diagnosis of laboratory plasma. For Ex, gas discharge plasma such as inductively coupled plasma (ICP), direct current plasma (DCP), etc. Plasma diagnostics are the techniques used to obtain information about the properties of plasma [27]. Such as the density of the plasma, electron temperature and electron/ion energy distributions, etc. Generally, spectral diagnostic methods attempt to establish selection relationships between the plasma parameters and the radiation features, such as the emission or absorption intensity and the broadening or shifting of the spectral lines [13, 14].

2.2.2 Types of radiations

If an atom or ion in plasma medium collides with an electron-ion, will emit radiation when the occurring transition between different energy levels. Where in plasma spectroscopy, the interaction of electrons and ions with the radiating species is important [28].

2.2.2.1 Line radiation

Line radiation occurs for electron transition between bound levels generate line spectra [14, 28]. If an electron falls off from the upper energy level (E_p) to the lower energy level (E_q), it will emit photon energy ($h\nu_{pq}$).
Where, (h) is Planck's constant and (ν_{pq}) is frequency of specific photon for those levels.

$$\boldsymbol{h\nu_{pq} = E_p - E_q} \qquad \textbf{(2.19)}$$

2.2.2.2 Recombination radiation (free - bound)

Recombination radiation occurs when a free electron in the continuum recombines with an ion [14, 28].

$$\boldsymbol{h\nu = E(\infty) + \frac{1}{2}mV^2 - E_p} \qquad \textbf{(2.20)}$$

Where, (m) is the mass of electron, (V) its velocity and (E_p) is energy level of an ion.

2.2.2.3 Free – free radiation.

Free-free radiation occurs due to friction between two free energy ions, called Bremsstrahlung [14, 28]. Usually, it generates as light *x-ray*.

$$\boldsymbol{h\nu_{ji} = \frac{1}{2}mV_j^2 - \frac{1}{2}mV_i^2} \qquad \textbf{(2.21)}$$

Where (V_j) is the velocity of electron before collision, (V_i) is the velocity of electron after collision, (m) is mass of electron and (ν_{ji}) is frequency of the radiation.

In plasma, the population of the various energy levels produce us the relative amounts of line recombination and continuum radiation. Such as the energy level stripped of its electrons has not line radiation. The intensive variables as the kinetic temperature and the number of density effect on the relativity of ionisation [14].

2.2.3 Analytical methods

The analytical methods of optical emission spectroscopy (OES) are divided dependent on target parameter, where, the electron temperature analysed by methods differ electron density methods. And, the average random kinetic energy is directly proportional to the temperature of ions and electrons. In thermal equilibrium, Maxwell distribution governs the distribution of velocities for each type of particles. where difficult to be achieved the thermal equilibrium condition into laboratory plasma [15]. In this case, when LTE is considered, the same temperature for atoms, ions, and electrons are associated in the plasma. However, in the absence of LTE, means the electrons, ions and atoms are characterised by its own temperature, in the plasma will not achieve equilibrium. Hence, the temperature of the plasma as a bulk to be the term plasma temperature in LTE. contributed mainly by the faster-moving electrons due to the smallest mass compared to atoms and ions.

2.2.4 Determination of Temperature

2.2.4.1 Ratio Method

The simplest approach to determine the temperature is done by the intensity ratio of two spectral lines [15, 28], provided that the population densities of the lines on the upper level are in LTE. Observe that the temperature decided from this strategy alludes to excitation temperature consequently if LTE condition holds, the temperature is then known as electron temperature. The intensity of the spectral line which is assumed to be optically thin is given by.

$$I_{pq} = \frac{hcA_{pq}g_p n}{\lambda_{pq}U(T)} . e^{\left(\frac{E_p}{kT}\right)} \tag{2.22}$$

Where (I_{pq}) is the intensity, (λ_{pq}) is the wavelength, (A_{pq}) is the transition probability, corresponds to transition between energy levels(p, q), (h) is Planck's constant, (c) is speed of light, number density of emitting species (n), (k) is Boltzmann's constant, excitation temperature (T), (g_p) is the statistical weight of upper energy level, U(T) is partition function and (E_p) energy of upper level in (eV). If the intensity ratio of two spectral lines of the same species and ionisation stage is taken, the constants will cancel each other, to yield the relationship as;

$$\frac{I_1}{I_2} = \frac{g_1.A_1.\lambda_2}{g_2.A_2.\lambda_1} . e^{\left[-\left(\frac{E_1-E_2}{kT}\right)\right]} \tag{2.23}$$

Where, (I) is the intensity, (g) is the statistical weight, (A) is the transition probability, (λ) is the wavelength, (E) is the energy of excited state and (k) is Boltzmann constant, the subscript (1) and (2) refer to the spectral lines of the same element selected.

2.2.4.2 Boltzmann Plot

In Boltzmann plot, we will use the intensity line equations,

$$I_{pq} = \frac{hcA_{pq}g_p n}{\lambda_{pq}U(T)} . e^{\left(\frac{E_p}{kT}\right)} \tag{2.24}$$

By rearrangement to yield,

$$\frac{\lambda_{pq}.I_{pq}}{hcA_{pq}g_p} = \frac{n}{U(T)} . e^{\left(\frac{E_p}{kT}\right)} \tag{2.25}$$

Taking natural logarithm of both sides of equation,

$$ln\left(\frac{\lambda_{pq}.I_{pq}}{hcA_{pq}g_p}\right) = -\frac{1}{kT} . E_p + ln\left(\frac{n}{U(T)}\right) \tag{2.26}$$

We will get a linear relationship when left side of equation vs (E_p), and the electron temperature (T) may be calculated via the slope. An advantage that Boltzmann plot has over the ratio method is that lines, which are optically thick, can be easily identifiable from the large deviation of the data points in the straight-line fitting [15, 28].

2.2.4.3 Saha-Boltzmann Equation.

The Saha-Boltzmann equation is considered the ionisation stage at the upper energy level, and hence the temperature is estimated by this method is known as ionisation temperature. the ionisation temperature will be equal to the electron temperature, Taking into consideration LTE conditions. Different, ratio method or Boltzmann plot, which two spectral lines are required from the same species, Saha-Boltzmann equation uses spectral lines of the same element and sequential ionisation stages [15, 28].

$$\boldsymbol{n_e = \frac{I_Z}{I^*_{Z+1}}\, 6.04 * 10^{21} (T)^{3/2} . e^{\left(\frac{E_{p,Z} - E_{p,Z+1} - X_Z}{kT}\right)}} \qquad \textbf{(2.27)}$$

Where,

$$\boldsymbol{I^*_Z = \frac{I_Z . \lambda_{pq,Z}}{g_{p,Z} . A_{pq.Z} . X_Z}} \qquad \textbf{(2.28)}$$

In which, (I^*_Z) is the ionization energy of the species in ionization stage (z) in (eV), ($\lambda_{pq,Z}$) is the corresponding wavelength of transition from level-p to level-q, (X_Z) is the line intensity for transition from upper level-p to lower level-q, ($A_{pq.Z}$) is the transition probability from level-p to level-q, ($g_{p,Z}$) is the statistical weight of transition from level-p, and (T) is the temperature of electron.

The ionisation stage of the species denotes by a subscript (z). However, the Saha-Boltzmann is utilised to determine the electron temperature by the knowledge of electron density. Therefore, this formula may work in two directions, such that one can also estimate the electron density via knowledge of electron temperature.

2.2.4.4 Doppler Broadening

If the spectral line profile appears as a Gaussian profile, this suggests that Doppler and pressure broadening control the plasma [15, 28], which given as:

$$\boldsymbol{FWHM = \Delta\lambda_{1/2} = 2\lambda\sqrt{\frac{2kT_P ln2}{mc^2}}} \quad \textbf{(2.29)}$$

Where, (k) is Boltzmann constant, (m) is the atomic mass, (c) is the speed of light, (T_P) is the plasma temperature, $(\Delta\lambda_{1/2})$ is the Full Width Half Maximum (FWHM) of Doppler broadened spectral line, and (λ) is the central wavelength value of the peak.

2.2.5 Determination of Electron Density.

In this part, the electron density of plasma is obtained by different techniques, namely the Saha-Boltzmann equation and Stark broadening relationship have been discussed. Where the other available methods are successfully applied to estimate an electron density of the plasma [28].

2.2.5.1 Stark Broadening.

The electric field of electrons and ions yield Stark broadening, will guide to spectral broadening [15, 28] with FWHM given by formula

$$\boldsymbol{FWHM = \Delta\lambda_{1/2} = 2\omega\left(\frac{N_e}{10^{16}}\right)} \quad \textbf{(2.30)}$$

Where, (ω) is the electron impact parameter and (N_e) is density of electron.
This method has been applied to determine the electron density from laser induced plasma by most researchers.

2.2.5.2 Saha-Boltzmann Equation.

As we mentioned before, Saha-Boltzmann Equation determined electron temperature by electron density, therefore, if the temperature of plasma is known, will find the electron density immediately by a formula provided emission lines from the same species of successive ionisation stage were present [15, 28].

2.3 TERAHERTZ RADIATION

2.3.1 Introduction

The terahertz district (THz) of the electromagnetic (EM) range (0.1 to 10 THz), existing between the infrared and microwave band, it called terahertz radiation, millimetre waves, T-rays or THz gap.

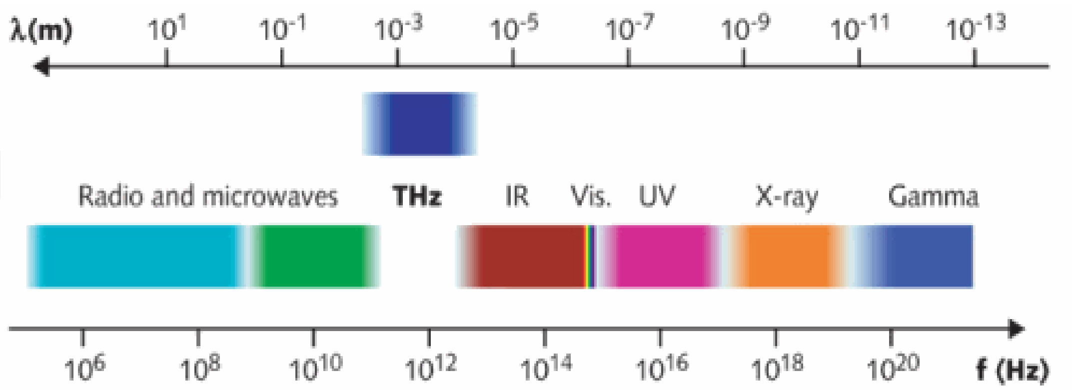

Figure 2.3 Electromagnetic Radiation Spectrum.

Has gotten impressive consideration lately, due to their broad logical and mechanical applications in medicinal finding, security screening, military recognition, radio space science, climatic reviews, fast communication, chemical and biological detecting. Regardless of the colossal significance of terahertz radiation, the propagation qualities of THz waves have not yet been contemplated in detail, particularly THz waves proliferation in plasma [1, 2].

2.3.2 Terahertz Apparatus

Exemplary terahertz trial station, for example, a created for imaging, tomography or spectroscopy, involves the three primary parts of the source, which delivers the terahertz radiation, the ingredients, which control the radiation, and the indicator, which detects the radiation [1].

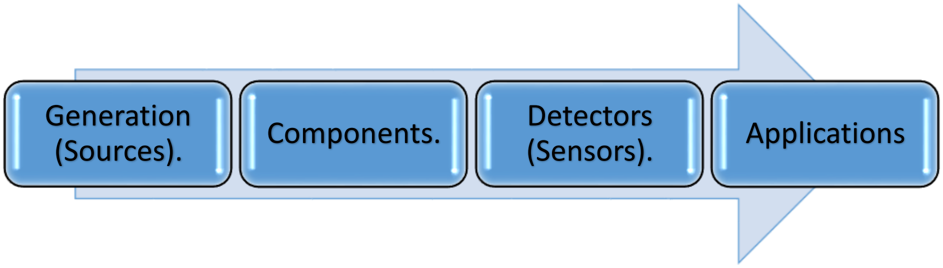

Figure 2.4 Typical terahertz apparatus.

(I) Generation. (II) Components. (III) Detectors. (IV) Applications.

Terahertz components. Optical ingredients are such things as mirrors, focal points and polarizers. As opposed to unmistakable optical frameworks, where focal points and comparative transmitting components prevail, terahertz frameworks tend to utilise reflecting components, which have insignificant misfortune and no scattering. Terahertz mirrors have ordinarily been made of metal. Different materials have been as of late trialled, for instance, doped and undoped GaAs and a cross breed of polypropylene and high-resistivity silicon. Tunable mirrors, in light of one-dimensional photonic gems, have additionally been produced [1]. we highlight a couple of the real part innovations that have been created for terahertz applications. They comprehensively fall into two classes: generation and detections.

2.3.3 Generation THz Radiation

The improvement of new sources in the terahertz (THz) spectral field has pulled in much consideration during recent years. There are lots of sources of the terahertz wave. The general source of THz radiation (thermal source) is the mercury bulb. And there are other sources as Vacuum electronic sources, Solid-state electronic sources, Lasers, Mechanical Excitation Sources pumped by lasers Continuous, and Optical rectification [1]. In addition, Coherent terahertz (THz) recurrence radiation is discharged from the surface of a semiconductor after excitation by an ultrafast laser pulsation [29]. Therefore, generation of continuous-wave terahertz (CW-THz) radiation by Photo-mixing with double-mode and multi-mode lasers in the sub-terahertz repetition zone [30]. Thus, is possible to generate an intensive terahertz radiation, by mixing short laser pulse with its frequency, the terahertz generation operation relies upon the relative polarizations of the lasers and the terahertz repetition

[31, 32] since the laser pulsation period is ordinarily in the picosecond or sub-picosecond range the producing radiation is in the terahertz or multi-terahertz range. Another generally utilised strategy for ultrashort THz pulsation generation is optical rectification (OR) of femtosecond laser pulses [1, 33]. Consequently, ultrashort laser-driven ionisation can radiate to a great degree broadband, single-cycle terahertz pulsations [34]. Otherwise, The utilisation of photoconductive switches is likely the most generally utilised technique for the generation and detection of THz pulsations in TDS [33].

2.3.4 Detection THz radiation (Sensors)

Terahertz radiation sensors are finding a key part in a different scope of uses, for example, communication, identification of the materials, imaging, quality control or biochemical. At present time there exist an extensive assortment of the conventional profoundly stayed millimetre and sub-millimeter wavelength detectors and also new suggestions based on various standards and materials, which show up amid most recent years [6]. In addition, there is a wide range of measurement equipment, such as Detectors with direct and heterodyne detection, Electromagnetic coupling, Photoconductive broadband THz antenna sensors, Thermal sensors, Schottky barrier diodes, Transition edge sensors, Field–effect transistor detectors, Pair braking detectors [7] and chemometrics [8]. Terahertz detectors have advanced quicker than whatever other sub-millimeter wave innovation. These days, there are close quantum-constrained sensors that can gauge both highly narrow-band waves or broadband up to or surpass one Terahertz [35]. The glow discharge detectors (GDDs) are utilised as a sensor for terahertz radiation (THz) can be employed them in applications like THz imaging [9]. Where the responsivity of glow discharge detectors (GDDs) dependent on the polarisation of the THz radiation [10]. Therefore, it can be used the neon indicator lamps (GDDs) as inexpensive detectors for terahertz radiation (THz) [11].

2.3.5 Applications

In this dissertation, will briefly introduce the applications. Obviously, terahertz innovation is quite recently starting to become an adult and numerous applications yet to be acknowledged lie in the holdup. Subsequently, as another sort of coherent light source shows extraordinary logical esteem and an extensive variety of uses in the comprehensive fields. for example, communication, physical chemistry, identification of the materials, imaging [36], information security, quality control, biochemical and medical technology, etc. [2, 33, 37].

2.4 INTERACTION PLASMAS WITH THz RADIATION

2.4.1 plasma Generation

Glow discharge plasma is possible to generate by applying sufficiently of electromagnetic radiation on a neutral gas [23] Such as capacitively and inductively coupled RF discharge plasmas, microwaves discharge plasmas, furthermore the ionisation radiations as X-rays and gamma rays. Also can be created the glow discharge plasmas by applied powerful terahertz radiation on a neutral gas [38], the characteristic in use the powerful terahertz radiation sources the possibility to investigate the discharge phenomenon in another frequencies domain. For example to create glow discharge plasmas by gyrotron [39] and femtosecond laser pulsed [40, 41].

2.4.2 Interaction with the plasma

The plasma phenomenon occurs when applying enough energy (electrical field) on a neutral gas to reject an electron or more from the atom of gas, to get an ionising medium with parameters; plasma density, plasma frequency, plasma temperature and collision frequency [3]. Where, those parameters effect on the transmission, reflection, and absorption of the terahertz THz radiation crossed the plasmas. Therefore, the terahertz radiation can cross a dense plasma with high collision frequency close to THz repetition, without noticeable absorption power and reflection [4, 5]. Likewise, with the absorption-less power of terahertz radiation in inhomogeneous collision frequency plasma [42]. Otherwise, the terahertz radiation transmission through the dc glow discharge plasma is dependent on the polarisation of the radiation with respect to the direction of the electric field of plasma [43]. As well, the responsivity (GDDs) increases when the direction (polarisation) of the electric field parallel with the electric field of the THz radiation [10].

2.4.3 Diagnostic the plasmas

The most common parameters in plasma diagnostic are plasma density, plasma frequency and plasma temperature, wherever there are several ways to measure them practical and estimate them theoretically. Recently the terahertz technicality has been used as a new method to diagnostic the plasmas, subsequently, the plasma temperature, plasma density, collision frequency and external magnetic field can bring about a huge change in the amount of absorption [44, 45]. Furthermore, the plasma electron density is measured by THz techniques in magnetic fusion plasmas [46]. Otherwise, terahertz time-domain spectral (THZ-TDS) techniques are utilised to characterise the glow discharge plasma, that methods have been applied to estimate characterization of plasma such as density and collisional frequency [47]. In addition, the features of terahertz time-domain spectroscopy (THZ-TDS) estimation is unaffected by the gas temperature and plasma density comparative with the traditional apparatus like a Langmuir-type double probe [48]. And gives high time determination and THz broader coverage of frequencies [49, 50].

2.5 FLUX DISTRIBUTION OF A MAGNETIC FIELD BY EM COIL

The magnetic field along the axis of a solenoid will change depending on the location point into a coil, can be shown by formula:

$$\boldsymbol{B} = \frac{\boldsymbol{\mu_0 i}}{\boldsymbol{2}}\left(\frac{\boldsymbol{N}}{\boldsymbol{L}}\right) * (\boldsymbol{sin\emptyset_2} - \boldsymbol{sin\emptyset_1}) \quad \textbf{(2.31)}$$

Where $\boldsymbol{i}$ is the current passing the coil, N is number of turns, L is the length of the coil, $\left(\frac{N}{L}\right)$ is number of turns per unit of length and angles $(\emptyset_1, \emptyset_2)$ as shown in the figure.

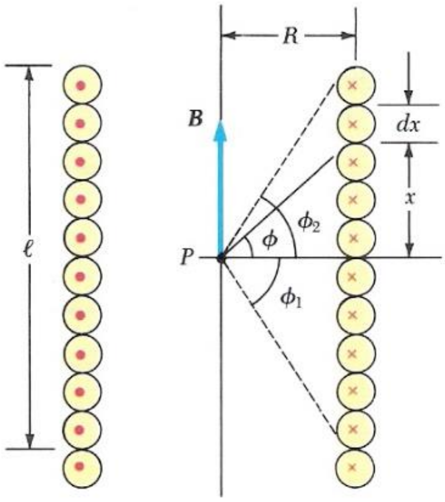

Figure 2.5 The magnetic field along the axis of a solenoid.

Where, the magnetic field B for long solenoid at the midpoint, when angles $(\emptyset_1 \; and \; \emptyset_2) = 90^o$. By using (1) will have:

$$\boldsymbol{B_{midpoint} = \mu_0 i * \left(\frac{N}{L}\right) = \mu_0 i.n} \qquad \textbf{(2.32)}$$

Where, $n = \frac{N}{L}$ is number of turns per unit of length.

Therefore, the net magnetic field at the end of a solenoid when $(\phi_1 = 0° \; and \; \phi_2 = 90°)$. will be half the value at the center of the solenoid. By using (1) will have:

$$\boldsymbol{B_{at\ the\ end} = \frac{\mu_0 i.n}{2}} \qquad \textbf{(2.33)}$$

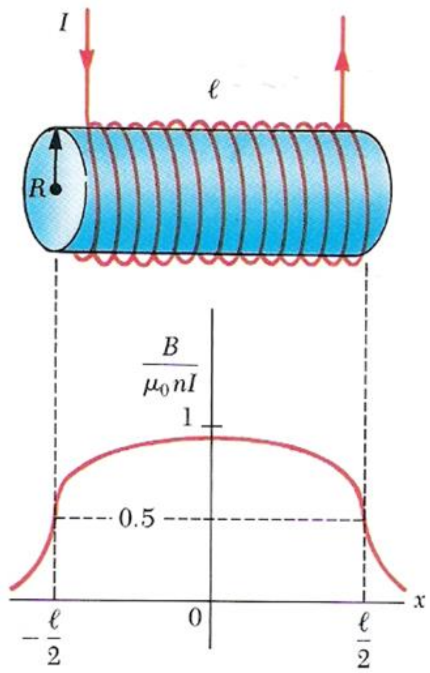

Figure 2.6 The magnetic field strength distribution along the axis of the EM coil.

Also, can be described the extension magnetic field B along the axis of a solenoid in air by

$$\boldsymbol{B} = \frac{\mu_0 iN.R^2}{2(x^2+R^2)^{\frac{3}{2}}} \qquad \textbf{(2.34)}$$

Where x is the distance along the axis of a coil. The net magnetic field B in the coil is the sum of the magnetic fields of all the N turns. Obviously, the magnetic field decreases whenever increase the distance x.

CHAPTER 3

THE METHODOLOGY AND IMPLEMENTATION

3.1 THE METHODOLOGY

There are many methods to diagnostic plasma physics. Therefore, the optical emission spectroscopy, in short (OES) is commonly utilised in the diagnostic lab plasmas, such as the glow discharge plasmas. Where the thesis' aim is investigating the effect of THz radiation and magnetic field on the GDDs by the optical emission spectroscopy methods. Furthermore, there are other research groups using the light intensity difference as an approach on the same topic. Keeping in mind the end goal to describe the glow discharge plasmas by methods for optical emission spectroscopy, an optically thin state of a spectral line is desired. In addition, the analytical methods of OES to glow discharge plasmas are divided dependent on target parameter, where, the electron temperature analysed by methods differ electron density methods [14, 15, 28]. In our approach, the target spectral line was selected (wavelength range is 821 to 825 nm) in the infrared region due to the highest intensity. Thereafter, the collected spectrums were processed by two paths. Firstly, the spectrums difference method ($\Delta I = I_f - I_b$), whereas, the effected spectrums were subtracted from the original spectrum. Knowing that, the effected spectrum is I_f either by THz radiation or the magnetic field and $I_b$is the original spectrum. Whereas, ***this method did not use before to analyzing of the optical emission spectroscopy.*** The second path, the common approach has been utilized (the ratio method $\frac{I_f}{I_b}$). Whereas, the ratio method is the simplest approach in determining temperature is done by taking the intensity ratio of two spectral lines [15].

3.2 Experiment apparatus

3.2.1 Terahertz Radiation Generation System

The improvement of new sources in the terahertz (THz) spectral field has pulled in much consideration during recent years. The terahertz radiation can be generated by lots of sources. The general source of THz radiation (thermal source) is the mercury bulb. And there are other sources as vacuum electronic sources, Solid-State electronic sources, Lasers, Mechanical Excitation Sources pumped by lasers Continuous, and Optical Rectification [1]. Subsequently, the solid-state electronic source (Schottky Terahertz Diodes) was utilised in thesis's experiment. Where the Schottky terahertz diodes are working as frequency multiplier to generate high-frequency signal [16].

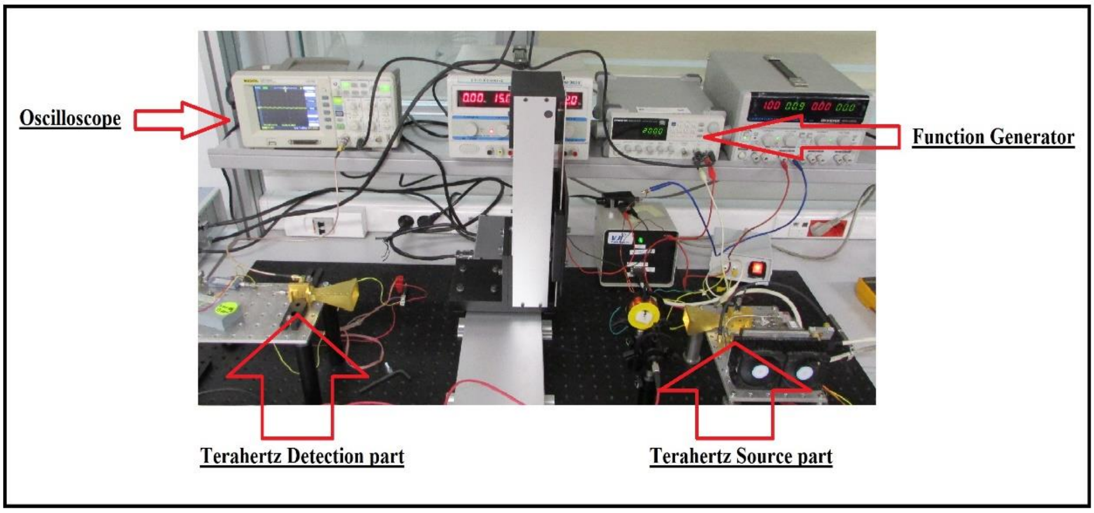

Figure 3.1 The Terahertz Radiation System.

Terahertz radiation generation system which shown in the figure below was designed and implemented in the Lab.

3.2.2 The Electromagnetic Coil (Solenoid)

The magnetic field strength B is the main component in the experiment of the thesis. Consequently, there are two ways to get a magnetic field B either by a permanent magnet or an electromagnetic coil. Considering the experiment setup, the permanent magnet couldn't use, due to several considerations; the permanent magnet has constant and weak magnetic field and inflexible tool. Furthermore, the electromagnetic coils have more advantages than the permanent magnets, due to the fact to create a DC magnetic field by just pass an electric current through a coil and it is an adjustable tool, to control the DC magnetic field strength via controlling the electric current. Based on what was said, the EM coils were utilised. The required DC magnetic field strength is ($B \cong 200, 300\ Gauss$), by wire diameter was used ($\emptyset = 0.361\ mm$) or American wire gauge (AWG No: 27), framework dimensions were ($d_{inner} = 28.0\ mm, c = 12.0\ mm,\ b = 27.0\ mm$). Where d_{inner} is the inner diameter, c is the high of the coil and b is the length of the coil, and the number of turns of the coil is ($N = 2016\ n$). The measured resistance approximately is $R = 44\ \Omega$. By using ohm's law ($V = IR$), can find the maximum current ($\boldsymbol{i}$) via the maximum value of the DC power supply was 30V;

$$\boldsymbol{i}_{30V} = \frac{30\ V}{44\ \Omega} = 0.681\ Amp = 681.8\ mA$$

The DC magnetic field B at midpoint of solenoid;

$$B_{midpoint} = \mu_0 i * \left(\frac{N}{L}\right) = \mu_0 i.n \qquad \textbf{(3.1)}$$

Thus, by using 30 VDC power supply can estimate a DC magnetic field strength at the midpoint of the solenoid. Where, $N = 2016\ n, L = b = 0.027m, and\ i_{30V} = 0.6818\ Amp$ is

$$B_{calculated} = 639.72\ Gauss$$

In fact, the magnetic field strength of short solenoid decreases along the axis from the midpoint in both sides. Accordingly, the experiment setup needs to apply a magnetic field B to impact on the GDDs at along the axis of the coils (opposite the coil), Subsequently, the effect on the GDDs does not homogeneous along the gap between the electrodes. more precisely, the GDDs structure has two parallel rod electrodes were placed on the extension of the axis of the coil. Of the above, the magnetic field distribution is inhomogeneous and decreases along the axis. So, the plasma interaction with a magnetic field B is weak and inhomogeneous along the electrode rods' gap. To solve this problem. We used two symmetrical EM coil facing each other, on the same an axis, separate them by a gap to put the glow discharge detector GDD and crossing

THz radiation their axis. By this experiment setup, we will get a good flux distribution lines along the gap between the coils. Also, the net value of the magnetic field in the gap is the sum of the magnetic fields for both coils.

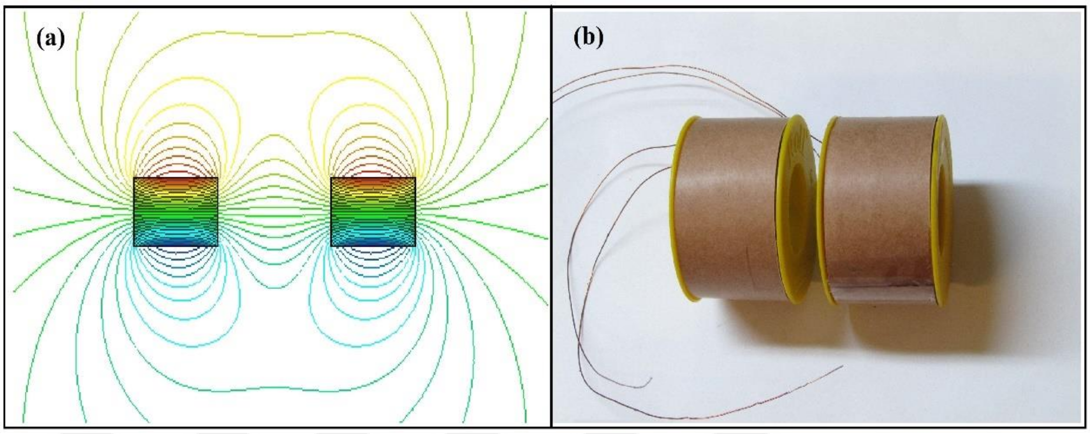

Figure 3.2 (a) The flux distribution lines between two EM coils. (b) The EM coils that were used.

3.2.3 The Glow Discharge Detectors (GDDs)

The glow discharge detectors (the Neon Indicator Lamps) are utilised as abnormal plasma generator in the experiment of the thesis. The GDDs content two parallel electrodes made of tungsten into a small tube have the gas or the metal vapour under vacuum. The GDDs' colour is depending on the type of gas or the metal vapour which used. Where each gas or metal vapour have a specific colour, more precisely, each gas or vapour metal have specific spectral (spectral fingerprint). Moreover, the GDDs are inexpensive detector due to the low cost.

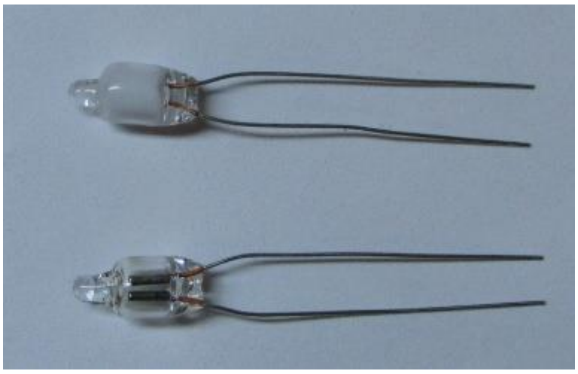

Figure 3.3 The Neon Indicator Lamp or Glow Discharge Detectors (GDDs) that were used.

3.2.4 The Spectrometer

A device utilised for recording and measuring spectra, particularly as a technique for investigation. The spectral data was taken by AvaSpec-ULS3648 Star-Line High-resolution Fiber-optic Spectrometer, which has wide range coverage UV/VIS/NIR (Wavelength range 200 - 1100 nm).

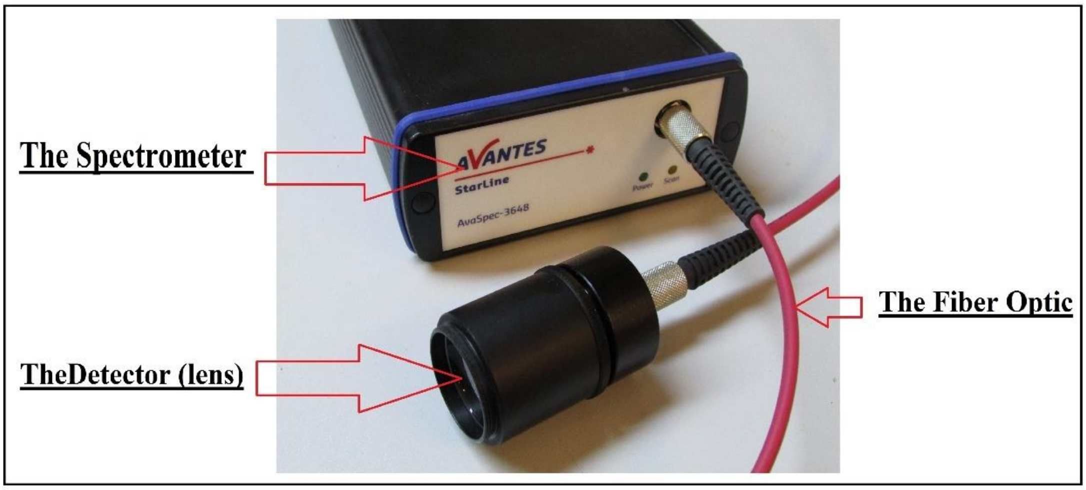

Figure 3.4 The Spectrometer that was used.

The intensity measurements (in A/D Counts) can be converted into irradiance data with known the calibration light source (in $\mu W\ /\ cm^2$) by data transfer function:

$$I = Caldata\left(\frac{sample-dark}{refcal-darkcal}\right) * \left(\frac{cal\_inttime}{S\_inttime}\right) \qquad \textbf{(3.2)}$$

Where, ($Caldata$) is Intensity of the calibration light source (in $\mu W\ /\ cm^2$), ($refcal$) is the reference spectrum for calibration light source, ($darkcal$) is the dark spectrum for calibration light source (in A/D Counts), ($samble$ and $dark$) means the spectrum of the sample and its the dark spectrum (in A/D Counts), respectively. ($cal\_inttime$) and ($S\_inttime$) are integration time for the calibration light source and the sample, respectively.

3.3 Experiment Setup

The interaction terahertz and magnetic field with abnormal plasma experiment include two electromagnetic coils, the glow discharge detector GDD, the terahertz source system and the spectrometer, as shown in the figure.

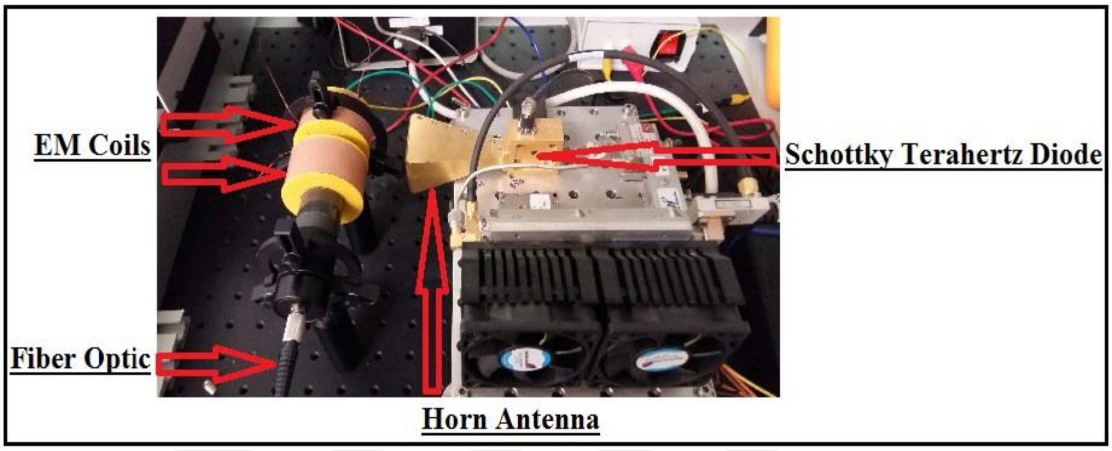

Figure 3.5 The Experimental Setup.

The EM coils were placed facing each other, on the same an axis by cylinder black paper, separate them a gap and connected series with an adjustable DC power supply. The glow discharge detector GDD was placed at the midpoint between EM coils and connected in series with a resistance (1 KΩ) to an alternate power supply. The Terahertz source (horn antenna) was placed confrontation the GDD to cross the EM coils' axis. Where the terahertz radiation and magnetic field have been orthogonal on the electric field of the plasma. The spectrometer detector was placed on the axis of the EM coils opposite the GDD and connected to spectrometer by fiber-optic. The spectrometer (AvaSpec-ULS3648) was connected to the computer by USB cable.

3.4 Experimental Procedure

Initially, it is important to perform a detailed analysis of the radiated spectra and select lines to be utilised for the investigation of the impact the THz radiation and the magnetic field on the GDDs. However, The THz radiation system (the millimetre waves system), where the system consists of the THz radiation source and a THz radiation detector. Firstly, run the THz radiation source to generate 0.2 THz, then can be checked THz radiation source by the detector part. After that, connect the EM coils to the DC power supply and connect the GDD to the alternate power supply to generate a plasma. Then, connect the spectrometer to the computer by USB cable also connect it to the detector by fibre optic and run the software (Ava soft 8).

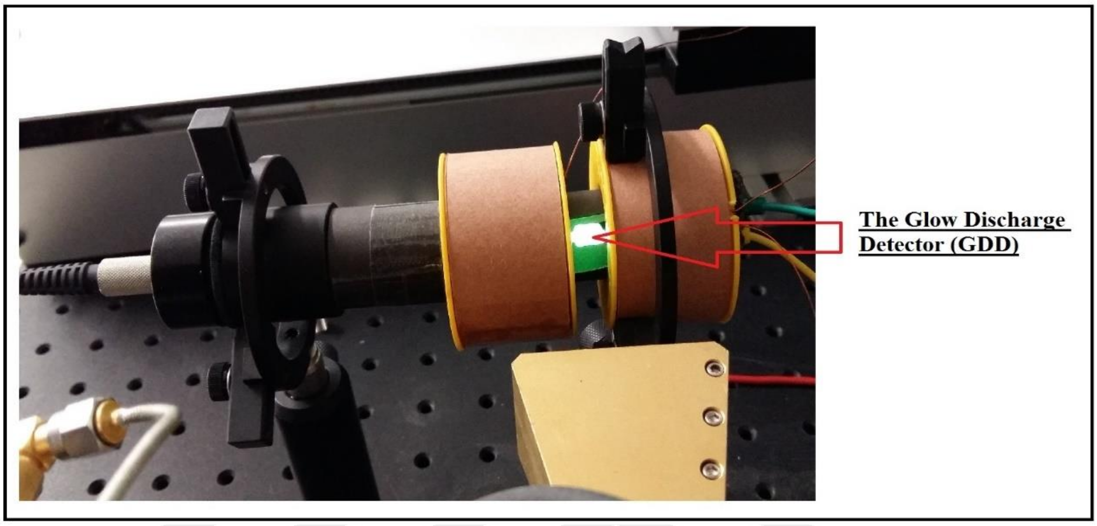

Figure 3.6 Illustrate the position of the GDD in the experiment setup.

Subsequently, the original spectra of the GDD were taken by the spectrometer (AvaSpec-ULS3648) and saved under the name (Base) on the computer via excel file, with absent THz radiation and Magnetic field. After that, the THz radiation had applied on the GDD, the affected spectra were taken and saved under the name (THz is on). While the THz radiation had been presenting, the current was passed through the coils to impact the GDD by B field, therefore the affected spectra took and saved under the name (B and THz are on). After that, the THz source turned off and left the magnetic field is running, the affected spectra had taken and saved under the name (B is on). Where the magnetic field strength was generated by a value of current 0.35 A. and all files were saved on the computer via excel files.

CHAPTER 4

THE EXPERIMENT RESULTS AND CONCLUSION

4.1 THE EXPERIMENT RESULTS

We selected the peak in the infrared range (821.0 to 825.0 nm) as shown in figure 4.1. Due to the highest intensity peak for the experiment. The GDD's spectrum without effect noted as (Base), the spectrum (B is on) means the GDD's spectrum affected by magnetic field, the GDD's spectrum affected by THz radiation noted as (THz is on), and the GDD's spectrum affected by both the magnetic field and THz radiation noted as (B and THz are on).

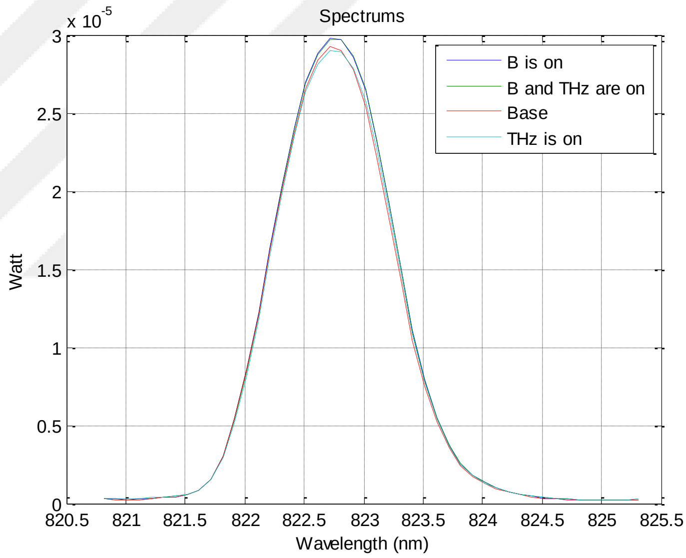

Figure 4.1.1 illustrates the peak was selected for a specific range, plotted by the power in Watt.

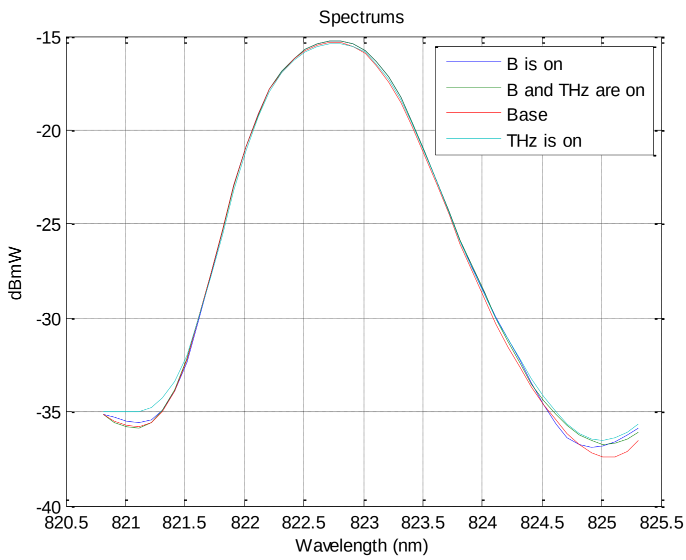

Figure 4.1.2 illustrates the peak was selected for a specific range, plotted by decibel milli-power.

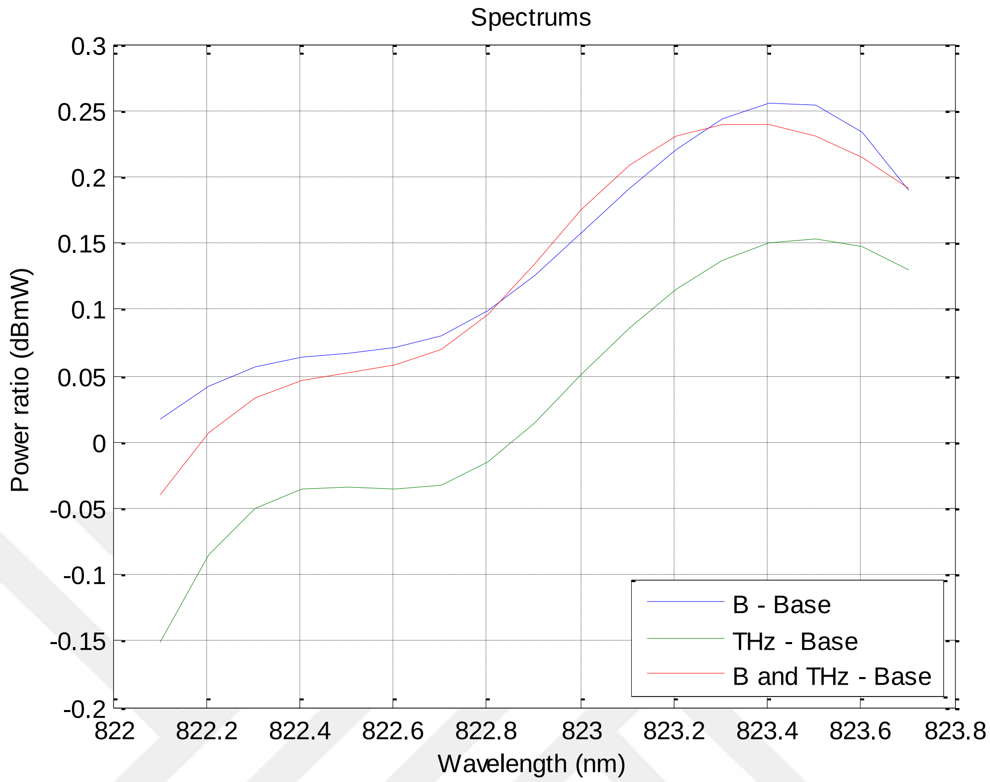

Figure 4.2 The ratio of the spectrums, data curves were plotted by decibel milli-power.

We utilised the ratio method for spectrums relative to the Base-Spectrum. The results were appeared as linear relation into spectral line range, as shown in figure 4.2. Which the results were processed by the ratio on the linear scale and decibel milli-power. However, the THz radiation effect was visible, where the light intensity of the GDD was decreased due to the THz radiation interaction with GDD's plasma, that can be clarified via data curve which is under 0 level as shown in fig 4.2, and some of the data curves are upper 0 level, that means the light intensity of those wavelengths increased. In addition, the intensity of the GDD was increased due to the interaction of the magnetic field with plasma of GDD, that can be explained via data curve which is above 0 level as shown in fig 4.2. As well as, the intensity of the GDD was increased due to the interaction both the magnetic field and THz radiation with GDD, almost the behaviour of the interaction was like the magnetic field interaction with the GDD's plasma.

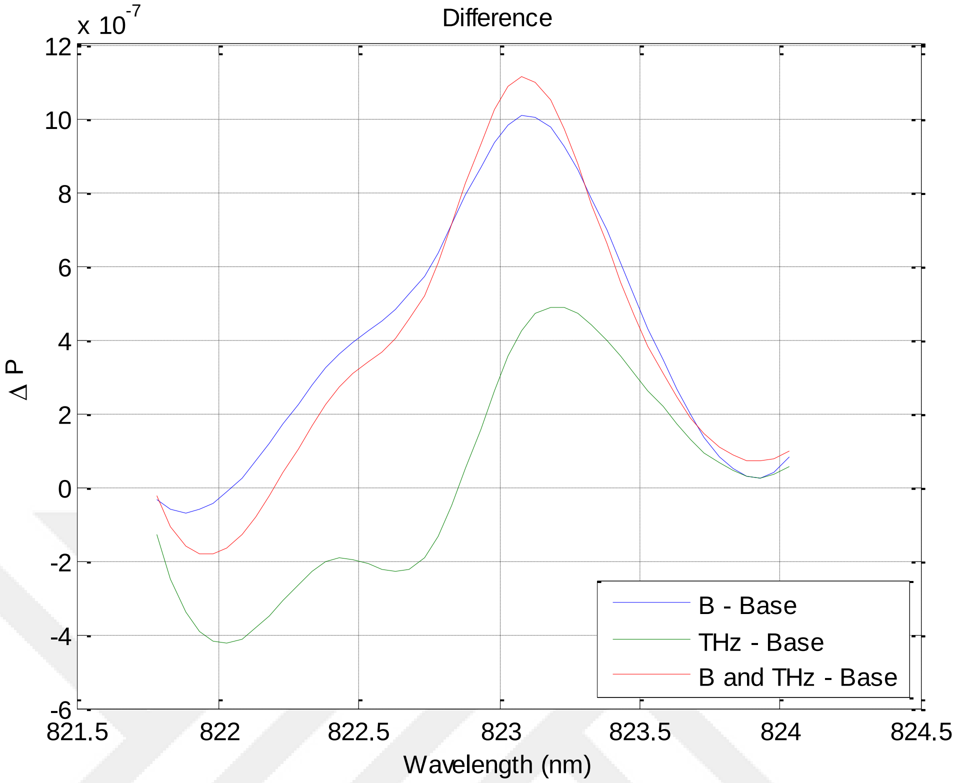

Figure 4.3 The difference of spectrums.

Also, we used the difference method, by subtracting the spectrums, relative to the Base-Spectrum. The data curves result were obtained as shown in figure 4.3. Manifestly, the differences of spectrums intensity describe the interaction between the THz radiation, the magnetic field and the GDD's plasma. Therefore, the magnetic field interacted with the GDD's plasma and increased the light intensity of GDD. Due to the circular motion of electrons via the magnetic field. On the other hand, the consequence of the circular motion of the path lengths of the electrons increased, Which increases the likelihood of collision resulting in an increase in the intensity of the light intensity of GDD. Likewise, the THz radiation and the magnetic field interacted with the GDD's plasma to yield data curve approximately same to the magnetic field's data curve. Can be explained by the magnetic field strength is more effective than the THz radiation. Which refers to the various characteristics of the magnetic field and the THz radiation, Otherwise, the THz radiation effect on the GDD's plasma quite different. Where observed the data curve has positive and negative values, due to the THz radiation worked to suppressed the light intensity of

GDD. Can be explained that, according to the waves properties, the interference, reflection, refraction and etc. The THz radiation as millimetre waves can interact with the waves which produced from GDD. In this case, the constructive interference and destructive interference is a significant factor in this state. This explains the existence of positive values and negative values of the data curve, which appears as a shift for spectrum line.

4.2 CONCLUSION

The terahertz radiation (THz) has gotten impressive consideration lately, due to their broad logical and mechanical applications. Regardless of the colossal significance of terahertz radiation, the propagation qualities of THz waves have not yet been contemplated in detail, particularly THz waves proliferation in plasma. However, the interaction of the THz radiation with plasmas was investigated by the transmission, reflection, and absorption of the THz radiation crossed the plasmas. Otherwise, the effect of the magnetic field on the plasmas was examined.

The interaction of the THz radiation and the magnetic field with cold plasma (GDD) was investigated by optical emission spectroscopy. Where the peaks were selected in the infrared range (821.0 to 825.0 nm). which the highest intensity peaks into the spectrum of the result. By utilising the ratio and subtraction methods for spectrums relative to the Base-Spectrum, the results were obtained as linear relationship into spectral line range by ratio method. Therefore, the magnetic field increases the GDD’s light intensity, due to the circular motion of electrons via the magnetic field. On the other hand, the consequence of the circular motion of the path lengths of the electrons increased, Which increases the likelihood of collision resulting in an increase in the light intensity of the GDD. Otherwise, the differences of spectrums intensity describe the interaction between the THz radiation and the magnetic field with the GDD. Therefore, the THz radiation worked to suppressed the GDD’s plasma intensity, according to the characteristics of the wave, the constructive interference and destructive interference is a significant factor in this case. This explains the existence of positive values and negative values of the data curve, which appears as a shift for spectrum line. As well, the THz radiation and the magnetic field interacted with the

GDD’s plasma to yield data curve approximately same the magnetic field’s data curve. Can be explained by, the magnetic field strength is more effective than the THz radiation. And the nature of the magnetic field and the radiation of the terahertz are different.

Therefore, this study supports the other researchers which utilised the inexpensive tool (GDDs) to detect the THz radiation. And, the optical emission spectroscopy is very useful to examine the GDDs than using the light intensity measurements of the GDDs.

4.2 THE FUTURE WORK

To importance of the subject and the development of GDDs to use in several fields of application and research, the study is recommended to complete the theoretical study to the interaction of GDDs with THz radiation and magnetic field.

The study is recommended to investigate the ratio method (line to itself) to determine the electron temperature of plasma by the THz radiation or magnetic field using optical emission spectroscopy. To be the newest method in diagnosis the plasmas.

APPENDICES

Appendix A: Characteristics of Neon gas spectrum (821.0 – 825.0 nm) [51].

Ion	Wavelength (nm)	A_{ki} (s^{-1})	E_i (eV)	E_k (eV)	Lower Level Conf.	Upper Level Conf.	g_k
Ne II	821.3046		36.1788192	37.68800503	$2s^22p^4(^3P)4p$	$2s^22p^4(^3P)5s$	4
Ne II	821.45712		34.63187023	36.14077580	$2s^22p^4(^3P)3d$	$2s^22p^4(^3P)4p$	6
Ne VIII	821.7	2.32e+06	[140.76269]	[142.2711]	$1s^23p$	$1s^23d$	6
Ne IX	822.1	4.25e+05	1 071.8384	1 073.3461	$1s3p$	$1s3d$	5
Ne II	824.4328		36.1788192	37.68227852	$2s^22p^4(^3P)4p$	$2s^22p^4(^3P)5s$	2
Ne I	824.86823		18.63679141	20.13945716	$2s^22p^5(^2P°_{3/2})3p$	$2s^22p^5(^2P°_{1/2})3d$	3

REFERENCES

[1] R. A. Lewis, "A review of terahertz sources," *Journal of Physics D: Applied Physics,* vol. 47, p. 374001, 2014.

[2] H. Hafez, X. Chai, A. Ibrahim, S. Mondal, D. Férachou, X. Ropagnol*, et al.*, "Intense terahertz radiation and their applications," *Journal of Optics,* vol. 18, p. 093004, 2016.

[3] P. M. Bellan, *Fundamentals of Plasma Physics*: Cambridge University Press, 2008.

[4] C.-X. Yuan, Z.-X. Zhou, and F. Yue, "Terahertz waves propagation in a bounded plasma slab with high plasma density and high collision frequency," in *Intelligent Computation Technology and Automation (ICICTA), 2012 Fifth International Conference on*, 2012, pp. 608-613.

[5] C.-X. Yuan, Z.-X. Zhou, and X.-L. Xiang, "Properties of terahertz waves propagation in a bounded plasma slab with high collision frequency and high density," in *Optoelectronics and Image Processing (ICOIP), 2010 International Conference on*, 2010, pp. 135-140.

[6] F. Sizov and A. Rogalski, "THz detectors," *Progress in Quantum Electronics,* vol. 34, pp. 278-347, 2010.

[7] F. Sizov, "THz radiation sensors," *Opto-electronics review,* vol. 18, pp. 10-36, 2010.

[8] J. El-Haddad, B. Bousquet, L. Canioni, and P. Mounaix, "Review in terahertz spectral analysis," *TrAC Trends in Analytical Chemistry,* vol. 44, pp. 98-105, 2013.

[9] K. Çınar, H. Altan, and A. Şahin, "THz transmission and detection through glow discharge detectors," in *SPIE Defense, Security, and Sensing*, 2013, pp. 87160J-87160J-9.

[10] A. Abramovich, N. Kopeika, and D. Rozban, "THz polarization effects on detection responsivity of glow discharge detectors (GDDs)," *IEEE Sensors Journal,* vol. 9, pp. 1181-1184, 2009.

[11] D. Rozban, N. Kopeika, A. Abramovich, and E. Farber, "Terahertz detection mechanism of inexpensive sensitive glow discharge detectors," *Journal of Applied Physics,* vol. 103, p. 093306, 2008.

[12] M. A. Lieberman and A. J. Lichtenberg, *Principles of plasma discharges and materials processing*: John Wiley & Sons, 2005.

[13] U. Fantz, "Basics of plasma spectroscopy," *Plasma sources science and technology,* vol. 15, p. S137, 2006.

[14] H. R. Griem, "Plasma spectroscopy," *New York: McGraw-Hill, 1964,* vol. 1, 1964.

[15] H.-H. Ley, "Analytical Methods in Plasma Diagnostic by Optical Emission Spectroscopy: A Tutorial Review," *Journal of Science and Technology,* vol. 6, 2014.

[16] A. Maestrini, B. Thomas, H. Wang, C. Jung, J. Treuttel, Y. Jin*, et al.*, "Schottky diode-based terahertz frequency multipliers and mixers," *Comptes Rendus Physique,* vol. 11, pp. 480-495, 2010.

[17] N. S. J. Braithwaite, "Introduction to gas discharges," *Plasma Sources science and technology,* vol. 9, p. 517, 2000.

[18] J. D. Walker, *Fundamentals of Physics Extended*: Wiley, 2010.

[19] A. Bogaerts, E. Neyts, R. Gijbels, and J. van der Mullen, "Gas discharge plasmas and their applications," *Spectrochimica Acta Part B: Atomic Spectroscopy,* vol. 57, pp. 609-658, 2002.

[20] N. Rubab and G. Murtaza, "Debye length in non-Maxwellian plasmas," *Physica Scripta,* vol. 74, p. 145, 2006.

[21] Z. L. Petrović, J. Sivoš, M. Savić, N. Škoro, M. R. Radenović, G. Malović*, et al.*, "New phenomenology of gas breakdown in DC and RF fields," in *Journal of Physics: Conference Series*, 2014, p. 012043.

[22] H. Smith, C. Charles, and R. Boswell, "Breakdown behavior in radio-frequency argon discharges," *Physics of Plasmas (1994-present),* vol. 10, pp. 875-881, 2003.

[23] H. Conrads and M. Schmidt, "Plasma generation and plasma sources," *Plasma Sources Science and Technology,* vol. 9, p. 441, 2000.

[24] J. Pisonero, J. M. Costa, R. Pereiro, N. Bordel, and A. Sanz-Medel, "Radiofrequency glow-discharge devices for direct solid analysis," *Analytical and bioanalytical chemistry,* vol. 379, pp. 17-29, 2004.

[25] V. M. Donnelly and A. Kornblit, "Plasma etching: Yesterday, today, and tomorrow," *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films,* vol. 31, p. 050825, 2013.

[26] X. Wang, M. Zhou, and X. Jin, "Application of glow discharge plasma for wastewater treatment," *Electrochimica Acta,* vol. 83, pp. 501-512, 2012.

[27] S. Ghosh, V. L. Prasanna, B. Sowjanya, P. Srivani, M. Alagaraja, and D. Banji, "Inductively Coupled Plasma–Optical Emission Spectroscopy: A Review," *Asian Journal of Pharmaceutical Analysis,* vol. 3, pp. 24-33, 2013.

[28] H.-J. Kunze, *Introduction to plasma spectroscopy* vol. 56: Springer Science & Business Media, 2009.

[29] M. B. Johnston, D. Whittaker, A. Corchia, A. Davies, and E. H. Linfield, "Simulation of terahertz generation at semiconductor surfaces," *Physical Review B,* vol. 65, p. 165301, 2002.

[30] M. Tani, O. Morikawa, S. Matsuura, and M. Hangyo, "Generation of terahertz radiation by photomixing with dual-and multiple-mode lasers," *Semiconductor Science and Technology,* vol. 20, p. S151, 2005.

[31] J. Peñano, P. Sprangle, B. Hafizi, D. Gordon, and P. Serafim, "Terahertz generation in plasmas using two-color laser pulses," *Physical Review E,* vol. 81, p. 026407, 2010.

[32] F. Blanchard, G. Sharma, L. Razzari, X. Ropagnol, H.-C. Bandulet, F. Vidal, *et al.*, "Generation of intense terahertz radiation via optical methods," *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 17, pp. 5-16, 2011.

[33] M. C. Hoffmann, "Intense ultrashort terahertz pulses: generation and applications," *Journal of Physics D: Applied Physics,* vol. 44, p. 083001, 2011.

[34] M. Clerici, M. Peccianti, B. E. Schmidt, L. Caspani, M. Shalaby, M. Giguère, *et al.*, "Wavelength scaling of terahertz generation by gas ionization," *Physical review letters,* vol. 110, p. 253901, 2013.

[35] P. H. Siegel, "Terahertz technology," *IEEE Transactions on microwave theory and techniques,* vol. 50, pp. 910-928, 2002.

[36] W. L. Chan, J. Deibel, and D. M. Mittleman, "Imaging with terahertz radiation," *Reports on progress in physics,* vol. 70, p. 1325, 2007.

[37] B. Zhu, Y. Chen, K. Deng, W. Hu, and Z. Yao, "Terahertz science and technology and applications," *PIERS Proc., Beijing,* p. 1166, 2009.

[38] V. Bratman, V. Zorin, Y. K. Kalynov, V. Koldanov, A. Litvak, S. Razin, *et al.*, "Plasma creation by terahertz electromagnetic radiation," *Physics of Plasmas (1994-present),* vol. 18, p. 083507, 2011.

[39] A. Sidorov, V. Bratman, M. Y. Glyavin, S. Golubev, I. Izotov, Y. K. Kalynov, *et al.*, "Low pressure gas discharge in the quasioptical beams of the powerful terahertz radiation," in *2013 19th IEEE Pulsed Power Conference (PPC),* 2013, pp. 1-4.

[40] J. Liu and X.-C. Zhang, "Terahertz-radiation-enhanced emission of fluorescence from gas plasma," *Physical review letters,* vol. 103, p. 235002, 2009.

[41] J. Liu and X.-C. Zhang, "Plasma characterization using terahertz-wave-enhanced fluorescence," *Applied Physics Letters,* vol. 96, p. 041505, 2010.

[42] Y. Tian, Y. Han, Y. Ling, and X. Ai, "Propagation of terahertz electromagnetic wave in plasma with inhomogeneous collision frequency," *Physics of Plasmas (1994-present),* vol. 21, p. 023301, 2014.

[43] Z. Tosun, D. Akbar, and H. Altan, "The interaction of terahertz pulses with dc glow discharge plasma," in *2009 34th International Conference on Infrared, Millimeter, and Terahertz Waves*, 2009, pp. 1-2.

[44] C. Yuan, Z. Zhou, X. Xiang, H. Sun, H. Wang, M. Xing*, et al.*, "Propagation properties of broadband terahertz pulses through a bounded magnetized thermal plasma," *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms,* vol. 269, pp. 23-29, 2011.

[45] J. Sun, J. Gallacher, R. Issac, Z. Huang, and D. Jaroszynski, "Experiment of THz transmission through plasma," in *International Symposium on Optoelectronic Technology and Application 2014*, 2014, pp. 929716-929716-7.

[46] B. Deng, C. Domier, A. Donné, K. Lee, N. Luhmann, E. Mazzucato*, et al.*, "THz techniques in plasma diagnostics," in *Microwave Symposium Digest, 2002 IEEE MTT-S International*, 2002, pp. 1587-1590.

[47] S. Jamison, J. Shen, D. Jones, R. Issac, B. Ersfeld, D. Clark*, et al.*, "Plasma characterization with terahertz time–domain measurements," *Journal of applied physics,* vol. 93, pp. 4334-4336, 2003.

[48] A. Ando, T. Kurose, V. Reymond, K. Kitano, H. Kitahara, K. Takano*, et al.*, "Electron density measurement of inductively coupled plasmas by terahertz time-domain spectroscopy (THz-TDS)," *Journal of Applied Physics,* vol. 110, p. 073303, 2011.

[49] B. Kolner, R. Buckles, P. Conklin, and R. Scott, "Plasma characterization with terahertz pulses," *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 14, pp. 505-512, 2008.

[50] B. Kolner, P. Conklin, N. Fontaine, R. Buckles, and R. Scott, "Terahertz characterization of pulsed plasmas," in *International Conference on Optical Terahertz Science and Technology in Orlando, Florida*, 2005, pp. 1-3.

[51] Kramida, A., Ralchenko, Yu., Reader, J., and NIST ASD Team (2015). NIST Atomic Spectra Database (ver. 5.3), [Online]. Available:

http://physics.nist.gov/asd [2017, May 12]. National Institute of Standards and Technology, Gaithersburg, MD.

RESUME (CV)

PERSONAL INFORMATION

Name Surname : Abdusalam Abdulmajed FKEREEN

Nationality : Libyan

Date of Birth : 12/01/1976

Place of Birth : Tripoli / LIBYA

Phone : **+90** 543 912 50 96, **+218** 92 516 98 81

E-mail : fkereen@gmail.com

EDUCATION

High School : School of Souq Al-Jumaa / TRIPOLI (1994 – 1995)

Bachelor : University of Tripoli / TRIPOLI (1998 – 1999)

Master Degree : Ankara Yıldırım Beyazıt University (2016-continued)

PROFESSIONAL EXPERIENCE

Employee : Nuclear Research Center / Tajoura - TRIPOLI (2001 – 2003)

Researcher Asst. : Plasma research Laboratory / TRIPOLI (2003 – 2005)

- Research Center of polymers / TRIPOLI (2005- continued)

TOPICS OF INTERESTS

- plasma physics
- Electricity and Magnetism