American Journal of Modern Physics
2013; 2(6): 276-281
Published online September 30, 2013 (http://www.sciencepublishinggroup.com/j/ajmp)
doi: 10.11648/j.ajmp.20130206.11

Effect of nitrogen gas pressure and hollow cathode geometry on the luminous intensity emitted from glow discharge plasma

Shamoo K. Awsi

Dept. of Physics, Faculty of Science, Zakho University, Duhok, Iraq

Email address:
shamookhudaida@yahoo.com

To cite this article:
Shamoo K. Awsi. Effect of Nitrogen Gas Pressure and Hollow Cathode Geometry on the Luminous Intensity Emitted from Glow Discharge Plasma. *American Journal of Modern Physics.* Vol. 2, No. 6, 2013, pp. 276-281. doi: 10.11648/j.ajmp.20130206.11

Abstract: The paper investigates the luminous intensity emitted from dc hollow cathode glow discharge plasma (HCGD) .The experiments were conducted at different nitrogen gas pressures ranged from (0.015 to 0.75Torr) and constant discharge current (Id=1.88 mA).The influence of both pressure and hollow cathode geometry such as diameter and depth of hollow cathode have been studied .The results show that the Photo-Luminous Efficiency emitted from the hollow cathode glow discharge decrease nearly exponentially with the increasing gas pressure. This is due to the characteristics of hollow cathode at the low pressures to produce more energetic excitation. On the other hand, the luminous efficiency increase linearly with the increasing inter-cathode distance of hollow, this is because increasing the inter - cathode distance of hollow cathode is equivalent to the decreasing of gas pressure. However the luminous intensity increase linearly with the depth of hollow cathode ranged from (1up to2.5) cm and then decrease. This behavior of the intensity with both the gas pressure and hollow cathode geometry is satisfactory agreement with previous works.

Keywords: Hollow Cathode Geometry, Gas Pressure, Luminous Intensity and Glow Discharge Plasma

1. Introduction

The main characteristics of plasma discharge such as the breakdown voltage , the voltage – current characteristics and the structure of discharge depends on the geometry of the electrodes and the container, gas used, pressure in the chamber, electrodes material and the external circuit, David Staacket al(2005) [1].The glow discharge is a luminous low pressure discharge which has widespread industrial applications like analytical chemistry, micro-electronics fabrication, lasers, and lamps, A. Bogaerts (1999) [2]. The radiation is the result of electron or ion interaction with others particles in the plasma. Because of their velocity, electron interaction tend to dominate the collision excitation and ionization processes, A. Abdouet al (2007) [3]. The intensity of radiation is dependent on the field current intensity on the cathode surface as well as on the value of the electron current supplying the anode, B. Mazurek, A. Nawak and A. Tyman,(1993) [4]. The spatial distribution of the emitted light depending on changes of pressure and intensity of electric current.Spatial distribution of light in discharges was recorded by means of a CCD camera connected to an IBM compatible personal computer (PC). On the other hand the experiment was conducted in a parallel plate chamber, the results obtained for dependence of the profile of radiation on the pressure and current are in good agreement with the dependence expected on the basis of the available literature, J Isidorovic(1995) [5]. Also experimental investigations are focused on the study of luminous radiation emission from coaxial plasma discharge device under the effect of applied transverse magnetic field B_{tr}. Where the experiment was done in (1.5 KJ - 10 KV) coaxial plasma discharge device. The discharge is operated in Nitrogen gas at pressures from 1 to 2.2 torr, the results show that the nitrogen gas pressure is the dominant parameter which affects the luminous radiation emission from plasma sheath and the other parameters of device under consideration are remain constant , M. Tareket al (2011) [6].

The present work aims to study the effects of both pressure and hollow cathode geometry (diameter and depth of hollow cathode) , on the shape, size and length of both negative and positive column , as well as on the luminous intensity emitted from the positive column of nitrogen glow discharge plasma (NGDP) for constants discharge current and gap between the electrodes.

2. Experimental Equipment

A schematic experimental arrangement is illustrated in figure .1.A laboratory plasma is created in a 25cm long by 5cm diameter cylindrical Pyrex chamber which is pumped to a base pressure of 1x10-3torr by a rotary pump. The tube is opened in both sides in such a way that one can move the electrodes through the cylindrical rubber which is used to close both sides to get a good vacuum and homogenous discharge as well as to prevent gas leakage. The pressure in the chamber is measured by vacuum gauge head [Thermovac TM21], the range about 10 mbar. The distance between electrodes is fixed to D=14 cm.Dischargechamber is connected to the vacuum system through a crossing piping unit. The four sides of this unit are connected to the vacuum gauge, rotary pump, gas container through needle valve and discharge chamber. Discharge tube was filled with N_2 gas to produce nitrogen glow discharge, in such away by filling and evacuating the system many time to ensure that the chamber container is the nitrogen gas.

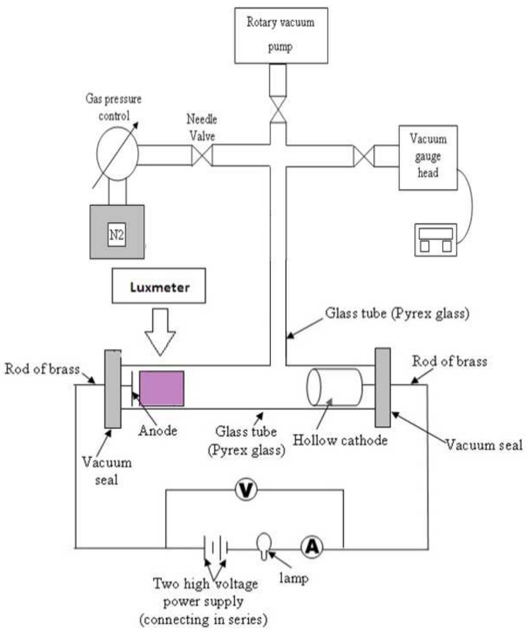


Figure 1. The electrical circuit of plasma system

Hollow cathodes are made of copper metal (brass) of the hollow cylindrical shape. The purpose behind using hollow cathode is to get more stable and denser plasma at the center of the discharge. Hollow cathodes has been covered on the outer shell by an insulator (Teflon) and back sides and edges by an insulator in order to get the discharge inside the hole of the cathodes, as shown in figure (2).Hollow cathode is connected to external electric circuit through the copper rode fixed at one end of the discharge chamber by vacuum seal to prevent leakage. The present work deals with two different cases concerning the hollow cathode geometry design. First Case: Hollow cathode which used are in different inner- cathode diameters i.d is ranged from (1-4) cm , all with thickness (0.5 cm) and depth, de= 3 and 4 cm in length, figure (3).Second Case: Was adopted for different depth of hollow cathode, de ranged from (1-3.5) cm. The thickness of these electrodes are fixed at (0.5 cm) for all experimental measurement.

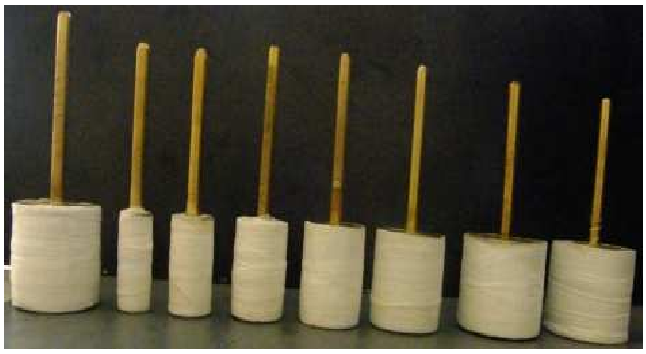


Figure 2. Hollow cathode with different diameters and various hollow

Anodes are made also from a copper metal (brass) of disk shape. In the first case used seven anodes with different diameters , d is ranged from (1-4) cm, and all of thickness (0.5 cm)as shown in figure (3).For the second case used one anode of diameter (3.5 cm) with one hollow cathode of same diameter and different depth . For each experiment the cathode is hollowed to the required depth as shown one of them in figure (4).Anode is connected to external electric circuit through the copper rode fixed at one end of the discharge chamber by vacuum seal to prevent leakage.

Figure 3. Anode with deferent diameter

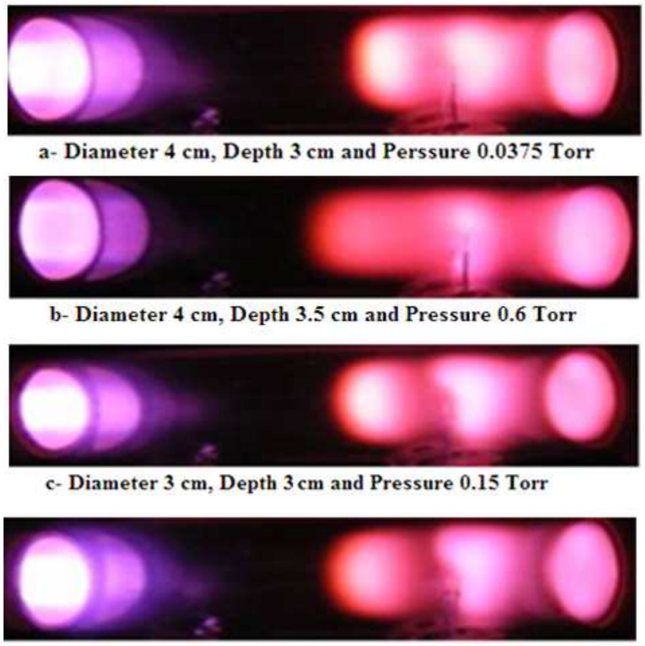
Figure 4. Hollow cathode electrode of 4cm diameter and 2cm depth

Discharge voltage has been supplied to the electrodes system by a dc- power supply [3B power supply U21060], it is a variable power supply of range (0-6000 V) and the maximum output current (2mA), two power supply have been connected in series to provides a (12KV) and current (2mA).this voltage is very sufficient to occurring breakdown of gas between anode and hollow cathode and generating glow discharge at different gas pressure. A digital multi-meter[ManTech M9803R True RMS MULTIMETER] is used to measure the discharge current (I_d). The non-linear protective resistor (lamp) is used to limit the discharge current and avoid the streamer to pass through the chamber to make the spark breakdown ,W. Lochet-Holtgreven (1968)[7]. This type of non-linear resistors is choosing because it provides a relatively high power of 25 watt out cooling process ,A. J. Salim (2007) [8].Luminance intensity is measured using an instrument known as lux-meter [ManTech Ms6610]. For more details see Sh.S.Shreen.Muhamad(2011)[9].

3. Results and Discussions

Investigation the effect of both diameter, depth of hollow cathode and gas pressure on the luminous intensity emitted only from positive column have been made regardless the others regions ofdischarge.In the present work, the lower and upper limit of operation Pdranged between (0.06 Torr.cm ≤Pd≤ 3 Torr.cm) is usedfor nitrogen gas, where P is the pressure and d is the inter – distance of hollow cathode. Outside this range, the glow is observed either outside the cathode cavity or did not develop voltage- current characteristics, W.Lochet-Holtgreven (1968) [7].

These effects illustrate in figure (5)) at low pressure for different diameter and depth. The four images are different in the shape and size of negative glow that appear inside the hollow cathode entirely in one of them and approximately for three others as well as different in the shape, size and length of positive column , in addition to that also different in the Faraday dark space between the positive column and negative glow. This is due to different in diameter and depth of hollow cathode as well as the gas pressure. This in turn emits different luminous intensity.If the pressure is low the mean free path of the electron will be larger at this diameter and depth then the glow will not go inside hollow cathode ,E. M. Van veldhuizen (1983) [10]. At large HC we must used very low pressure and it is necessary to reduce the diameter of HC at higher pressure to obtain the best characteristics and to avoid going negative glow outside the hollow cathode, also to increase the range of operating pressure, J. Chen, S. Jin Park, Z. Fan, J. G. Eden and C. Liu (2002),[11] and V. Nehra, A. kumarand H. K. Dwivedi(2007)[12]. Furthermore it is appear from images that the positive column is very close to the anode and its length increase with depth of hollow cathode , means with the gap of electrodes, David Alexander Staack,(2008)[13].For hollow cathode discharge in a specific range of operating pressure, the negative glow which has the highest electron density moves inside the hollow structure, and discharge takes place almost entirely inside the hollow cavity,H. kirkici (1999) [14]. In these regions electron are caught and oscillate, causing additional ionization and excitation of atoms. This is known as the hollow cathode effect (HCE). Much higher current densities and much higher emitted light intensities can be achieved in hollow cathode discharges compared to a planar cathode discharge , S. Janosi, Z. Kolozsvary and A. kis (2004)[15].In addition to that we take into the consideration the luminous intensity emitted from the positive column of glow discharge as shown in experimental system of discharge.



a- Diameter 4 cm, Depth 3 cm and Perssure 0.0375 Torr

b- Diameter 4 cm, Depth 3.5 cm and Pressure 0.6 Torr

c- Diameter 3 cm, Depth 3 cm and Pressure 0.15 Torr

d- Diameter 2.5 cm, Depth 3 cm and Pressure 0.15 Torr

Figure 5. *Glow discharge image of different pressure and HC geometry.*

3.1. Pressures Dependence of the Luminous Intensity of Hollow Cathode Discharge (HCD)

The luminous intensity emitted from (HCGD) was measured using lux-meter and is plotted versus gas pressure in figures (6 and 7). The relation between them is nearly decreasing exponential. In other word the intensity is appears to decrease with increasing pressure according to the following equations as a result of fitting.

$$Y = 7.12e^{-2.15X} \quad (1)$$

$$Y = 12.23e^{-3.25X} \quad (2)$$

Where Y = N and X = P.

This behavior is due to the characteristics of hollow cathode at the low pressures to produce more energetic excitation, V. Yu. Bazhennovet al (2001) [16].Also this effect can be interpret according to the mean free path and its relation with the pressure. Because at low pressure studied in the present work, the mean free path of electron is large. Then electrons gain a lot of energy from the applied electric field to create more excitations and ionizations through inelastic collisions with others plasma particles. Consequently during emission transitions and recombination of electrons with the ions, the luminous intensity will be increased and tend to decrease with the increasing pressure (decreasing mean free path of electrons) due to the (non- excitations and ionizations collisions with plasma particles). This behavior of luminous intensity with pressure is well agreement with the previous work, G.M EL- Aragi, et al (2010) [17].

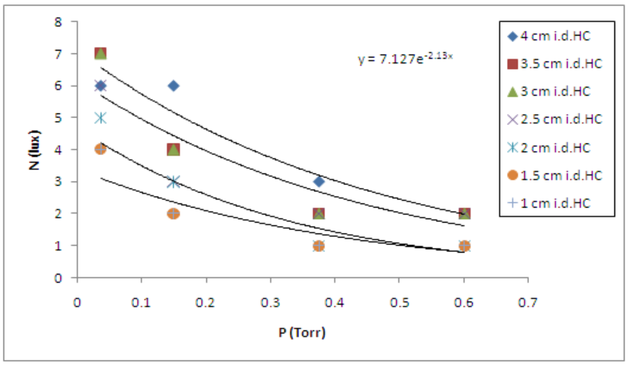


Figure 6. *Luminous intensityas a function of pressure at different inter cathode distance.*

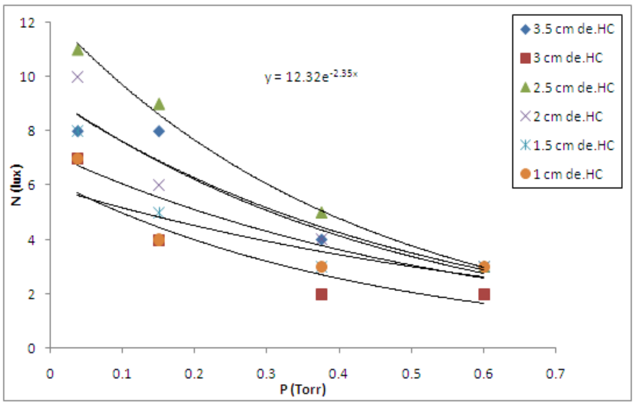


Figure 7. *Luminous intensity as a function of pressure at different depth.*

3.2. Cathode Geometry Dependence of the Luminous Intensity

On the other hand, the luminous intensity increase with the increasing inter-cathode distance as shown in figures (8), this is because increasing inter - cathode diameter of hollow cathode is equivalent to the decreasing of gas pressure and increasing mean free path of electrons, Bimal Kumar Pramaink (2008) [18]. These behaviors of intensity with both gas pressure and hollow cathode diameter are satisfactory agreement with previous work,V. Yu. Bazhennov et al (2001) [16] and Bimal Kumar Pramaink (2008) [18] . However luminous intensity increase linearly with the depth of hollow cathode ranged from (1 - 2.5) cm as shown in figure (9) and then decrease .Because this range plus the distance between the electrodes (D), represents the minimum of Panchen's curve for various gases. Where the breakdown voltage V_b can be written as a function of pressure and the distance between the electrodes as follows:

$$V_b = kpd \tag{3}$$

Where k is constant that depends on the geometrical factor of electrodes and the nature of gas, for most gases the minimum breakdown voltage is between 100 and 500V and occurs for Pd in the range of (0.1-10)torr.cm, David Alexander Staack, (2008) [13] and A. Grill (1993) [19]. After this range the breakdown of gas need high voltage for occurring discharge , because the election will lose almost of its energy during the non -excitations and ionizations collisions with others plasma particles.

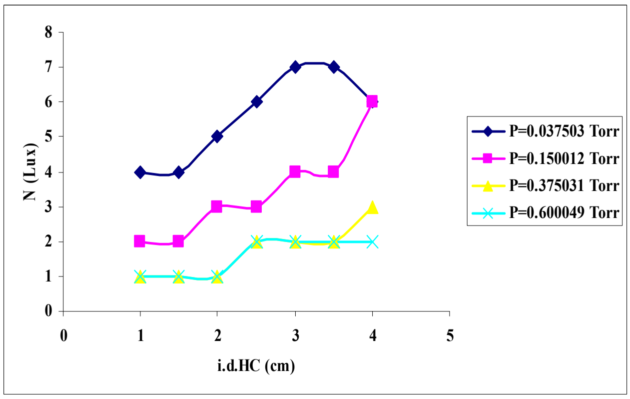


Figure 8. *Luminous intensity as a function of depth of hollow cathode at different pressures.*

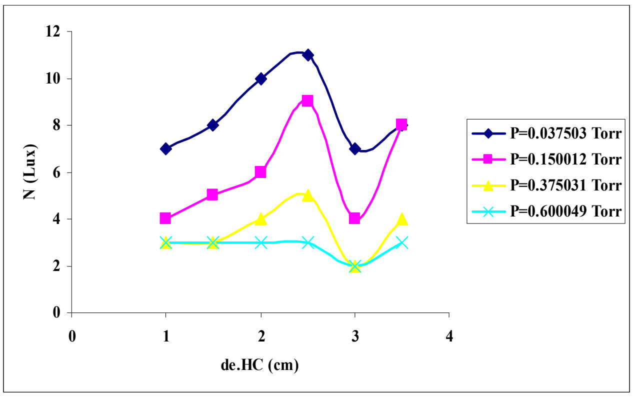


Figure 9. *Luminous intensity versus depth at different pressures.*

For more discussion and explanation these behaviors of luminous intensity with hollow cathode geometry, it is better to plot the average intensity measured at different pressures as a function of hollow cathode geometry. The variation of luminous intensity with inter- cathode distance is approximately linear behavior, figure (10). The results of fitting provide the following equation:

$$Y = 0.061X + 2.244 \tag{4}$$

Where $Y = N$ and $X =$ i.d inter cathode distance and the number 2.244 is the intersection with y- axis. However the luminous intensity increase linearly with the depth of hollow cathode ranged from (1 - 2.5) cm , and decrease as shown in figure (11) due to the previous reasons.

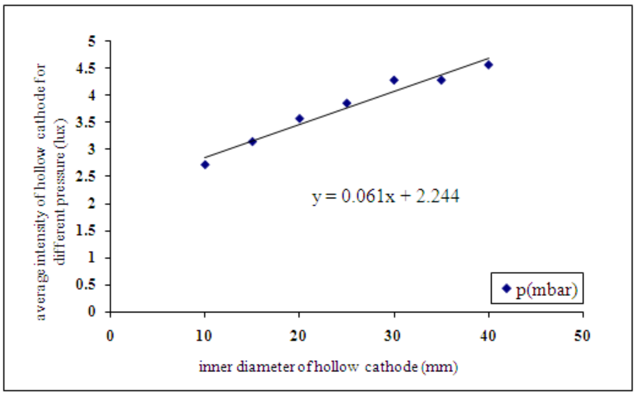


Figure 10. *Average luminous intensity for different pressure versus inter-cathode distance.*

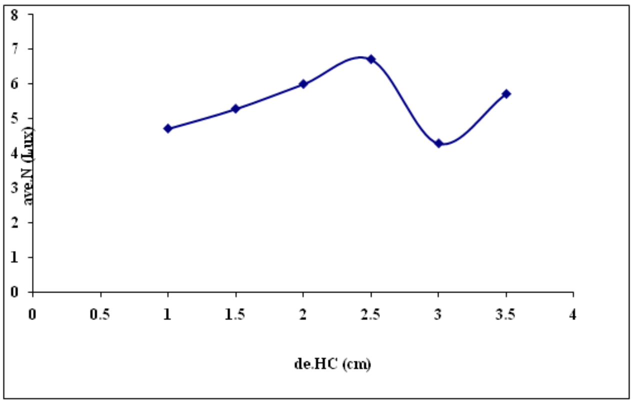


Figure 11. *Average luminous intensity for different pressure as a function of depth.*

4. Conclusion

The experiments performed show the effectiveness of hollow cathode glow discharge,for the luminous intensity emitted from the positive column at low pressures investigated .The variation of the luminous intensity with the gas pressure close to nearly decreasing exponential as a results of fitting .This is due to the characteristics of hollow cathode at the low pressures to produce more energetic excitation. This means a large mean free path of electron at these range of pressures and the electron can produce excitations and ionizations due to its energy. Contrary to that increasing inter- cathode diameter causes increasing of emitted radiation according to that and the relation is approximately linear equation, this is because increasing inter- cathode diameter is equivalent to the decreasing of gas pressure. However luminous intensity increase linearly also with the depth of hollow cathode and can be concluded that the linear portion, represents the minimum of Panchen's curve (minimum voltage breakdown). While the other part represents the right hand branch curve of Panchen's which is needs higher breakdown voltage for occurring discharge. Therefore, it can be expected that the pressure and the hollow cathode geometry are the most effective experimental conditions that affect the luminous intensity emitted from glow discharge plasma and its physical phenomena.

Recommendations

The present work provides the basis for advanced researches of (HCGD),Such as study the effect of magnetic field on the luminous intensity emitted from coaxial glow discharge plasma. One of the most convenient suggestions is to study the effect of hollow anode geometry on the emitted radiation from glow discharge in order to make comparison between the hollow anode and cathode. Also it is important to use different types of gases to ensure which one of them is more effective for emitted radiation. On the other hand it is better to use spectroscopic method for the hollow cathode and anode effect on the emitted intensity from different luminous regions of discharge speciallynegative glow and positive column. For more advantage and applications as well as emitting high luminous intensity or wide range of spectrum, building and design electric arc is very active and useful for this purpose. In addition to the stated suggestions it important also to use advanced radiations detectors such as Andor's digital camera to measure light down to single photon and capture events occurring within one billionth of a second.

Acknowledgements

I should like to acknowledge Mr.Sulaiman H. M. Al-Sadoon for his helping, formatting the paper and made many valuable suggestions. Also of my friends at Physics department.

References

[1] David Staack, Bakhtier Farouk, AlexsanderGutsol and AlexsanderFridman, "Characterization of a dc Atmospheric Pressure Normal Glow Discharge", Plasma Science and Technology .14(2005) 700-711.

[2] A. Bogaerts, "The glow discharge: an exciting plasma", Journal of Analytical Spectroscopy, Vol. 14, pp.1357-1384, (1999).

[3] Abdou A. Garamoon, Ahmed Samir, Farouk FahmyElecshar, A. Nasai, and Eizaldeen, FKotp, " Spectroscopic Study Of Argon DC Glow Discharge", IEEE Transaction on Plasma Science ,Vol. 35, No. 1, February (2007).

[4] B. Mazurek, A. Nawak and A. Tyman, "X- Ray Emission Accompanying Cathode Microdischarge", IEEE Transaction on Electrical Insulation" Vol. 28, No. 4, August (1993).

[5] J Isidorovic, "Paschen's Curve and Spatial Distributions of Emitted Light of Glow Discharge in the Air", Acta Physic .Pol.A88 Supplement, S-37(1995).

[6] Tarek M. Allam, Hanna A. EI- Sayed, Hanna M. Soliman, "Study of Luminous Emission From Coaxial Discharge Device in the Presence of External Transverse Magnetic Field", Energy and Power Engineering , 3, 444-449, 2011.

[7] W. Lochet-Holtgreven, "plasma diagnostics", ed., Ch.11, North Holland, Amsterdam, Holland.(1968)

[8] A. J. Salim, "Study the Properties of Glow Discharge Helium Plasma Using Langmuir Single Probe and Data Acquisition System", M.Sc. Thesis, College of Science, University of Mosul, Iraq.(2007).

[9] Sh.S.Shreen.Muhamad“ Effect of Geometrical Factor on Nitrogen Glow Discharge Plasma”,Ms.C Thesis , Zakho University , November (2011).

[10] E. M. Van veldhuizen, "The Hollow Cathode Glow Discharge Analyzed by optogalvanic and other Studies", PhD Thesis ,Eindhoven University of Technology, Eindhoven.(1983).

[11] J. Chen, S. Jin Park, Z. Fan, J. G. Eden and C. Liu,"Development and Characterization of Micromachined Hollow Cathode Plasma Display Devices", Journal of Microelectromechanical Systems, Vol.11, No.5, P.536-543.(2002).

[12] V. Nehra, A. kumar and H. K. Dwivedi, "Atmospheric Non-Thermal Plasma Sources", International Journal of Engineering, Vol.2, Issue.1, P.53-68.(2007).

[13] David Alexander Staack , " Characterization and Stabilization of atmospheric Pressure Dc Micro plasma and their Applications to thin film Deposition", PhD Thesis , Drexel University , December (2008).

[14] H. kirkici, "hollow cathode discharges for plasma light sources" ELECO'99 International Conference on Electrical and Electronics Engineering, Auburn University, Auburn AL 36849, USA, P.145-148.(1999).

[15] Janosi, Z. Kolozsvary and A. kis, "Controlled Hollow Cathode Effect: New Possibilities for Heating Low-Pressure Furnaces", Metal Science and Heat Treatment, Vol.49, Nos.7-8, P.310-316.(2004).

[16] V. Yu. Bazhennov, A. V. Ryabtsev, I. A. Soloshenko, A. G. Terentyeva, V. V. Tsiolko, A. I. Shchedrin, "Investigation of the Electron Distribution Function in the Glow Discharge with Hollow Cathode", Proceedings of 15th International Symposium on Plasma Chemistry, Orleans, France, Vol.III, P.879-884.(2001).

[17] G.M EL- Aragi, M.A Ayad , M.A.WL- Kolaly and W. Madkour (2010) [17], " Scattered Ionizing Radiation From Low – Focus Plasma and Radiation Dosimetry Assessment", Vol. 25,No. 4, PP.727-736 October (2010).

[18] 18.BimalKumarPramaink, "Microwave Discharge of Nitrogen and Oxygen Gas Mixture for UV Light Source ", A dissertation submitted to a Kochi University oh technology in partial fulfillment of the requirement for the degree of doctor of philosophy. Department of electronic and photonic system Engineering .(2008).

[19] A. Grill, "Cold Plasma in Materials Fabrication From Fundamentals to Application", Institute of Electrical and Electronic Engineers, Inc, New York, USA.(1993).