Open Access **Baghdad Science Journal** **P-ISSN: 2078-8665**
Published Online First: September 2022 **2023, 20(2): 637-641** **E-ISSN: 2411-7986**

DOI: http://dx.doi.org/10.21123/bsj.2022.7069

Influence of Glow and Afterglow Times on the Discharge Current of Argon at Low Pressure

Ahmed Y. Owaid

Department of Electronics, Technical Institute of Mosul, Northern Technical University, Mosul, Iraq
E-mail address: ahmedowaid69@gmail.com

Received 18/2/2022, Revised 10/5/2022, Accepted 12/5/2022, Published Online First 20/9/2022
Published 1/4/2023

Abstract:

An experimental investigation of the variation of argon discharge current with a glow and afterglow time intervals of a square discharge voltage was carried out at low pressure (6-11 mbar). The discharge was created between two circular metal electrodes of diameter (7.5 cm), separated horizontally by a distance (10 cm) at the two ends of a Pyrex cylindrical tube. A composite of two Gaussian functions has been suggested to fit and explain the variation graphs clearly. It is shown that the necessary times of glow and afterglow needed to attain a maximum discharge current are (70 us) and (60 us), respectively. The discharge current is observed to drop to the lowest value when the two times are serially longer than (85 us) and (72 us). Furthermore, the difference between the two times required to obtain a maximum rate of change in the discharge current, or a maximum discharge current, is deduced to be comparable to the breakdown time delay of gases reported in the literature. These observations can be useful for the design of plasma devices requiring specialized engineering.

Keywords: Afterglow time, Argon Plasma, Discharge current, Glow time, Square discharge voltage.

Introduction:

In practical engineering designs, the breakdown of a gap of gas due to rapidly changing voltages or impulse voltages is of great importance. There is a time difference between the application of a voltage sufficient to cause a breakdown and the occurrence of the breakdown itself. The breakdown time lag consists of the statistical and formative time lags [1-3]. The time delay between the application of breakdown voltage and the appearance of an initiating electron is called the statistical time lag. The formative time lag is the time required for the ionization processes to develop fully to cause the breakdown [1,2]. The formative time lag has been examined for a number of gases at low pressure [3,4]. The relaxation time (afterglow time) of a discharge voltage has a distribution effect on the time lag of breakdown [5-8]. For values of afterglow time (3–70 ms), the statistical time delay contribution to the total electrical breakdown time delay can be neglected [9]. During the Townsend mechanism of discharge, the created seed electrons are accelerated by the anode voltage and can give rise to a series of consecutively growing electronic avalanches, cause the breakdown of the gas after a formative time interval [10]. After the discharge has been turned off, the free electrons that have been recombined in the discharge volume may still be important in the initiation of the next breakdown, and the development of the next discharge will be faster if the number of initial electrons is high [11]. The influence of discharge products on the subsequent breakdown process depends on the discharge conditions [12–16]. The Townsend ionization mechanisms and rates were found to be sensitive to the pressure times of electrodes spaced (pd) on the left branch of the Paschen curve [17]. Some recombination processes in low temperature plasma can influence the decrease of electron number density, depending on the discharge conditions [18]. During the glow time of a discharge and after the gas breakdown delay time, the discharge will develop from a dark (Townsend) to a glow discharge and produce a specific density of active particles (electrons and ions) that will depend in some way on this time. When the discharge is switched off for an afterglow time interval, the active particles will decrease (recombined) with time in the discharge volume, but still be of great importance in the initiation of the next breakdown[19]. The square discharge voltage can have significant impacts on the discharge current characteristics, which could provide new application possibilities.

The aim of the present study is to investigate experimentally the influence of the glow and afterglow time intervals of a square discharge voltage on the discharge current of argon at low pressure (6-11 mbar).
In addition, the study purpose is to examine the relationship between the two times with a breakdown time lag of gases.

Experimental details

A schematic diagram of the experimental arrangement is shown in Fig. 1 two circular electrodes of diameter (7.5 cm) made of aluminum are placed at the two open ends of a Pyrex discharge tube at an inter-electrode distance of (10 cm) to create the discharge. The pressure of the working gas (argon) is measured and controlled in the range (6-11 mbar) by a vacuum system (a rotary oil pump and a thermocouple vacuum gauge). Before installing the electrodes in the discharge tube, they were polished and cleaned. The anode is powered by a stabilized high DC voltage supply through a ballast resistance R (470Ω/2W) and a programmable high voltage switch PSW, while the cathode is grounded. The discharge voltage and current are measured using an accurate oscilloscope (OSC).

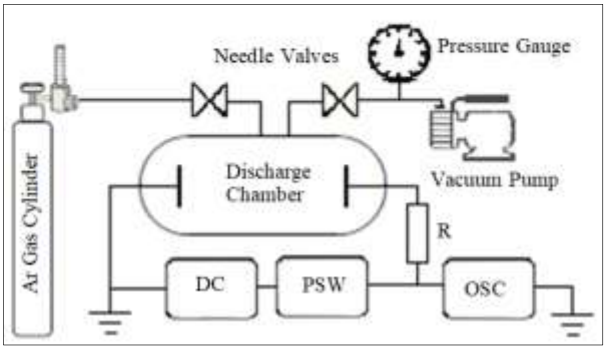

Figure 1. A schematic diagram of experimental arrangement, DC is an external direct current voltage source, PSW is a programmable switch, OSC is an accurate oscilloscope and R is a ballast resistor.

As illustrated in Fig. 2, the programmable switch is programmed to pass a sequence of square DC pulse voltages to the anode, with a glow time (t_{on}) duration ($54-108\,us$) and an afterglow time (t_{off}) interval ($46-92\,us$). The glow and afterglow times were set to represent 54 and 46 percent of the square DC voltage duration (t_p), respectively. The rising time of the square DC voltage, which is mostly affected by the stray capacities and the load resistor [20], was measured directly using the oscilloscope, and it was found to be ($35\,ns$).

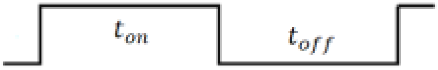

Figure 2. A schematic drawing of glow and afterglow times of a square DC voltage.

The curve fitting tools of Matlab R2009b are used to fit the variation curves of discharge current with the glow time of discharge voltage, as well as to find and plot the rate of the variation of the fitted curves.

Results and Discussion:

Fig. 3 shows the time intervals, glow time and afterglow time that are used to ignite the discharge of argon gas at low pressure in the range (6-11 mbar).

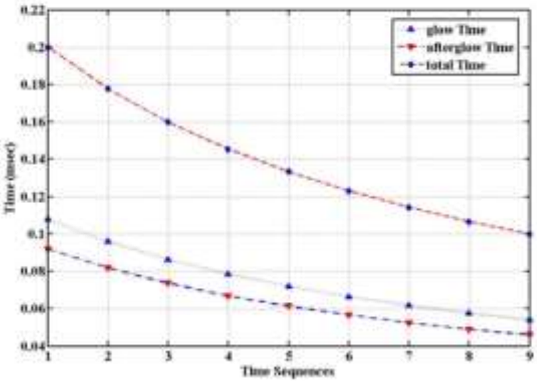

Figure 3. Time intervals (t_{on}), (t_{off}) and (t_p) that used to create the discharge.

The effective value (V_{eff}) of a square DC voltage is expressed as [20]

$$V_{eff} = V_o\sqrt{D} = V_o\sqrt{\frac{t_{on}}{t_{on}+t_{off}}} \quad \text{------- 1}$$

where (V_o) and (D) are the square voltage amplitude and duty cycle, respectively. The DC voltage that is required to breakdown the argon gas at low pressure is ($180\,V$) [21,22]. To breakdown the argon gas at low pressure in the range of (6-11 mbar), a square voltage of amplitude ($250\,V$) and duty cycle of (54%) was used to generate an effective voltage ($183\,V$) that is similar to the DC breakdown voltage of argon at low pressure.

Fig. 4 displays how the discharge current varies with the discharge voltage time interval (t_{on}) for various working pressures. The maximum discharge current is clearly attained at the minimum of the Paschen curve pd value (79 mbr.cm) [21-22] and around the minimum from both sides. This result can be explained by two facts: a maximum amount of energy gained by electrons between two consecutive ionizations and a high rate of gas ionization are both available at this minimum [23].

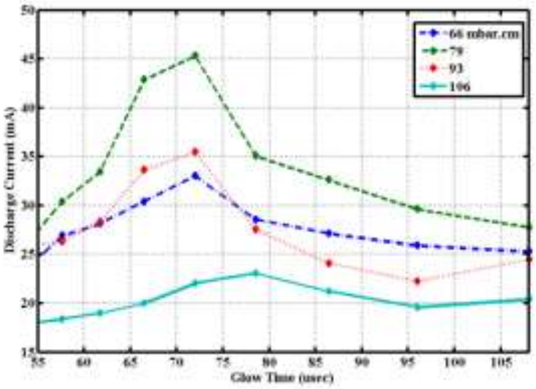

Figure 4. Changes in the discharge current with (t_{on}) of discharge voltage.

The Matlab curve fitting tools are used to create a fitted curve for the variation of discharge current (i) with the glow time of discharge, and the resulting curves are presented in figure 5. The Gaussian function is the suitable function for fitting and given by [24]

$$i = a_1 \exp - \left(\frac{t_{on}-b_1}{c_1}\right)^2 + a_2 \exp - \left(\frac{t_{on}-b_2}{c_2}\right)^2 \text{----- } 2$$

where $a_{1,2}, b_{1,2}, c_{1,2}$ are arbitrary real constants that represent the height, the position of the center of the peak, and the width of the bell curve of the variation, respectively.

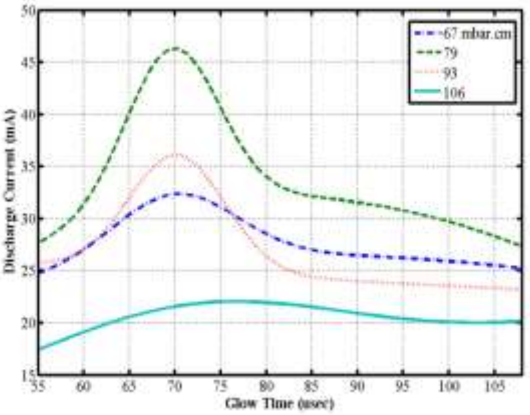

Figure 5. Fitted curves for the variation of discharge current with on time of discharge voltage.

From Figs. 4, 5, it is seen that the discharge current at all pressures in the range started to increase from the lowest value as the glow time of discharge increased, and after reaching a maximum value, it turned to decrease to the lowest values again. It also appears that all maximum values of discharge current are obtained at a glow time interval ($t_{on} = 70$ us) and an afterglow time interval ($t_{off} = 60$ us). Furthermore, when the glow and afterglow times exceeded (85 us) and (72 us) respectively, the discharge current decreased to the minimum values at all pressure values in the range. This means that the glow time required to produce a full breakdown and the afterglow time needed to maintain a high density of charged particles (electrons and positive ions) remaining in the discharge volume have a significant influence on the discharge current. According to the literature [1], the values of glow and afterglow times required to produce a maximum discharge current are expected to depend on the cathode material (secondary electron emission efficiency), the gas type (charge production and loss processes), and the discharge volume (diffusion dimensions). The influence of pressure on discharge current is well discussed in the literature [1,25,26], and an additional experimental result is presented here.

After differentiating eq.2, the rate of change of the discharge current with glow time (t_{on}) could be derived as follows

$$\frac{di}{dt_{on}} = \left(\frac{-2a_1}{c_1}\right)\left(\frac{t_{on}-b_1}{c_1}\right)\exp - \left(\frac{t_{on}-b_1}{c_1}\right)^2 + \left(\frac{-2a_2}{c_2}\right)\left(\frac{t_{on}-b_2}{c_2}\right)\exp - \left(\frac{t_{on}-b_2}{c_2}\right)^2 \text{ ------- } 3$$

Fig. 6 shows two regions of rapid increase and decrease in the discharge current obtained at glow times (65 us) and (75 us) and afterglow times (55 us) and (64 us), respectively. The glow and afterglow times were set to represent 54 and 46 percent of the square DC voltage duration, respectively, so we find the relationship between the two times can be given as

$$t_{off} = \left(\frac{46}{54}\right) t_{on} \text{ ------- } 4$$

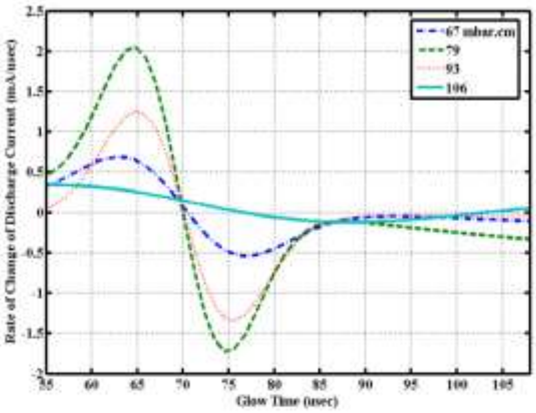

Figure 6. Rate of change of discharge current with discharge time (t_{on}).

The difference between these timings is clearly close to the breakdown time delay (10 us), which has been stated in the literature [1].

Furthermore, at pd value (79 mbar.cm) of the from both sides, the maximum rate of change of discharge current is obtained, whereas a minimum rate of change is obtained at all pressures values in the range when the glow and afterglow times exceed (85 us) and (72 us), respectively. Table 1 summarized the influence of glow and afterglow times on the discharge current and the rate of change of discharge current. The results indicate how the two times affect the net charges created and lost during the breakdown and diffusion procedures.

Table 1. Glow and afterglow times of maximum discharge current, minimum discharge current and maximum rate of increase and decrease of discharge current.

Discharge pressure (mbar.cm) 67 , 79 , 93 , 106		
Discharge current times	Glow time (us)	Afterglow time (us)
Maximum discharge current	70	60
Minimum discharge current	85	72
Maximum rate of increase / decrease of discharge current	65/75	55/64

Conclusions:

The experimental graphs obtained about the variation of argon discharge current with a glow and afterglow time interval of a square discharge voltage of amplitude (250V) and duty cycle (54%) show the following observations within a low pressure range (6-11 mbar). The necessary times of glow and afterglow required to reach a maximum discharge current at a pressure in the range are (70 us) and (60 us), respectively. The maximum value of discharge current is clearly measured at the minimum of the Paschen curve pd value (79 mbr.cm), where (p) is the working pressure and (d) is the inter-electrodes distance, which is here equal to (10 cm). The discharge current (at all pressures in the range) is observed to drop to the lowest value when the two times are consecutively longer than (85 us) and (72 us). Furthermore, the difference between the two times required to obtain a maximum rate of change in the discharge current, or a maximum discharge current, is deduced to be (10 us) which is comparable to the breakdown time delay of gases. These results may be beneficial for the development of plasma devices needing specialist engineering. More research may be needed to demonstrate the influence of the two times on the first ionization coefficient of the argon Paschen curve minimum and near the minimum and the secondary electron emission of discharge electrodes.

Author's declaration:

- Conflicts of Interest: None.
- I hereby confirm that all the Figures and Tables in the manuscript are mine. Besides, the Figures and images, which are not mine, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in Northern Technical University.

References

1. Raizer Y P. Gas discharge physics Corrected edition. Springer. 2001: 128-138.
2. Braithwaite N S J. Introduction to gas discharge. Plasma Sources Sci. Technol. 2000; 9(4):517.
3. Dutton J, C Haydon S C, Jones F L. Formative time lags in the electrical breakdown of gases. Br J Appl Phys. 2002; 4(6):170.
4. Xiaotong C, Jing H, Ruixue Z, Weijie H, Yulei F, Wansheng Z. Dependence of pre-breakdown time on ionization processes in a pseudo spark discharge. AIP Adv. 2017; 7 115005.
5. Suzana N S, Vidosav L M, Aleksandar P J, Marjan N S. Voltage Dependent models of the formative time delay in argon. FU Phys Chem Tech. 2017; 15 (2): 81–93.
6. Milic P, Momcilo M P, Koviljka S. Physico-Chemical Processes Induced by Electrical Breakdown and Discharge Responsible for Memory Effect in Krypton with, Plasma Chem Plasma Process. 2018; 38(2).
7. Cedomir I B, Koviljka D S, Milic M P, Predrag V O. The Influence of the Magnetic Field on DC and the Impulse Breakdown of Noble Gases. Materials. 2019; 12 752.
8. Milic P, Momcilo P, Cedomir B, Koviljka S. Separation of vacuum and gas breakdown processes in argon and their influence onelectrical breakdown time delay. Vacuum. 2020; 173 109151.
9. Irina V S, Matthew H, Barnat E V, Michael K. Controlling the breakdown delay time in pulsed gas discharge. Plasma Sources Sci Technol. 2021; DOI:10.1088/1361-6595/ac417a.
10. Emilija Z, Marija Z, Milic P. The evolution of breakdown voltage and delay time under high overvoltage for different types of surge arresters. FU Elec Energ: Electronics and Energetics. 2021; 34(2): 307-322.
11. Irina S, Matthew H, Barnat E, Michael K. Theoretical and experimental study of breakdown delay time in pulse discharge. IEEE Xplore. 29th International Symposium on Discharges and Electrical Insulation in Vacuum. 2021.
12. Marjan S, Aleksandar P J, Markovic V L, Stamenkovic S N. Conversion of an atomic to a

molecular argon ion and low pressure argon

13. Fan G, Shi H, Wei J, Junna L, Zhiqiang C, Yanzhao X. Experimental Study on Breakdown Time Delay of Hundreds of Nanoseconds Pulse Under Different du/dt for mm Gaps. IEEE Trans Plasma Sci. 2019; 47 (10): 4579 – 4583.
14. Woolsey G A, Ogle *D* B. Statistical time lags in low-pressure SF_6 breakdown. J Appl Phys. 1989; 66 2920.
15. Van Brunt R J, Glahn P V. Anomalous stochastic behavior of partial discharge on aluminum oxide surfaces. J Appl Phys. 1997; 81 840.
16. Kudrle V, LeDuc E, Fitaire M. Breakdown delay times and memory effects in helium at low pressure. J Phys D: Appl. Phys. 1999; 32 16.
17. Dmitry L, Robert R. A, Vladimir I. K. Modified Paschen curves for pulsed breakdown. J Plasma Phys. 2019; 26 064502.
18. Dohnal P, Rubovic P, Kotrik T, Plasil R, Glosík J. Recombination in He/Ar Afterglow Plasma at Low Temperatures. WDS12 Proceedings of Contributed Papers. 2012; Part II: 18–24.
19. Salamov B G, Kasap M, Lebedeva N N. Prebreakdown current behaviour in the ionization cell with a semiconductor cathode. J. Phys. D: Appl Phys. 2000; 33: 2192–2195.

relaxation. Chin Phys B. 2016; 25(1):015204.

20. Barrett S F, Pack D J. Microcontrollers Fundamentals for Engineers and Scientists. Morgan & Claypool Publishers, 1st ed. 2006.
21. Waleed I Y. Study of DC Breakdown Voltage in Low Pressure Argon and Nitrogen Gases for Several Electrode Gap. ANJS. 2017; 20 (1) 89-92.
22. Hassouba M A, Elakshar F F, Garamoon A A. Measurements of the breakdown potentials for different cathode materials in the Townsend discharge. Fizika A. 2002; A 11 (2): 81–90.
23. Yangyang Fu, Peng Z, John P. V, Xinxin W. Electrical breakdown from macro to micro/nano scales: A tutorial and a review of the state of the art. Plasma Res Express. 2020; 2(1): 013001.
24. Vedder J D. An invertible approximation to the normal distribution function. Computational Statistics & Data Analysis. 1993; 16 (1): 119-123.
25. Sarah K T, Sabah N M, Mohammed K K. A Comparative Study on the Electrical Characteristics of Generating Plasma by Using Different Target Sources. Baghdad Sci J. 2018; 15(2): 436-440.
26. Abdulretha S H, Ala FA, Abdalhasen A K. Impedance Characteristics of Pulsed Atmospheric Electrical Discharge in Spherical Plasma Switch. Baghdad Sci J. 2011; 8(2): 630-637.

تأثير زمن التوهج والاطفاء في تيار التفريغ لغاز الارجون تحت ضغط منخفض

احمد يونس اعويد

قسم التقنيات الالكترونية، المعهد التقني الموصل، الجامعة التقنية الشمالية، الموصل ،العراق.

الخلاصة:

تم الاستقصاء تجريبيا عن تأثير زمن التوهج والاطفاء لفولتية تفريغ مربعة في تيار الفريغ لغاز الارجون تحت ضغط واطئ (6-11 mbar). انشئ التفريغ بين قطبين معدنيين دائريين بنصف قطر (7.5 cm) مفصولين افقيا لمسافة (10 cm) ومثبتين عند النهايتين المفتوحتين لا نبوبه اسطوانية زجاجية صلدة. تم اقتراح دالة تتألف من دالتين لكاوس لمواءمة وتفسير الرسوم البيانية لتغير التيار بوضوح. لقد تبين بان الازمنة اللازمة للحصول على اعظم تيار للتفريغ هي (70us) و (60 us) لزمن التوهج والإطفاء على التعاقب. لوحظ ايضا بان تيار التفريغ يهبط الى ادنى قيمة له عندما يكون الزمنان على التوالي اطول من (85 us) و (72 us). علاوة على ذلك تبين ان الفرق اللازم بين الزمنيين للحصول على أعظم تغير في تيار التفريغ او أعظم تيار تفريغ يكون قريب وقابل للمقارنة مع زمن التفريغ للغازات المنشور في البحوث السابقة. هذه المشاهدات العملية يمكن ان يكون لها اهمية في تصميم اجهزة البلازما التي تتطلب هندسة خاصة.

الكلمات المفتاحية: زمن الاطفاء، بلازما الارجون، تيار التفريغ، زمن التوهج، فولتية التفريغ المربعة.