ABSTRACT

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A cylindrical coaxial DC glow discharge system has been designed for the first time, in order to generate free plasma. The system consists of two cylindrical coaxial electrodes made of stainless steel. The outer electrode is 15 cm length and 5 cm diameter, while the inner one is 10 cm length and 4 cm diameter and it is a grid. The outer cylinder is the discharge vessel. The two cylindrical electrodes are isolated from each other by two glass discs. Helium and nitrogen gases were used as working gases. A DC power supply of 1 kV and 100 mA was used to operate the discharge. The discharge vessel is evacuated by gas ballast rotary pump. Then the system was filled with helium or nitrogen gases. The pressure is controlled by dynamic continuous flow through a needle valve.

There are three main studies carried out in this work. In the first one the outer cylinder of the cylindrical coaxial discharge system (discharge vessel) was positively biased, while the inner grid cylinder was negatively biased. Helium was used as a working gas. The distance between the two coaxial cylindrical electrodes was fixed at 5 mm, it is comparable to the mean free path of electrons. So, plasma was formed inside the inner grid cylinder. The positive ions will move toward the cathode and passing through the grid inward toward the center. A virtual anode was formed around the cylindrical center by the convergence of ions.

I-V characteristic curves of the coaxial DC discharge showed that it operates in a region similar to abnormal glow discharge. The breakdown voltage decreased with increasing working gas pressure, which is similar to the left hand side of Paschen's curve. The radial distributions of plasma potential and electric field was studied. Location of the virtual anode was found at 2 mm and 8 mm from the center, at discharge current 10 and 20 mA respectively.

Electron energy distribution function EEDF was studied for the discharge at different radial positions, at (P = 3 mbar and I = 10, 20 mA). Results of EEDF indicated that there are two groups of electrons , high energy group and low energy group, both have non-Maxwellian distribution, at radial interval from the grid cathode to R = 5 mm from the center. While one group of electrons with Maxwellian distribution was detected, at radial interval from R = 5 mm up to the center i.e. at R = 0 mm.

Single and double probes, were used to estimate the variation of the electron temperature T_e with the radial position, at constant helium pressure 3 mbar and two discharge currents 10, 20 mA. Fair agreement was obtained between electron temperatures measured by single and double probe. Values of electron temperatures varied in the range from 1.4 eV to 2.6 eV at discharge current of 10 mA. While they varied from 1.7 eV to 3 eV at discharge current of 20 mA. The electron temperature had maximum value near the grid cathode and it decreased as the electrons move radially toward the center.

Plasma density for DC virtual anode cylindrical coaxial discharge, using helium gas, was determined at different radial positions by three methods, single probe, double probe and from potential using Poisson equation. The same behavior was obtained from the three methods. Plasma ion density increased as moving from the grid cathode toward the center until it reaches a certain point, approximately the point at which the virtual anode was formed. After that it decreased slightly with moving toward the center, and at last plasma ion density increased gradually until it reaches center of the system.

Plasma density measured by the single probe varied from the grid toward the center in the range 2.3×10^{15} m^{-3} to 7.8×10^{15} m^{-3}. For double probe, radial plasma density varied from 1.6×10^{16} m^{-3} to 4.3×10^{16} m^{-3}. Calculated plasma density varied radially in the range 4×10^{13} m^{-3} to 6×10^{14} m^{-3}. Comparison between values of plasma density as a function of the radial position, obtained by the different methods showed that, plasma density values calculated using Poisson equation were different and less than that obtained using single and double probes. Also plasma density measured by the single probe was less than that obtained by the double probe.

In the second part of the study the outer cylinder of the cylindrical coaxial discharge system was negatively biased, and the inner grid cylinder was positively biased. Nitrogen was used as a working gas. Also plasma was formed inside the inner grid cylinder. High voltage is applied between the two electrodes. The electron beam which ejected from the cathode, passes through the mesh and a virtual cathode is formed at a certain position that reflects a certain part of the electron beam.

The I-V characteristic curves of the DC coaxial virtual cathode discharge showed that it operates in the region similar to that in the normal glow discharge region. The discharge voltage (the voltage at which the normal glow region starts) as a function of the gas pressure was studied, and it decreased with increasing the working gas pressure, similar to that in the left hand side of Paschen's curve.

The potential and electric field distributions were measured radially at constant pressure 3 mbar and three discharge currents 2, 4 and 6 mA. The location of the virtual cathode was found at 2.5, 3 and 4 mm from the center at the discharge currents 2, 4 and 6 mA respectively. The radial distribution of the electron temperature, from the grid anode toward the center, was obtained for the DC coaxial virtual cathode discharge, using single and double probes, at the same conditions (P = 3 mbar and I = 2, 4, 6 mA).

Electron energy distribution function EEDF was investigated at different radial positions, at the same previous conditions of pressure and discharge currents. Results of EEDF showed that it consisted of one group of electrons with Maxwellian distribution at all radial positions from the grid anode until the center.

The radial distribution of the electron temperature T_e was estimated, for the discharge at the same previous conditions, using single and double probes. Results showed that, for the single probe, the electron temperature varied from 2 eV to 3.6 eV, while it varied from 1.6 eV to 3.22 eV for the double probe. The electron temperature increased with increasing the discharge current, and radial position away from the center.

Plasma density for the DC coaxial virtual cathode discharge, using nitrogen gas, was determined experimentally using electric probe techniques, and estimated theoretically by Poisson equation, at different radial positions. Plasma density, measured by the single probe, varied radially in the range of 7×10^{13} m^{-3} to 5.9×10^{15} m^{-3} at range of discharge currents from 2 mA to 6 mA. While plasma density, measured using double probe, varied radially from 1.9×10^{14} m^{-3} (at discharge current 2 mA) to 3.9×10^{16} m^{-3} (at discharge current 6 mA). Variation of the calculated plasma density, from Poisson equation, with the radial positions was in the range of 3.58×10^{13} m^{-3} (at discharge current 2 mA) to 2.32×10^{15} m^{-3} (at discharge current 6 mA). It has been found that the plasma density obtained by the three methods increased with increasing the discharge current at constant radial position. The plasma density, obtained by the three methods, was slightly increased as the electrons move from the grid anode toward the center until the virtual cathode starts to form. The plasma density was nearly constant when moving radially inside the virtual cathode region. At last it increased gradually until reached the center of the system (at R = 0).

The third part of this work was surface modification using plasma for treatment, of polyester samples, in order to improve its surface wettability. Polymer films, for converting and laminating industries, are commonly treated by glow discharge to enhance their surface energies leading to improvement in wettability, printability and adhesion.

The plasma system used in that treatment was cylindrical coaxial virtual cathode DC glow discharge. Nitrogen gas was used as a working gas. The variable in the experimental conditions used in this treatment was nitrogen gas pressure which varies in the range of 1–5 mbar, discharge current from 2 mA to 6 mA and plasma duration time up to 50 minutes. The polyester textile sample was rectangle 10 cm of length and 4 cm of width.

Results showed that there is no significant changes occurred in thickness and mechanical behavior for polyester samples, due to the plasma treatment, at different conditions. The wettability of the polyester samples was decreased with increasing radial position away from the center. The wettability of the polyester samples increased with increasing both the nitrogen pressure and the exposure time. Discharge current variation during the treatment showed no effect on the wettability of the polyester samples.

A photographic image and IR spectrum of the treated polyester samples, at different conditions, confirmed that the wettability of these polyester samples increased with increasing both the nitrogen pressure and the exposure time. This was due to the formation of new construction of the textile component. It has been found that the optimum conditions for treatment were when polyester samples were placed at the center of the system R = 0, at nitrogen pressure of 5 mbar, discharge current of 4 mA and duration time of 30 minutes.