PLASMA DISCHARGE VARIATIONS USING A POLARIZED SCREEN UNDER A FLOATING POTENTIAL

AXINTE Mihai[1], NEJNERU Carmen[1], PERJU Manuela Cristina[1], HOPULELE Ion[1]

[1]*Technical University "Gheorghe Asachi" of Iaşi-România, E-mail address: mihai.axinte@gmail.com*

Abstract: *The hollow cathode effect occurs when the two close surfaces cathodic discharge lights are overlapping. To highlight the occurring effect parameters we used two types of samples: one of them had a wedge shape cut and the other presented a set of holes with different diameters. The sample with a wedge shape cut promotes the superheating effect on the narrowest part of the cut. In the other case, at the sample with holes, hollow cathode discharge is initiated in, by sequence, in each one of these holes. The hollow cathode effect was studied at the regular discharge and using a cathode grid under floating potential.*

Keywords: *Hollow cathode effect, plasma discharge*

1. Introduction

In general, for the plasma nitriding process, the components to be treated are subjected to a high cathode potential and the grounded wall while the furnace wall forms the anode. The parts are directly involved in the discharge process [1].

The positive ions generated by glow discharge are accelerated in the cathode fall region near the cathode surface and bombard the surface of the specimen. The ion bombardment causes sputtering, transfers kinetic energy to the component and raises its temperature. Many studies have indicated that the geometry, size and ratio of the surface to mass of the component have substantial effects on the temperature distribution within the component and lead to inhomogeneous response to nitriding.[1]

In general, for the plasma nitriding process, the components to be treated are subject to a high cathode potential and the grounded wall of the furnace forms the anode. The components are directly involved in the discharge process.

Many studies have indicated that the geometry, size and ratio of the surface to mass of the component have substantial effects on the temperature distribution within the component and lead to inhomogeneous response to nitriding.[2]. Hollow cathode effect has the potential for electric arc occurrence that leads at destruction of part surface. Since the geometry is very wide range, on parts subject to nitriding process may appear hollow cathode effect.

Hollow cathode effect occurs when the cathode glow drop discharge zone from the two surfaces of the part or two separate parts interfere with each other[1]. Under these conditions the electrons accelerated in the cathode potential drop zone, in front of an area are slowed down and reaccelerated in other area of the cathode drop region.

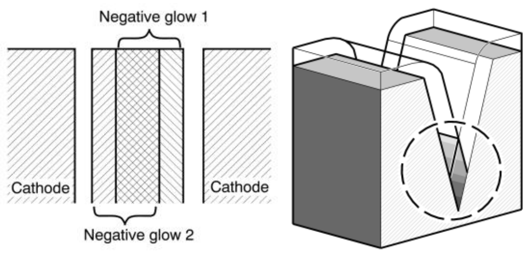


Figure 1. *Highlighting the hollow cathode effect.*
a) parallel plane surfaces b) cross section through a narrow channel wedge shape

Because the repeated oscillation in space between the two surfaces, electrons runway length increases very much, so the default number of ionization. The flow of electrons originating from the collision of electrons by neutral atoms is very intense.

Increasing concentrations of ions causes an increase in ion bombardment (at cathode) which makes the cathode temperature to rise very much (a few hundred degrees)

The area is very bright due to emission of photons. Local current density increases, almost short-circuiting the rest of discharge. Discharging is so predominantly in the hollow cathode effect occurring here as well negative phenomena: delayed until melting and frequent switching under the electric arc.[3]

Hollow cathode effect appears when the distance between cathode surfaces is in the range (2-3) dan, when it crosses the cathode fall discharge zone – called negative lights.

The loss of electrons is low due to the special geometry and because they are repelled by the negative walls of the cathode, and in fact, they oscillate between the sample and the wall (figure 1). The plasma density (that is the electron concentration) increases and reaches values as high as 1012 cm-3[29]. As a consequence, the production of ions rises too, and the ion flux density on the substrate surface increases. Due to these factors, such surfaces can be heated to extremely high temperatures even at relatively low bulk substrate temperatures of 200–500˚C and the local heating can produce melting surface, which means destroying the part [4]

For the abnormal discharge, the length dc = dan depends on discharge current according to the law of Aston.

$$d_c = d_{an} = a \cdot j^{\frac{-1}{2}} + b \cdot p^{-1} \text{, in cm} \quad (1)$$

Where j= current density, p = pressure

In general, when the cathode emits a large number of electrons or the occurrence for favorable conditions through ionization processes appears, the cathode drop zone impedance decreases and switches to an electric arc glow discharge.

Because the electric arc occurrence in the process of ion nitriding and its destructive effects on the burden and source of electricity supply, the conditions of its occurrence should be avoided.[1]

2. Materials and method

To avoid this disadvantage an experimental study on installation was build, a plasma nitriding facility build in the heat and thermochemical treatments laboratory from Faculty of Materials Science and Engineering, University "Gheorghe Asachi" from Iași, Romania.

This installation is equipped with a cathodic grid. In such a case a glow discharge is largely "transferred" from the surface of the parts to the grid surface, and the ion bombardment of the parts becomes less intense [3].

This grid is made of stainless steel, and has the role to modify the electrical discharge field between anode and cathode, on the ionic triode principle. According to [4], the use of active screen virtually does not reduce the growth rate of the layer. Such a system is a triode.

Constructive principle of the installation is presented in figure 2.

Changing the electric field between anode and cathode changes the degeneration conditions for arc discharge, and hollow cathode occurrence by adjusting the electrical potential of the grid. In our case the grid is situated under a floating potential.

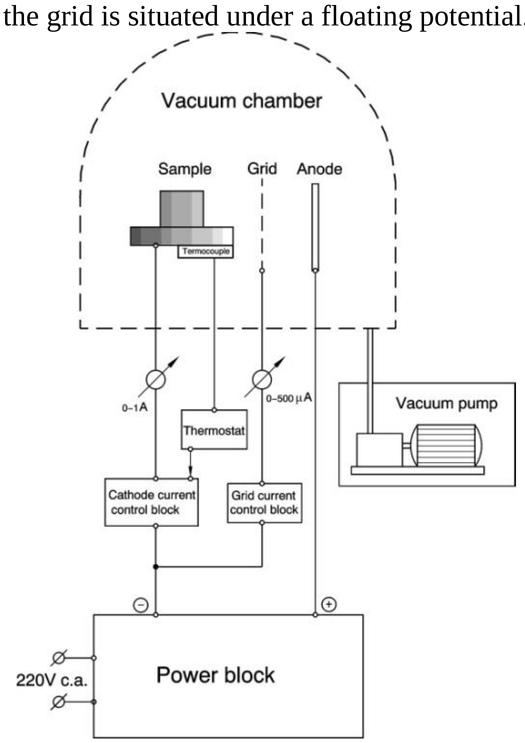


Figure 2. *Constructive principle for installation, electrical block diagram*[5]

Figure 3. *Installation working place during plasma discharge*

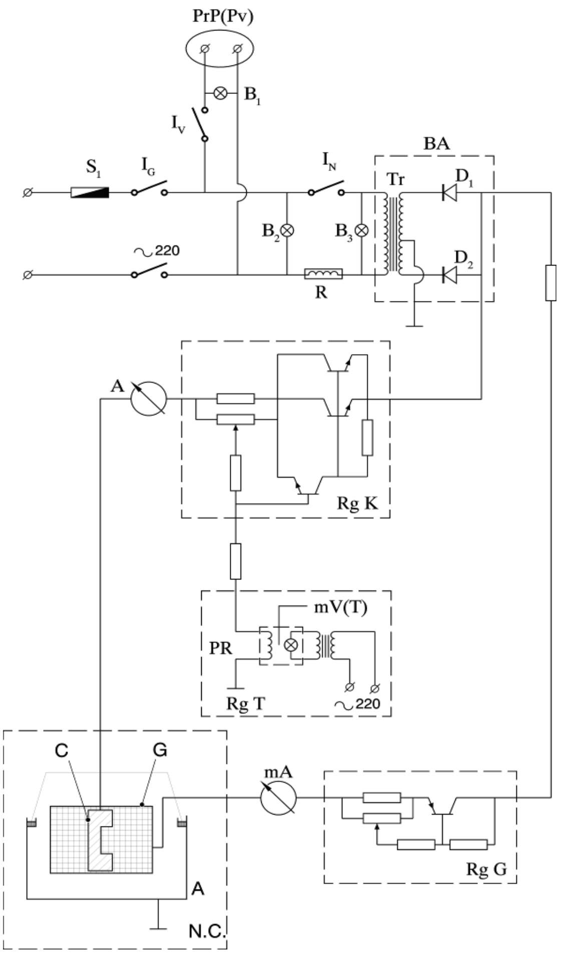


Figure 4. Fig. 5.12. .Detailed electrical diagram for the nitriding installation : S_1= safety fuse; I = general power switch; B_1, B_2, B_3 = Signal light bulbs; R = protection resistor; D_1, D_2 = rectifier diodes; Tr = transformer; Rg K = cathode current regulator; Rg G = grid current regulator; RgT = temperature regulator; I.N. = Nitriding chamber; PrP = Vacuum pump power; FR = photoresistor; mV(T) = Millivoltmeter regulator; A = ampermeter; mA = miliampermeter; C = cathode; G = grid

In fig. 4 is presented the detailed electrical diagram. In ionic triode case the interposed grid between anode and cathode is electrically polarized, so it changes the configuration of the anode and cathode electric field.

For this experiment the 38CrMoAl09 steel samples were used with chemical composition shown in table 1.

Table 1. Chemical composition for 38CrMoAl09 steel

Element	Fe	C	Cr	S	Cr	
Procent	95.4	0.503	1.49	0.296	1.49	
Element	Mo	Ni	Al	Cu	W	Ti
Procent	0.127	0.122	1.17	0.122	0.065	0.016

The samples were placed inside the vacuum chamber, the plasma discharge working place, showed in figure 3.

Also, to highlight the emergence of hollow cathode effect and its dependence on process parameters (voltage, current, pressure), we used two types of samples. One is wedge-type, and its dimensions are represented in figure 5a. And the other one is a sample with different dimensions holes, showed in figure 5b. The boundary dimensions are similar for both samples: cylinders with exterior diameter d=10mm, and height h=50mm. The fixing device, requires a hole on the bottom with d=8mm. The detailed dimensions are presented in figure 5.

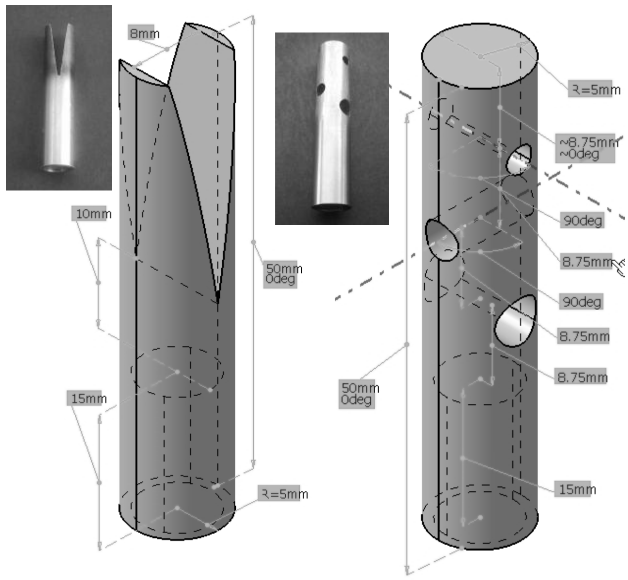


Figure 5. *Cylindrical samples:* a) wedge shape cut; b) *different diameters holes*[6]

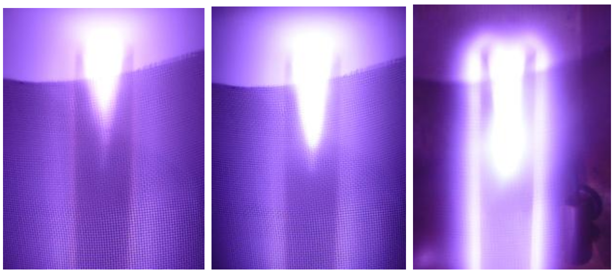
3. Experimental data

A number of tests were performed on plasma discharge equipment and the medium results, beside a relevant picture for each case are showed in the following.

The process parameters results were registered into the tables and the medium values are presented separate for each particular case.

Table 2. Process parameters using wedge shape cut cylindrical sample with cathode grid grid

Figure	Pressure	Cathode voltage	Anode intensity	Temp.	Grid intensity
	torr	V	A	˚C	mA
6a	0.5	500	0.04	500	10
6b	1	467	0.11	500	10
6c	2	407	0.16	500	10



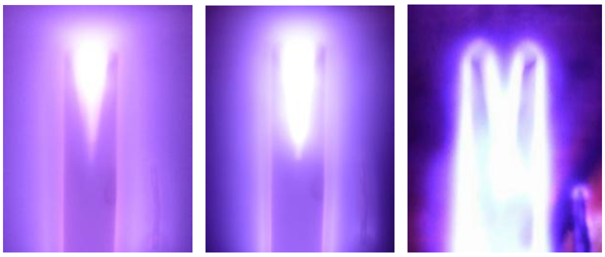
a) b) c)

Figure 6. *Images for cathode grid plasma discharge modification dependent to the pressure on wedge shape cut sample with cathode grid. a)discharge initiation; b) discharge middle phase; c) discharge final phase*

Table 2 and table 3 shows the experimental data parameters registered at plasma discharge on wedge shape cut samples with and without cathode grid.

Table 3. Process parameters using wedge shape cut cylindrical sample without cathode grid

Figure	Pressure	Cathode voltage	Anode intensity	Temp.	Grid intensity
	torr	V	A	˚C	mA
7a	0.5	505	0.02	500	-
7b	1	472	0.12	500	-
7c	1.8	409	0.17	500	-



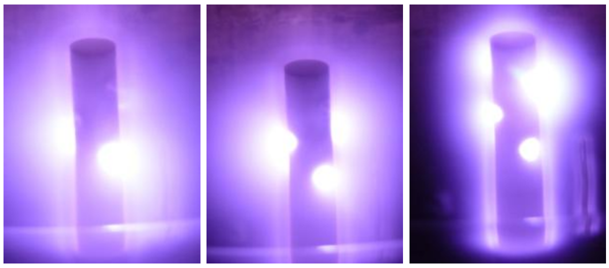
a) b) c)

Figure 7. *Images for plasma discharge modification dependent to the pressure on wedge shape cut sample without cathode grid a)discharge initiation; b) discharge middle phase; c) discharge final phase*

Table 4 and 5 summarizes the data obtained at the discharge on facility with or without the cathode grid for the samples with different dimension holes placed at 90˚.

Table 4. Process parameters for plasma discharge using cylindrical sample with holes without cathode grid

Figure	Pressure	Cathode voltage	Anode intensity	Temp.	Grid intensity
	torr	V	A	˚C	mA
8a	0.7	507	0.03	500	-
8b	1	460	0.15	500	-
8c	2	424	0.18	500	-



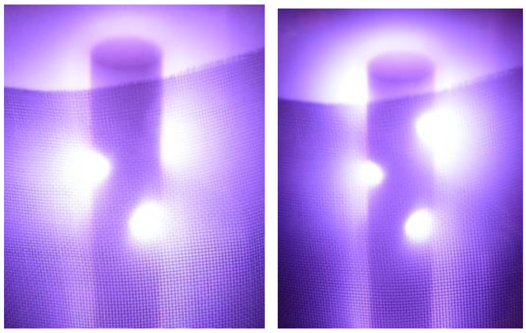
a) b) c)

Figure 8. *Images for cathode grid plasma discharge modification dependent to the pressure on holes sample without cathode grid: a)5mm hole; b) 5mm+4mm hole; c) 5mm+4mm+3mm hole*

In table 5 are presented data obtained at discharge without cathode grid for the samples with holes.

Table 5. Process parameters for plasma discharge using cylindrical sample with holes with cathode grid

Figure	Pressure	Cathode voltage	Anode intensity	Temp.	Grid intensity
	torr	V	A	˚C	mA
9a	1	472	0.06	500	10
9b	2	446	0.14	500	10



a) b)

Figure 9. *Images for cathode grid plasma discharge modification dependent to the pressure on holes sample with cathode grid: a)5mm hole; b) 5mm+4mm hole; c) 5mm+4mm+3mm hole*

Introducing the cathodic grid, the hollow cathode discharge effect is not initiated into the smaller hole, with diameter 3mm. The effect was blocked although the pressure was similar even lower than the pressure for the hollow cathode effect initiation into the same hole but without the cathode grid.

Otherwise the effect on the discharge is obvious, meaning the different pressure range for the initial appearance of the hollow cathode discharge.

4. Results and discussion

The plasma hollow cathode discharge, affects the sample predominant on the part sharp edges, where the two negative glow discharges overlaps. The discharge lowers to the bottom of the wedge shape cut once the pressure modification increases from 0.5 torr to 1 torr.

A very bright light cathode discharge is observed at the 2 torr pressure, and this is the maximum pressure where the discharge in on. The maximum pressure in case of cathodic grid where the powerful luminescent discharge appears at is the 1,8 torr pressure.

The effect of the cathodic grid is the discharge parameters modification, and the occurrence at the low rate electric tension and higher intensities, from the data values, presented in the synthesis experimental table dates. The cathodic fall region distance is in inverse ratio with the pressure in the vacuum chamber.

The cathodic grid lowers the hollow cathode effect, modifying the cathodic discharge parameters and the cathodic fall region distance. Comparative studies on grid discharge over discharge without grid on the wedge cut shape sample show minor differences between the correspondent values for electric potential and intensity.

Otherwise a more suitable geometry for highlighting the hollow cathode effect is the different dimensions hole sample figure 5. The influence of cathodic grid over plasma discharge and the hollow cathode effect is pointed better at the sample with different diameters holes (D=3mm, 4mm, 5mm).

The experiment consists in creating high vacuum conditions, and once the pressure progressively increases it can be observed that the preferential discharge occurs into the holes.

Plasma discharge without cathodic grid shows that the hollow cathode discharge initiation occurs at 0,7 torr, into the bigger hole (D=5mm), then into the second hole at the pressure 1torr then, at 2 torr discharge is set into all three holes. We observed almost the same pressure on the cathode grid discharge for the hole sample. The difference is that the stability for the one hole discharge is very small, a transient state, so we could not register the electrical current values. Studying the electric current parameters for the 4mm and 5 mm diameter hole we can observe an important difference between the electric current parameters (table 4 and 5).

5. Conclusions

1. The sample with holes placed at 90 degrees highlights in a proper manner the floating potential cathode grid positive effect regarding the double cathode effect.

2. The floating potential cathode grid changes the cathode voltage drop shape between anode and cathode, introducing a intermediate step, fact that generates a less intense cathode sputtering.

3. Hollow cathode effect changes its parameters in the presence of cathode grid meaning a slower discharge ignition (increasing discharge ignition intensity for hollow cathode effect) from 0.02 to 0.04 A. It also drops 10% from discharge pressure for hollow cathode effect occurrence.

4. Effect of the grid on the hollow cathode discharge is beneficial to part temperature, avoiding excessive growth for electric arc danger.

6. References

[1] Li, Y., *Plasma nitriding of 42CrMo low alloy steels at anodic or cathodic potentials*, Surface & Coatings Technology 204 (2010) 2337–2342

[2] Corujeira Gallo, S., Dong, H., *Study of active screen plasma processing conditions for carburising and nitriding austenitic stainless steel*, Surface & Coatings Technology 203 (2009) 3669–3675

[3] Janosi, S., *Controlled hollow cathode effect: new possibilities for heating low-pressure furnaces*, Metal Science and Heat Treatment, Vol. 46, Nos.7–8 (2004) 310-316

[4] Alves Jr., C., *Nitriding of titanium disks and industrial dental implants using hollow cathode discharge*, Surface & Coatings Technology 194 (2005) 196–202

[5] Axinte, M., Nejneru C., Ştefan, M., Hopulele, I., *Facility for study heating and diffusion processes in terms of ionic triode plasma* - Tehnomus XV, Suceava, Ed. Matrix Rom, pag. 223-228, ISSN-1224-029X, 2009.

[6] Axinte, M., Nejneru, C., Perju, M.C., Cimpoeşu, N., Hopulele I., *Research on hollow cathode effect and edge effect avoidance in plasma nitriding treatment*, Tehnomus New Technologies and Products in Machine Manufacturing Technologies, 2011, no.18, Suceava, pg. 181-184, ISSN 1224-029X