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Mixing and cathode material effects on breakdown voltage of DC Ar glow discharge

Omar. F. Farag*, Magdy. M. Mansour, Naglaa. M. El-Sayed and Mohammed. H. Elghazaly

Physics Department, Faculty of Science, Zagazig University, Egypt

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ABSTRACT

Effects of gas admixture and of cathode material on breakdown voltage of argon in DC electric field in cylindrical discharge tube are investigated experimentally. The results demonstrate that the breakdown voltage increases by increasing He and N_2 percentage in (Ar-He) and (Ar-N_2) gas mixtures, respectively. The lower breakdown voltages are associated with lower work function of the cathode material. Moreover, the breakdown voltage decreases by increasing the effective surface area of the cathode.

Key words: Glow discharge/ Breakdown voltage / Paschen's curves/ Cathode Material.

INTRODUCTION

Dc glow discharges are widely applied for depositing thin polymer and oxide films, for cleaning the surface of materials, voltage stabilizers, etc. therefore, the research into the conditions of the glow discharge breakdown is of considerable interest [1,2].

Electrical breakdown of gases is the transition from an insulator to a conducting state and the minimum voltage at which this transition occurs is called the breakdown voltage V_{br} [3]. As far as it is known, the breakdown curves of the glow discharge are described by Paschen's law $V_{br} = f(Pd)$, i.e. the breakdown voltage depends on the electrode spacing (d) and the gas pressure (P) [4]:

$$V_{br} = \frac{BPd}{Ln\left(APd\right) - Ln\left[Ln\left(1+\gamma^{-1}\right)\right]} \tag{1}$$

where, A and B are constants for a particular gas and γ is the secondary electron emission coefficient of the cathode.

From equation (1) it is clear that, V_{br} of a gas depends only on pressure and gap distance product (Pd) and cathode material [5]. The breakdown voltage also depends on factors such as charged and non-charged particles in the gas, electrode configuration, the surface properties (state and area) of the electrodes and inner radius of discharge tubes. However, these factors are not considered in the Paschen's law and might therefore responsible for the deviation between experimental and theoretical results [6].

This paper reports the results of experimental study of the effects of gas admixing and cathode material on breakdown voltage of argon in DC electric field in cylindrical discharge tube.

MATERIALS AND METHODS

We measured the breakdown curves of the glow discharge in Ar, (Ar-He) and (Ar-N_2) gases within the range of DC voltage lower than 600 V and pressure P = 10^{-2}-1 Torr. We used Pyrex glass discharge tubes with different inner diameters of 13 and 20 and 18 cm in length. The anode was made out of aluminum, while the cathode was made out of three different materials, copper, stainless steel, and aluminum, values of their work function are listed in Table1. The diameter of the electrodes was 5 and 7 cm and the cathode-to-anode separation was fixed at 7 and 10.7 cm.

Table1: Characteristics of the electrode materials used to generate DC glow discharge plasma [7].

Electrode Material	Work Function (eV)
Copper (Cu)	4.65
Stainless steel (Ss)	4.4
Aluminum (Al)	4.17

By means of a gas rotary pump (*Edwards H. vacuum pump, model ED 200*), the discharge system (Pyrex tube) could be evacuated to a base pressure down to 10^{-3} torr. The flow of argon, nitrogen, and helium gases is monitored with mass flow meters whereas pressure in the chamber is recorded by using pirani gauge.

RESULTS AND DISCUSSION

Figure (1) shows Paschen's curves of Ar, at different He and N_2 percentage in (N_2-He) and (N_2-Ar) mixtures under copper electrode. A general remark of these curves is that, all the curves have nearly the same general behavior and obey the standard Paschen's curve. The breakdown voltage, V_{br} , initially decreases with increase in *Pd*, and then begins to increase with *Pd* after going through a minimum value [8].. On the left-hand side of the minimum Paschen's curves, V_{br} decreases fast when increasing *Pd* which can be attributed to the increase in collision frequency, equivalent to an increase in the number of collisions between electrons and neutral atoms or molecules. However, on the right-hand side of the minimum, V_{br} increases slowly with the increase of *Pd*, i.e. the ionization cross-section increases. Therefore, electrons need more energy to breakdown the discharge gap, resulting in an increase of V_{br} [3].

Also it has been found that the breakdown voltage increases by increasing He and N_2 percentage in (N_2-He) and (N_2-Ar) gas mixtures. The increase in breakdown voltage with He addition can be attributed to the higher ionization potential of helium as compared to argon [9]. On the other hand the increase in breakdown voltage with N_2 addition can be explained as follows: N_2 is a molecular gas contains additional electron energy loss channels, such as vibrationally and rotationally excited states and the molecular dissociation [10]. Thus, increasing number of nitrogen atoms on the account of the argon atoms increase the additional electron energy loss channels. This decreasing number of high energy electrons which are mostly responsible for ionization. As a consequence, rate of ionization decreases and breakdown voltage increases.

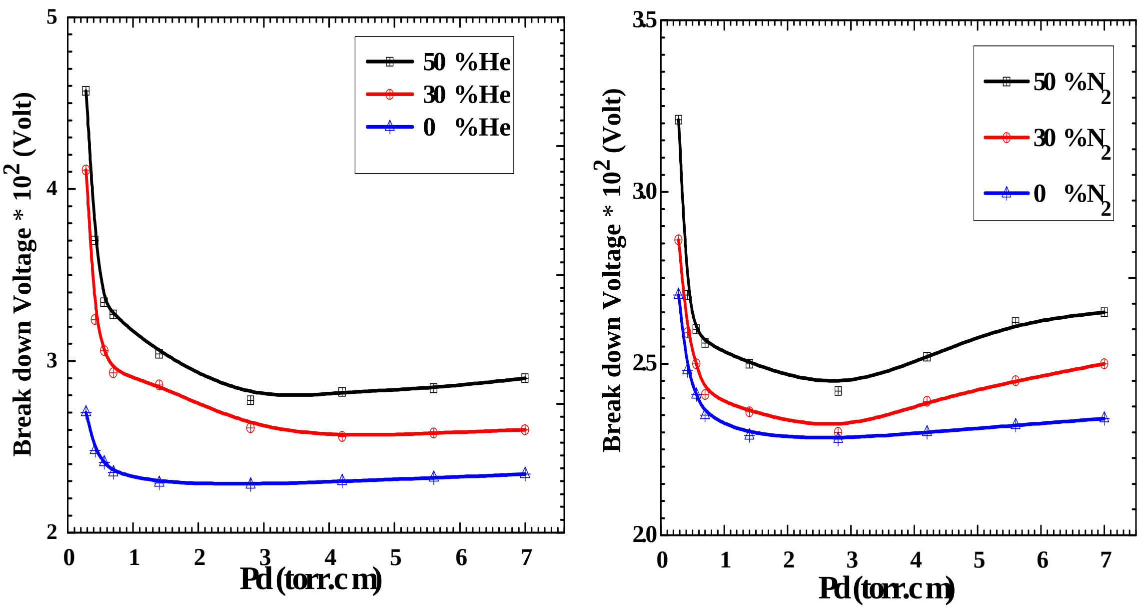

Figure 1: Paschen's curves for Ar, at different He and N_2 percentages.

Figure (2) shows Paschen's curves of Ar under different electrode materials (copper, stainless steel and aluminum). It follows from this figure that for the cathodes with lower secondary electron emission coefficient, γ (copper), the breakdown curve is shifted simultaneously to higher breakdown voltages. Increasing the secondary electron emission coefficient of the cathode surface leads to a shift of the breakdown curve to lower breakdown voltages. This can be explained as follows: increasing secondary electron emission coefficient (decreasing work function) increases number of emitted secondary electrons from cathode surface due to ion impact, which are responsible for the ionization of neutral gas atoms and molecules [11]. As a consequence, rate of ionization increases and breakdown voltage decreases. At the same time the minima of the breakdown curves we measured are on one straight line (at the same *Pd*). This agrees with the results of [1] and [3].

Figure (3) shows Paschen's curves of Ar obtained for a pair of copper cathodes with different effective surface areas. It follows from this figure that for the cathode with lower effective surface area, the breakdown curve is shifted simultaneously to higher breakdown voltages. This can be explained as follows: as the effective surface area of the electrode is decreased, fewer electrons are available from the surface and the breakdown voltage increases. Also figure (3) refutes the assumption that the breakdown voltage is influenced by the work function of the electrode material alone. This result is similar to that reported by Ledernez et al. [12].

Figure (4) presents two breakdown curves that we measured in discharge tubes with different radius. The interelectrode gap was chosen such that the ratio of the interelectrode gap to the tube radius remained constant *d/R* = 1.07. It is seen from the figure that in this case the breakdown curves actually superimpose onto each other. The discharges with geometrically similar electrode dimensions and interelectrode gaps possess the same breakdown voltage [1].

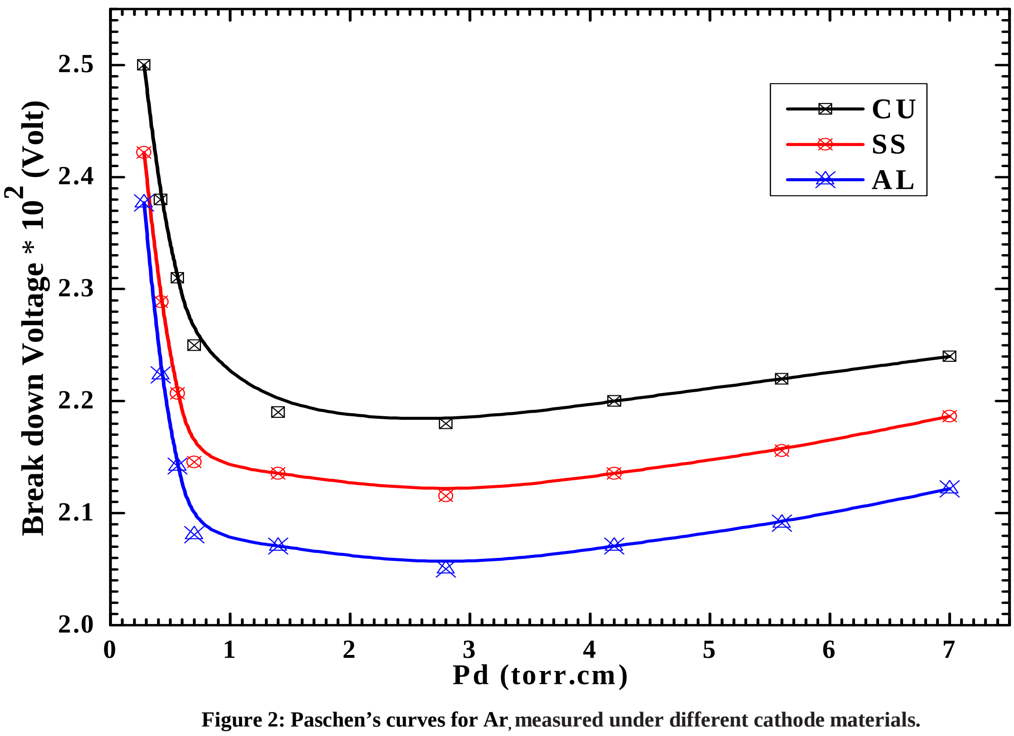

Figure 2: Paschen's curves for Ar, measured under different cathode materials.

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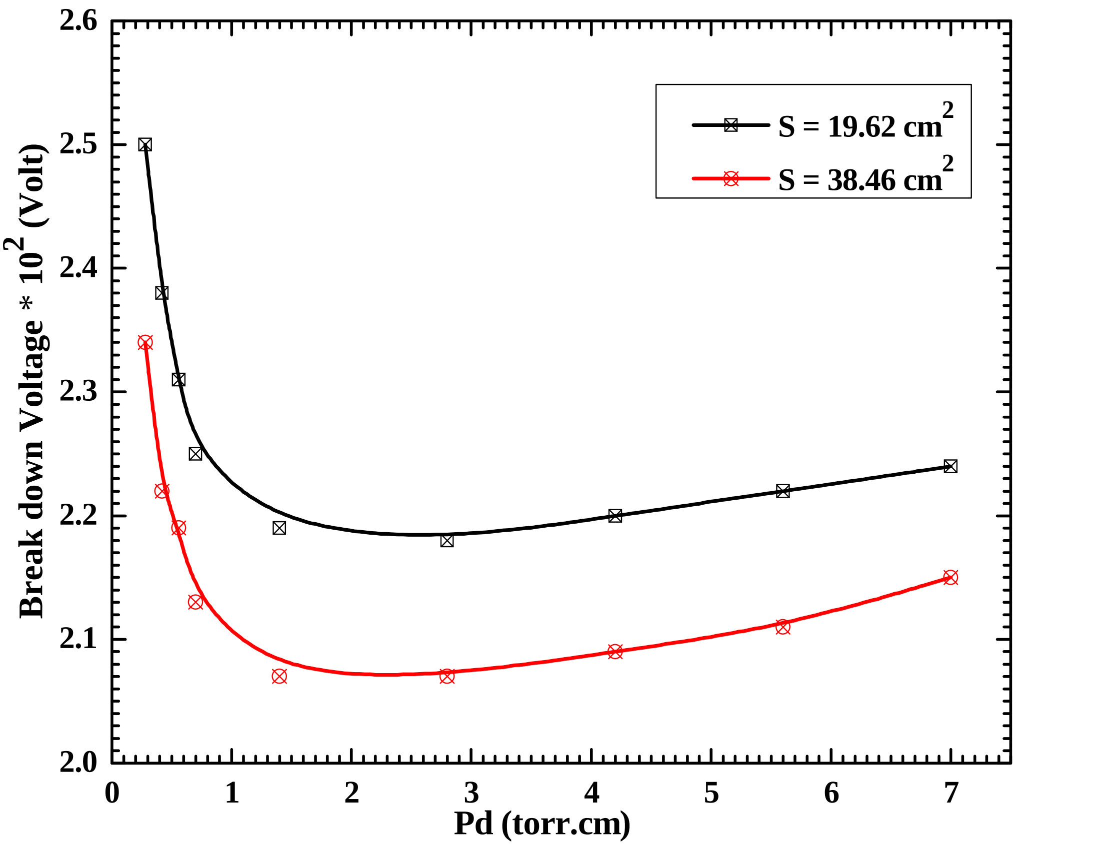

Figure 3: Paschen's curves for a pair of copper electrodes with two different effective surface areas S = 19.62 and 38.46 cm^2 for an inter-electrode distance 7 cm.

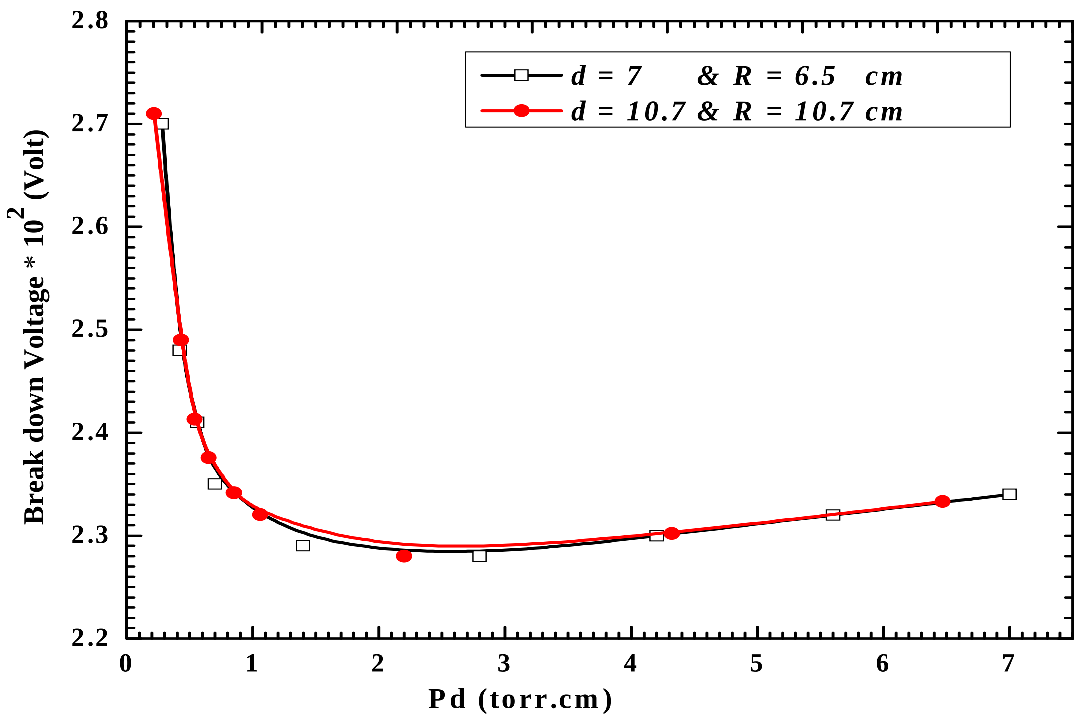

Figure 4: Breakdown curves in argon for copper electrode at *d/R* = 1.07.

CONCLUSION

The present study shows experimentally that breakdown voltage of DC Ar glow discharge can be influenced considerably by admixing of He or N_2 gas and work function of the cathode material. The main results obtained here are summarized as follows:

(1) The addition of He or N_2 to Ar discharge causes an increase in the values of breakdown voltage of the discharge.
(2) The breakdown voltage increased with the increase in the work function of the cathode materials.
(3) As the effective surface area of the cathode is increased, the breakdown voltage decreases.
(4) The discharges with geometrically similar electrode dimensions and interelectrode gaps possess the same breakdown voltage.

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