EFFECT OFHOLLOW ANODE DEPTHON SOME CHARACTERISTICS AND PARAMETERS OF ARGON GLOW DISCHARGE PLASMA

SH. KH. AL-HAKARY

Prof. Department of Physics, Faculty of Sciences,University of Zakho,Duhok, Iraq
E-mail: shamokhudaida@yahoo.com

Abstract- An experimental investigation of hollow anodeargon glow discharge plasma has been carried out at different argon gas pressure ranged from $2.2 \times 10^{-2}$to 3mbar forconstant discharge current. The glow discharge usually obtained by applying a high voltage between the electrodes sufficient to occurring breakdown of argon gas and sustaining the discharge.The experiments were conducted firstly to measure the breakdown voltage and Paschenc's law under the influence of hollowanode depth.A constant cathode disc of radius 20mm as well as hollow anodes of constant inner diameter 20mm and depths of values (10, 15, 20, 25, 30, 35, and 40) mm have been taken into consideration.Secondly, the study has been extended to measure some plasma parameters in the negative glow region ofdirect current argon glow discharge under the same conditions. Electric probes and a computer MATLAB program are used to obtain the temperature and density of electrons in the negative glow region from the double probes (I_p-V_p) characteristic. It was found from the results that the measured Pashence's curve closes to the well-known theoretical Pashence's law. The voltage breakdown and its minimum breakdown voltage decrease due to increasing the depthof cylindrical hollow. Increasing the hollow anode depth, the Paschen's curve is widening.A dens and luminous intensity of plasma occurs in the negative glow region due to reduction of hollow anode depth. Both electron temperature and density of electron are decreases due to increasing the depth.

Keywords- hollowanode depth, argon glow discharge, double probes Plasmaparameters, negativeglow Region, MATLABprogram.

I. INTRODUCTION

Experimental and theoretical studies of hollow anode glow discharge show that the variation of hollow inter depthis an important factor that affect the plasma parameters, and especially in the negative glow region.Miljevic (1985) [1], obtained highly ionized plasma using hollow anode and concave cathode. The density of high-energy electrons is increase and indicated that the hollow anode discharge have been effective if the dimensions of the hollow anode is small.Anders et al (1996) [2], used hollow anode discharge with very small anode area, a positive anode voltage drop of 30-40 V and the thickness of anode sheath is increased, leads to ignition of dense plasma in front of anode.

Shigeru Yokota et al (2004) [3], study the effect of lowand high magnetic flux density on the plasma density, ion sheath and electron sheath. The hollow anode glow discharge lamp, as first developed by Grimm, has been extensively employed in optical emission spectrometry (GD-OES). This analytical technique has an advantage for the direct analysis of solid samples because the sample atoms are directly introduced into the plasma through cathode sputtering,Hyunkook Park et al (2007) [4].Laser induced fluorescence of the ferroelectric plasma source assisted hollow anode discharge developed by Vekselman et al (2009) [5], it was shown that the plasma filling of the hallow anode cavity occurs and the plasma expand cause to increasing the plasma density.Savkin et al (2010)[6],used longitudinal hollow anode and several cathode materials (Cu, Mo, Au) and argon as operating gas to generate a mixer of gaseous-metal ion beams. A hollow anode discharge source was developed by Kang et al (2013) [7], to produce supersonic plasma jet as well as to provide the high density of the high-energy electrons, also it is easily controllable generating power according to applied input power. Gleizer et al (2014) [8], used a hollow anode discharge at low-pressure to generate a high-current electron beam.

It was found that the risen time is decrease monotonically with increasing the pressure. Timoshenko et al (2015) [9], presented plasma parameters of non-self-maintained discharge with hollow anode to increase the ion flux, this type of discharge may be effectively used for ion pumping film deposition.Ivan et al (2016)[10], used the non-self-sustained glow discharge with a hollow anode for ion pumping, film deposition, ion etching, diffusion saturation of metallic materials, fusion and brazing of metals. The present study investigates experimentally the effect of inter hollow anode depthupon the breakdown voltage of discharge (Paschen's curve).Also study this effect on some plasma parameters (electron temperature and its density) in the negative glow region of discharge at different argon pressures.

II. EXPERIMENTAL EQUIPMENT

The discharge tube is a cylindrical Pyrex glass of 5cm diameter and 25cm length as shown in figure 1. The

tube is opened in both sides in order to move the electrodesor varying the gap between electrodes to obtainbest homogenies discharge. The tube has two pipe connections,one pipe is connected to a rotatable valve which is consist of two aperture one of them for gas inlet and the other for rotary vacuum pump. The second pipe has a diameter 2.95cm and 2.5cm length, for entering the probe. Hollow cylindrical anodesare made of brass metal of inner depth of values (10, 15, 20, 25, 30, 35 and 40 mm) all of them have the same diameter, thickness and length (30mm, 5mm and 40mm) respectively.

Cathodes also made of brass like a circle disk plate with thickness of 5mm and 20mm in diameter. Cathode and hollow anodes are connected to external electric circuit by the copper rod fixed on the back side of electrode and pass through a cylinder rubber to prevent leakage. Rotary vacuum pump (Trivac E2, Pr. Nr. 140000, Lybold), is used to evacuated the discharge tube to an ultimate pressure 1×10^{-3}mbar.This in turn is connected to the discharge chamber by one sides of cross shaped unit pipe.The pressure was measuredby thermocouple vacuum gage (Thermovac TM21),connected to the one side of this unit pipe. Double probes are made from the alloy of (Nicle - Crome) wire of 0.25mm in diameter and 6mm in length separated by a distance of (4mm).The probes are fixed in a capillary tube of glass and covered by a plastic insulator except the probe tip and it is passed through a glass tube to the discharge chamber to measure plasma parameters in the negative glow region.Direct current voltage has been applied to the electrodes from a variable DC power supply of range (0-6000)volt,3B power supply U21060),sufficient to occurring breakdown.

The nonlinear protective resistor (lamp) is used to control the discharge current and produce avoidable stream to path through the chamber to make spark breakdown as shown in figure1.The probe voltage is obtained from a variable AC power supply (LyboldDidactive GMHZ 52135 WR00001888, 250-50) HZ, bias the probe about 12 Volt using isolated transformer. Also a direct resistance (100kΩ) is used to convert the voltage to real value of current through MATLAB program. The capacitor (C50 Samer 29539), was used to reduce the phase difference in (Ip–Vp) characteristic of probe. The (X-Y) recorder (oscilloscope) traces the I-V characteristic of the probe, so the x-axis is recorded the voltage on the probe, while the current through the probe was recorded on the y-axis, as the current passed through the resistance of value (100kΩ).

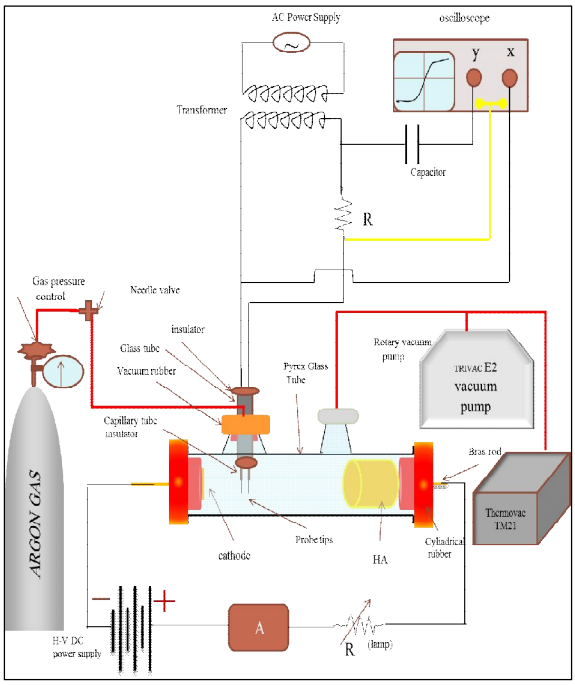


Figure .1 Schematic diagrams of electric discharge and probes circuit.

III. RESULTS AND DISCUSSION

The experiments were conducted firstly to measure the breakdown voltage at different value of pressure ranged from $2.2 \times$ to 3mbar. The processes are repeated for different depth of hollow anode and constant cathode disc of radius 20mm to investigate the Paschen's curve under the influence of hollow anode geometry. The experimentally obtained Paschen's curve at different depth are close to the well-known Paschen's law; which is indicate that at low and high (Pd) it is need high voltage breakdown. While the curves are widening when the depth of hollow anode is increase, this agree with the resent year'sstudies, Teo Yong Siah and Teng Po-Wen Ivan [11]as shown figures 2 and 3.

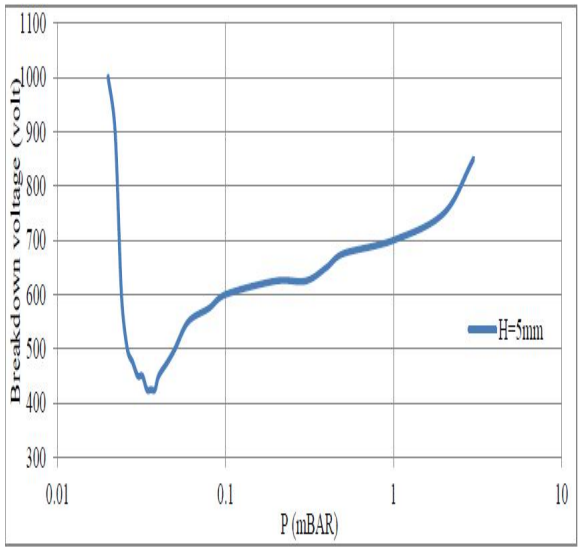


Figure 2.Paschen's curve for depth5mm

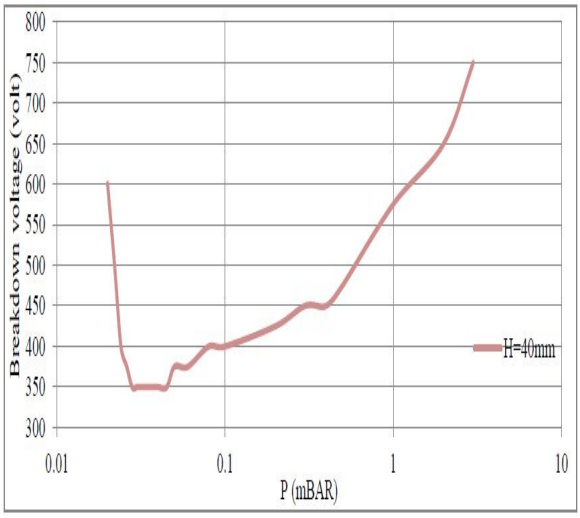


Figure 3. Paschen's curve for depth 40mm

The effect of increasing internal depth of hollow anode cause increases the secondTownsend coefficient, because the probability of creating secondary electron will increase. Consequentlythe electron current flux density is increase and reduces the breakdown voltage for glow discharge. It is observed that the breakdown voltage decrease according to increasing the depth of hollow anode, as shown in three-dimensional figure 4.

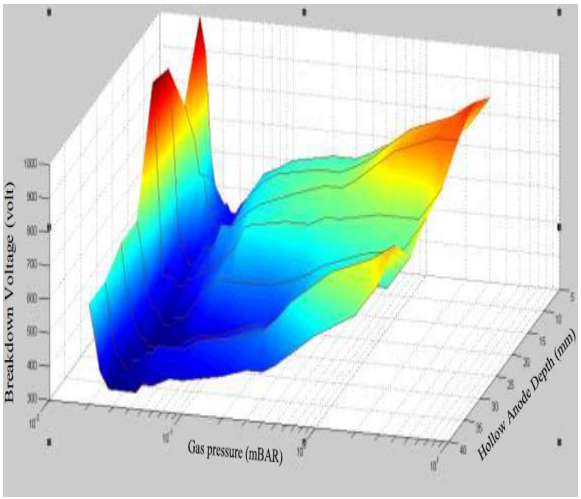


Figure 4.Breakdown voltage versus hollow anode depth

Figure 4, indicate that at any fixed value of pressures the breakdown voltage decrease due to enhancing hollow anode depth which are represented in the figure by dark lines. This attributed to increasing the local ionization collisions in the anode sheath leads to increase the second Townsend coefficient.Figure5; indicate that, this region such as a valley and this valley toward to the lower breakdown voltage and lower pressure as the hollow anode depth increase, which indicated that the minimum breakdown voltage is a function of second Townsend coefficient. This means that the needed voltage can be reduce by using a cylindrical hollow anode with large depth as shown in figure 6.

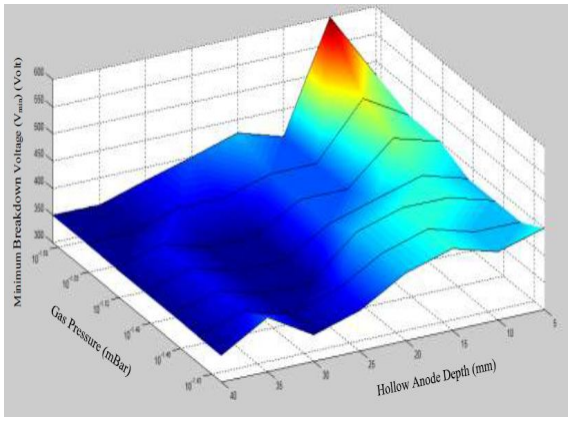


Figure 5. Minimum breakdown voltage (Vmin) and corresponding pressure as a function of hollow anode depth.

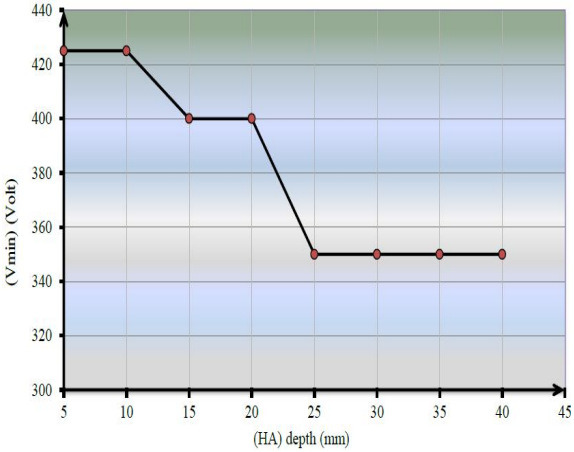


Figure 6. Minimum breakdown voltage versus anode depth

On the other, increasing anode depth will enhance the number of gas atom inside the hollow anode. According to that the radial electric field per atoms(Er/N) decrease, therefore it is difficult for electron to make ionizing collision with neutral atoms as well as to impact the wall side of anode at same pressure, so the process need a less pressure to get minimum breakdown voltage as shown in figure 7.

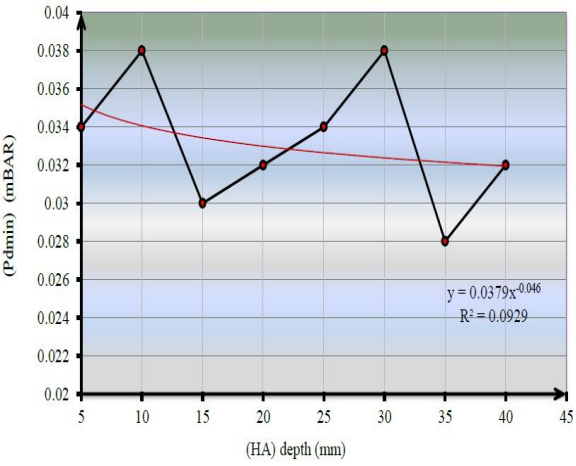


Figure 7. (Pdmin) versus hollow anode depth

In the second part of our study electron density and its temperature in the negative region of glow

discharge were determined. Since this region is the second large luminous region after positive column. For this purpose Langmuir cylindrical double probes inserted in the center of this region and fixed in the discharge axis. The double probes (Ip-Vp) characteristics figure 8, were measured as well as a computer MATLAB program is used to determine electron temperature and its density under the effect of hollow anode geometry.

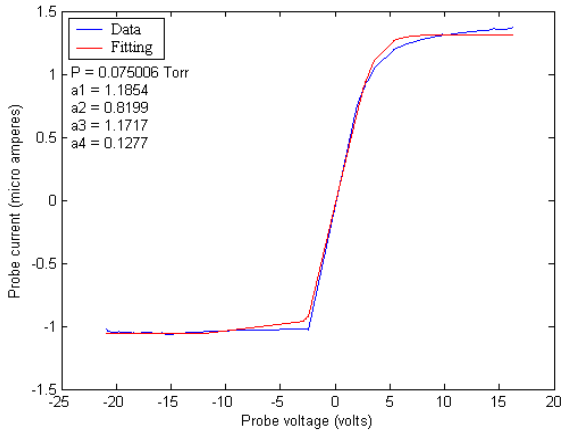


Figure 8. Double probe (Ip-Vp) characteristic at center of negative glow region, Id = 1.850 mA)

Electron temperature is one of the most important parameter which is depending on the fact of ionization collisions and transfers of energy; Andre el al [12].The electron temperature was calculated from double probe (Ip-Vp) characteristics at different pressure for each hollow anode using the following equation,Ghimire et al [13] andJohnson et al [14]:

$$Ip = I_{is} \tanh\left(\frac{eV_p}{2K_B T_e}\right)$$ ---------- (1)

By fitting the characteristic curve with tanh function

$$Ip = a_1 \tanh\left(\frac{V-a_2}{2*a_3}\right) + a_4$$ ----------(2)

Where $(a_1, a_2, a_3 \text{ and } a_4)$ are constantswhose values can be taken from fitting, by comparing between equations (1 and 2),we getting:

$$T_e K_e = 2a_2$$ ---------- (3)

Where Te is the electron temperature can be obtained.Figures 9and 10,represent the electron temperature as a function of hollow anode depth for pressures 0.04 and 0.045mbar.

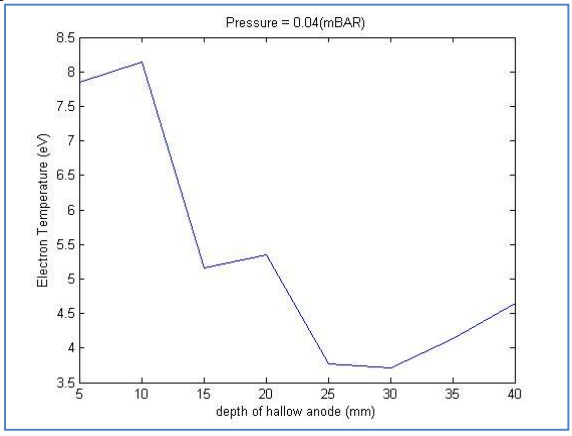


Figure 9.Electron temperature varsuse hollow anode depth

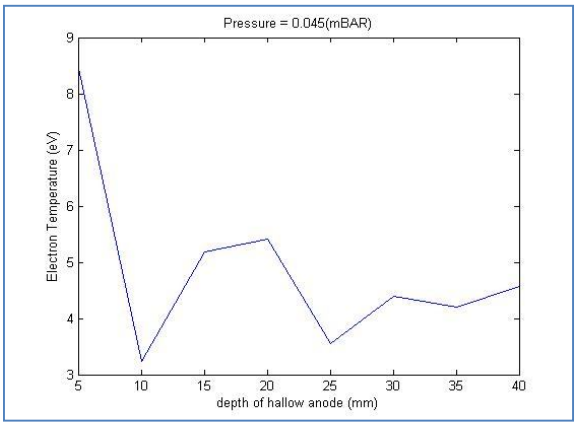


Figure 10.Electron temperature varsuse hollow anode depth

It is obvious from the figures 9and 10, that increasing of hollow anode depth at constant diameter, the electron temperature is decrease. This behavior is return to the reduction of length of negative glow region and consequently reduction of luminosity in aforementioned region. Also it is attributed to the decreasing of the number of electron excitation and ionization collisions with the other plasma particles in this region, therefore the electron temperature will be decreased.

Electron density is an important parameter in plasma processing because the efficiency of the processes occurring in the plasma and their reaction rates are generally dependent directly on the density of the charged particles, Alfred Grill [15]. This parameter isdetermined using the followingequation, Sahme et al [16]:Iis =$\frac{1}{4}$nieAp(KBTe/ mi) 1/2---------- (4)

Where,Iis and mi are the ion saturation current and its mass respectively. Ap is the probe area is given by equation

$$Ap = \pi r^2 A = \pi r^2 + 2\pi rh$$ ---------- (5)

r and h are probe radius and its length respectivelyElectron density isplotted as a function of the hollow anode depth at different pressure as shown in figures 11and 12.

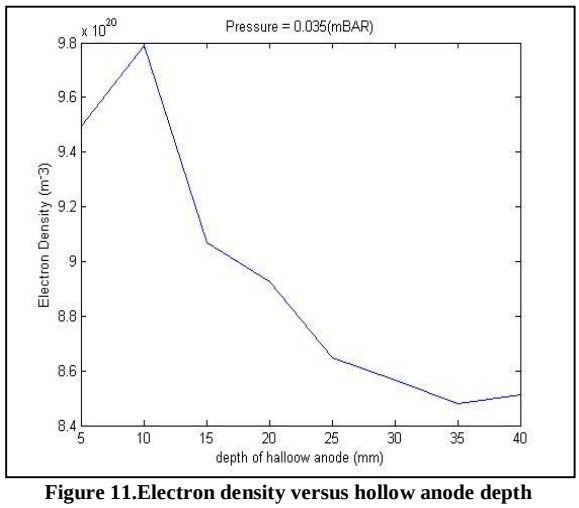


Figure 11.Electron density versus hollow anode depth

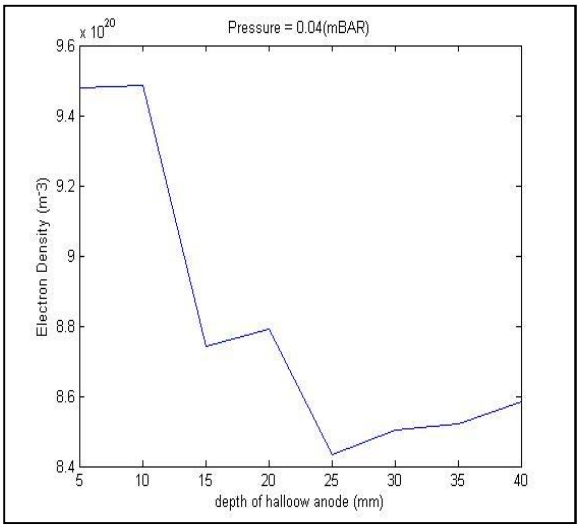


Figure 12.Electron density versus hollow anode depth

It is appear from the above figures 11and12 that the electron density decreases due to increasing hollow anode depth. This effect attributed to decreasing the number of excitation and ionization collisions. In addition to the previous description, the ion saturation current decrease with increasing hollow anode depth.

CONCLUSION

A comprehensive experimental study for the hollow anode DC glow discharge from the NG and PC in argon gas has been performed. The Pashence's curve has been measured as a function of hollow anode geometry for different argon gas pressure. In parallel to that measurements of some important plasma parameters in the negative glow region of discharge have done. The most important conclusions deduces from this work were Inferred and summarized in some points as flows:

1. Measured Pashence's curve close to the well-known theoreticalcurve.
2. It is able to minimize the breakdown voltage, also minimum breakdown voltage by increasing the depth hollow anode.
3. Increasing the hollow anode depth, the Paschen's curve is widening.
4. A dens and luminous intensity of plasma occurs in the negative glow region by reducing the depth of hollow anode.
5. A Computer MATLAB program which is made to estimate the Teand ne gave reasonable results of plasma parameters.
6. Electron temperature and its density decreases due to increasing depth of hollow anode.

REFERENCES

[1] V.I.Miljevic (1985),"Characteristics of the Hollow Anode Ion-Electron Source" J. Appl. Phys. 57, 4482.
[2] A. Anders, N. Newman, M. Rubin, M. Dickinson, A. Thomson, E. Jones, P. Phatak and A. Gassmann (1996), "Hollow Anode Plasma Source for Beam Epitaxy of Gallium Nitride" Lawrence Berkeley National Laboratory, Berkeley, CA 94720.
[3] Shigeru Yokota, KimiyaKomurasaki, and Yoshihiro Arakawa (2014) "Plasma Density Fluctuation inside a Hollow Anode-Layer Hall Thruster".
[4] Hyunkook Park, MachikoTsukiji, Kazuaki Agatsuma, and Sang Chun LEE (2007)" Emission and Sputtering Characteristics of Ne-Ar Mixed Gas Glow Discharge Plasmas"Analytical Science September, VOL. 23
[5] V. vekselam, J. Glaizer, S. Yatom, D. Yarmolich, V. Tz. Gurovich, G. Bazalitski, Ya. E. Krasi and V. Bernshtam (2009), "Laser Induced Fluorescence of the Ferroelectric Plasma Source Assisted 0hollow anode discharge" Physics of Plasmas, 16. 113504.
[6] K.P. Savkin, Yu.G. YuSkov, A.G. Nikolaev, E.M. Oks, and G.Yu.Yushkov (2010) "Generation of Gaseous and Metal Ions in Vacuum Arc Discharge with the Longitudinal Hollow Anode in a Magnetic Field", TUBITAK and RFBR under the joint Turkish-Russian research program (Grant Nos. 108M394 and RFBR-09-08-91219- CT a).
[7] In Je Kang, Soon Gook Cho, Min KeunBae, Sung KiuJoo, Jin Woo Kim, Hyung Jin Kim, and Kyu Sun Chung (2013), "Design of a Hollow-Anode Discharge Source for Generation of Supersonic Plasma Jets" APS division of Plasma physics, Vol. 58, No.16.
[8] J. Z. Glaizer, D Yarmolich, A Krokhmal, Ya E Krasik, and J Felsteiner (2005) "Optimization of a Low-Pressure Hollow-Anode Electrical Discharge for Generation of High-Current Electron Beams" Journal of Physics D: Appl. Phys. 38. 2.
[9] O.I. Timoshenkov, I.O. Misiruk, V.S. Taran, and I.E. Garcusha (2015) " non-self-maintained discharge with a hollow anode : characteristics and application" 32nd ICPIG, Iaşi, Romania
[10] Ivan O. Misiruk,Oleksandr I. Timoshenko,Valeriy S. aran,Igor E. Garkusha(2016) "Non-self-sustained discharge with hollow anode for plasma-based surface treatment" Nukleonka ,61(2):195-199.
[11] Teo Yong Siah and Teng Po-Wen Ivan, (2010) "Plasma Physic: Paschen Curve, Measure the Breakdown Voltages Ubr at Varying Electrode Gap Distance d Under a fixed pressure P of air "
[12] Andre Anders and Simone Anders (1995), "Working Principle of the Hollow-Anode Plasma source", Plasma Sources Science Technology, 4: p. 571-575.
[13] B. Ghimire, R. khanal and D.P. Subedi (2014), "Diagnostic of Low Pressure DC Glow Discharge Using Double Langmuir Probe" Journal of Science, Engineering and technology, 10. 1
[14] E. O. Johnson and L. Malter (1950),"A Floating Double Probe Method for Measurements in Gas Discharges", RCA Laboratories Division, Radio Corporation of America, Princeton, New Jersey.
[15] A. Grill (1993), "Cold plasma in materials fabrication from fundamentals to applications", Institute of electrical and electronicengineers, Inc, New York, USA.
[16] Sahme (2016) "Effect of hollow anode geometry on some argon discharge plasma parameters" A thesis submitted to the council of the Faculty of Science, University of ZAkho in partial fulfillment for the requirement of master degree of science in plasma physics.

★★★