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Investigation of gas breakdown in cylindrical inertial electrostatic confinement device with inner cage anode

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ABSTRACT

The gas breakdown in the Inertial Electrostatic Confinement (IEC) device has been studied by DC discharge of Nitrogen gas in the pressure range between 0.03 Torr and 0.7 Torr. Paschen curves and Townsend coefficients are obtained in a cylindrical system with inner anode in shape of rods and the outer grid cathode. The breakdown occurs and the plasma is formed at the center of the electrodes. Townsend coefficients are calculated for anode transparencies of 84%, 92%, and 96% (24, 12, and 6 rods respectively). On the left hand side of Paschen curves, the high transparency has a higher breakdown voltage. More electrons are allowed to pass the anode. So, the collisions increase, leading to a slight increment of the first Townsend coefficient (α) decreasing of the second Townsend coefficient (γ) while the ionization efficiency (η) is not affected. For high reduced electric field E/P, i.e. a high electric field with low pressure, the probability of ionizing collision events decreases. This causes a decrement of α while γ is raised because the ions' energy is not exhausted in collisions at the center. The coefficients α and γ are working in harmony to balance the rates of electrons generated in gas ionization so that the relation between the two coefficients is satisfied.

1. Introduction

Electric discharge is a process in which the non-conducting gas is transformed into conducting one by increasing the electron-neutral ionizing collisions when applying a sufficient electric field to occur of gas breakdown. Paschen curves are a criterion of the breakdown voltage V_b as a function of a pressure of gas P and the distance between the electrodes d [1,2]. The breakdown voltage depends on Pd product, as well as the distribution of the electric field [3–5]. For low values of Pd, the electrode separation is shorter than the mean free path so, most of the electrons will be lost to the walls before reaching the ionization and a higher electric field is needed to generate the breakdown [1].

The discharge occurred in the left hand side of Paschen curve using Nitrogen gas and the minimum breakdown voltage was 325 V at 1.2 Torr cm [6]. In case of inner mesh anode, short gap between the electrodes, and low gas pressure, the electrons can pass the distance gap and ionize the gas behind the mesh electrode, creating the virtual or pseudo discharge on contrary, in the classical glow discharge [7–9]. The minimum voltage for air was reduced to about 270 V instead of 311 V [9]. It was found that the gas gain is higher for thicker wire diameter in the wire chamber experiment for the low pressure regime and for the same applied voltage [10]. For discharge tubes of length greater than the tube radius, the breakdown curves are shifted to lower pressure and to higher breakdown voltage so the conventional Paschen law seems valid only for short discharge tubes where $L \leq R$ [11].

The reduced Townsend coefficient (α/P) was studied for different gases. Electric discharge of helium as well as other gases depends mainly on the reduced electric field E/P [1,12]. The secondary coefficient γ increases with increasing the reduced electric field. At high pressure, the secondary coefficient decreases. The reduced electric field and gas type can affect the ionization efficiency η but the presence of filament electrode doesn't change it [1,13]. The minimum $1/\eta$ expresses the minimum breakdown voltage. Electron makes several ionizations because of passing in the electric field to achieve collision with neutral gas [14].

The inertial electrostatic confinement discharge has been investigated for spherical geometries and different gas types [15]. The breakdown voltage decreased with pressure range from 0.5 to 3 mbar in cylindrical discharge geometry [7]. Gas pressure and transparency have a major effect on the discharge for planner and

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spherical geometries [9,16]. The minimum breakdown voltage increased when the ratio of the outer to inner electrode radii increased in a cylindrical geometry [17]. A transparent sphere needed a lower breakdown voltage than a solid sphere and secondary ionization was more important than the first ionization [18].

For micro-scale discharge, a deviated gas breakdown expression had been derived [19,20]. Space charge affects the electron multiplication in micro gaps the calculations of the ionization coefficients [21,22] with consideration of the field emission mechanism [21,23]. It creates a field opposite to the original external one to enhance the motion of positive and negative charges. When the space charge field is equal to the external field, the breakdown will grow quickly as a result of several ionizations [22,24].

The aim of the present work is to study the impact of the anode transparency on the electric discharge in cylindrical geometry. It is to clarify how the anode transparency can affect the number of electrons that pass through the anode hence, affecting the discharge. This work is concerned with studying the electric breakdown and Paschen curve for the coaxial system of outer grid cathode and cylindrical inner cage anode. It will show how Paschen curves, Townsend coefficients, and the ionization efficiency may be affected by the anode transparency.

2. Experimental setup

The discharge system consists of two electrodes which are fixed concentrically inside cylindrical glass tube as shown in Fig. 1. The outer electrode is the cylindrical grid cathode of 5 cm radius. The inner anode consists of several rods (6, 12, or 24 rods) each of them is 1.9 mm diameter. These rods are distributed in a circular circumference of 4.6 cm radius. These rods are connected electrically with each other by an isolated thin copper ring. The anode transparencies are 84%, 92% and 96%for 24, 12, and 6 rods respectively. The least distance of the gap between cathode grid and anode rods is 4 mm. The glass tube is evacuated using rotary pump and it is closed in both sides with two insulator flanges. Nitrogen gas is used as the working gas.

3. Experimental results

Fig. 2 shows the cross section of cylindrical IEC. When the gas pressure is low enough so that the mean free path is longer than the inter-electrode distance, then the electrons release from the cathode and it will pass the anode rods. Electrons which have a sufficient energy will collide the neutral gas atoms and ionize them leading to breakdown, forming the plasma at the center of coaxial cylinder.

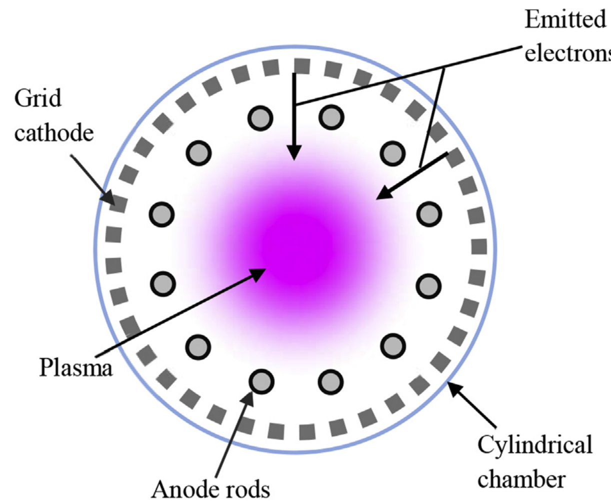

Fig. 2. Cross section of cylindrical IEC.

Many processes take place during the electric discharge such as elastic collision, excitation, and ionization of neutral gas. The electric field accelerates the electrons to make ionization; so, the electric field is an important factor. Also, the mean free path that the electron moves on between two successive collisions is inversely proportional to the gas pressure. So, E/P is a significant factor in the study of behavior of charged particles. Increasing the field E or the gas pressure P is controlling the breakdown process [25].

3.1. Paschen curves

Paschen curves are a criterion of the voltage required for gas breakdown as related to the inter-electrode distance and the gas pressure. Paschen's law is the relation that describes the breakdown process through the relation between the breakdown voltage V_b and the product of the gas pressure ‘P’ times the inter-electrode

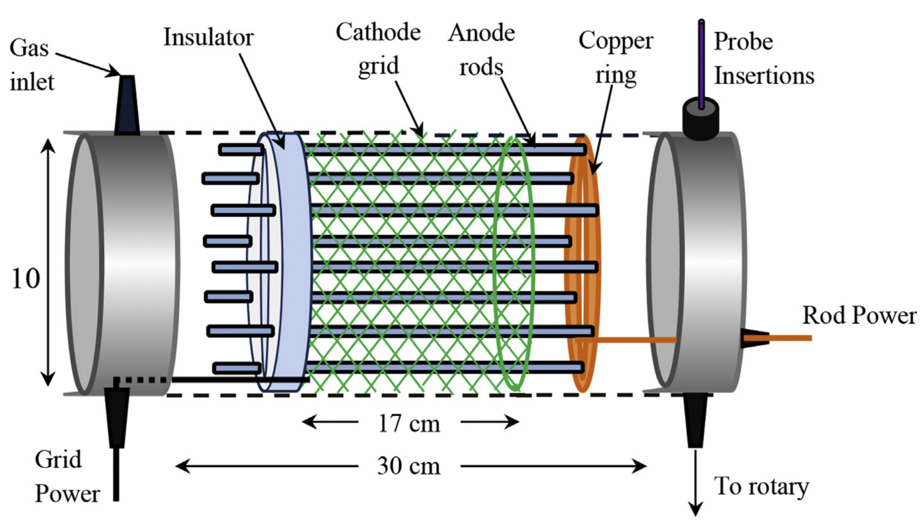

Fig. 1. Configuration of IEC device.