Diagnostic of Plasma Discharge Parameters in Helium Filled Dielectric Barrier Discharge

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Abstract: This paper reports the discharge parameter analysis of helium filled parallel plate dielectric barrier discharge (DBD) configuration. The investigation has been performed using sinusoidal supply for the generation of discharges where two current pulses have been observed with different polarities in one period. A homogeneous type of discharge has been observed for different operating conditions in helium DBD. The discharge properties are characterized by the electrical measurements and spectroscopic analysis. The electrical measurements give reliable discharge information in the DBD system. The electron density and electron temperature within the microdischarges are estimated using line-ratio technique from the identified neutral helium spectral lines. The estimated electron density from the experimental results has also been verified by the plasma simulation.

Introduction:

Dielectric barrier discharge (DBD) is an effective method for generating low temperature plasma at atmospheric pressure. Recently, much attention has been paid to dielectric barrier discharge (DBD) due to its numerous potential industrial applications [1]. These types of plasma discharges are characterized by the presence of at least one insulating layer in contact with the discharge between two planar or cylindrical electrodes connected to an ac or pulse power supply [2]. The main advantage of such discharges is that non-equilibrium and non-thermal plasma conditions in atmospheric-pressure gases can be established in an economic and reliable way. The most DBDs operated at about atmospheric pressure shows breakdown in large number of independent current filaments, when specific voltage is applied to the electrodes. Besides the filamentary behaviour, the discharge can also operate in homogeneous or diffused mode [3].

In the present work a dielectric barrier discharge using sinusoidal waveform at different pressures is studied to understand the uniform mode operation of the discharge. Electrical measurements and spectroscopic analysis are also performed to characterize the plasma discharge. The plasma parameters of DBDs such as electron plasma temperature and electron plasma density using the observed neutral helium visible spectra and collisional-radiative line-ratio technique are reported.

Experimental Set-up:

The DBD geometry of the discharge consists of two parallel plate electrodes which are covered by the dielectric barriers made of quartz discs. Both the electrodes are made of copper of 3 mm thickness and 18 mm radius while the quartz discs are 1 mm thick and 20 mm in radius. The space between the electrodes has been fixed of 2mm. The DBD cell has been mounted inside the ultra high vacuum chamber. At room temperature, the helium gas of 99.9% purity (BOC Gases) has been filled in the DBD cell. The complete experimental set-up is shown in Fig. 1. A sinusoidal voltage is applied to the discharge electrodes for the generation of plasma discharge, and the source frequency is kept at 34.5 kHz. The total current and applied voltage waveforms are visualized by means of a four-channel digital oscilloscope (Tektronics DPO 4054). The oscilloscope is interfaced with a personal computer for real time analysis and recording the voltage and current waveforms. An ocean optics visible spectrometer (HR4000) was also interfaced with the system and the personal computer to analyze the emission lines of the helium spectra. This spectrometer uses grating 300 lines/mm and having spectrum bandwidth 2000-11000 Å with the spectral resolution ~ 0.75 nm.

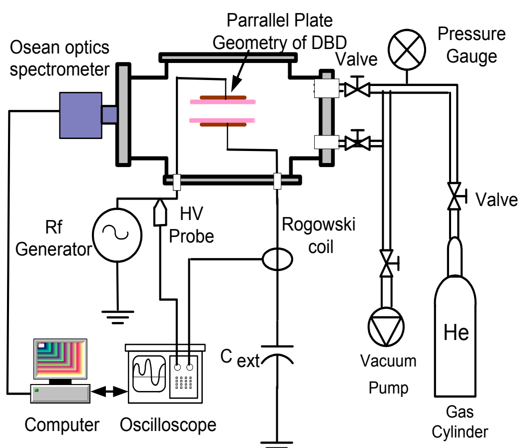

Figure 1. Experimental Setup

Results and discussion:

The electrical behavior of the discharge has been characterized by measuring the applied voltage and the discharge current. In the experiment the voltage applied to the upper electrode has been manually increased very slowly. When the applied voltage rose to a certain value V_{bd} (breakdown voltage), the discharge began with some filaments distributed on the dielectric wall. When the applied voltage is increased further, the number of filaments increases and finally gets diffused. Here Fig. 2(a) shows low voltage discharge with some filaments whereas Fig. 2(b) shows the diffused structures of the filaments. For the electrical discharge characterization in the DBD discharge, the equivalent circuit model [2] is used.

The obtained internal temporal dynamic parameters at 100 mbar operating pressure is obtained and are shown in Fig. 3, which shows the waveforms indicating the temporal behaviour of total applied voltage $V_a(t)$, total external current $I_{tc}(t)$, and estimated parameters specially memory voltage $V_m(t)$, gas gap voltage $V_g(t)$, dielectric barrier voltage $V_d(t)$, the DBDs current $I_{dbd}(t)$ and conduction current $I_{dis}(t)$. To estimate these parameters in the equivalent electrical circuit model the gap capacitance C_g (11.30 pf) and dielectric barrier capacitance C_d (20.48 pF) are used as input parameters and are obtained from the geometry of the configuration.

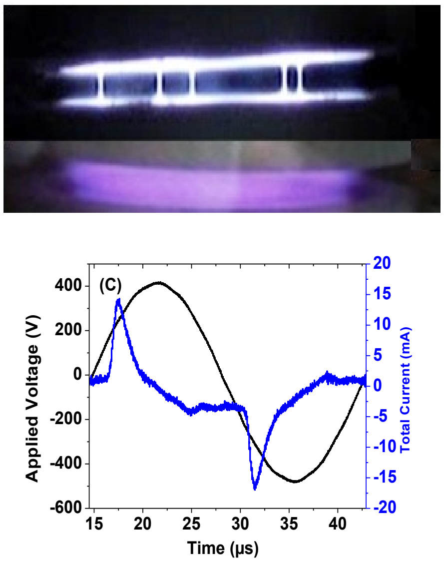

Figure 2.(a)Filamentary and Homogeneous discharge,(b) I-V Characteristic

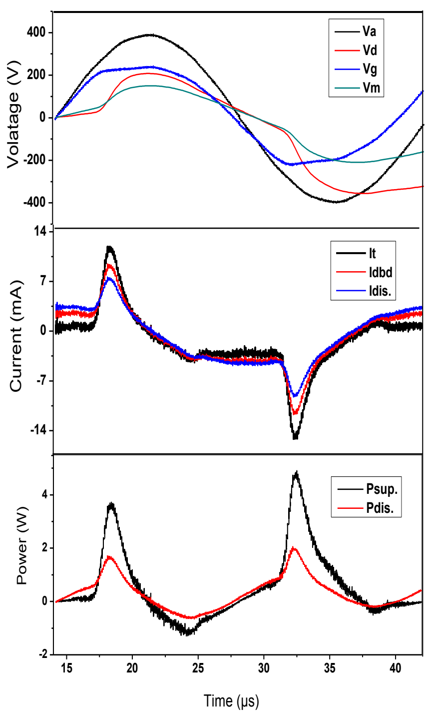

Figure 3 Experimental waveforms of dynamic processes occurring in gap (gas: Helium at f = 34.5 kHz) for the Parallel plate DBD Geometry. at 100 mbar.

Typical spectrum obtained by the visible spectrometer from the used DBD at 100 mbar working pressure and 1000V applied voltage is shown in Fig. 4. A large number of neutral helium line emissions –like, He I 3888.6 Å (2^3S-3^3P^o), He I 4921.9 Å (2^1P^o-4^1D), He I 5015.6 Å (2^1S-3^1P^o), He I 5875.6 Å (2^3P^o-3^3D), He I 6678.1 Å (2^1P-3^1D), He I 7065.1 Å (2^3P^o-3^3S), and He I 7281.3 Å (2^1P^o-3^1S) etc are observed from the plasma discharge. To estimate the electron plasma temperature and electron plasma density well-known line-ratio technique is used [4]. We have derived spectral line intensity ratios using CR-model from the ADAS code [5]. The line ratios that are sensitive to one of the quantities (either temperature or density) and insensitive to other quantity are useful to determine the required basic plasma parameters N_e and T_e. By using density sensitive singlet-singlet line pair 6678.1 Å (2^1P-3^1D)/ 7281.3Å(2^1P-3^1S), we estimated N_e = (3.5±1.5) x10^{11} cm^{-3} and by temperature sensitive singlet–triplet line pair of intensity ratio 7281.3Å (2^1P-3^1S)/ 7065.1Å (2^3P-3^3S) at 100 mbar working pressure we obtained T_e = (6.5±0.5) eV. The existence of plasma density ~ 10^{11} cm^{-3} is an indication for larger existence of metastable states [6].

Furthermore the 2D object-oriented particle in cell code OOPIC Pro (Tech-X Corp., USA) [7] has been used to study the electrical as well as the kinetic behavior of the DBD and the density estimation is found nearly equal to the estimated value.

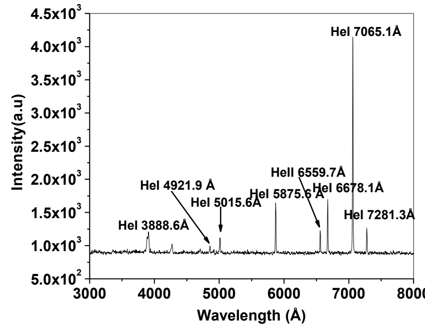

Figure 4. (a) Helium neutral lines at working pressure 100mbar, applied voltage 1000V and at frequency 34.5 kHz.

Conclusion:

The homogeneous type of discharge has been observed at two different gas pressures 100mbar and 500mbar at a fixed frequency 34.5 kHz in parallel plate DBD cell filled with helium gas. Two discharges are generated per single voltage cycle. The electron plasma temperatures and electron plasma density obtained for present VD configuration at 100mbar gas pressure are typically (6.5±0.5) eV and (3.5±1.5) $x10^{11}cm^{-3}$ respectively. The existence of such density and temperature in this source is useful for existence of higher metastable states which needs to be further investigated. The electron plasma density estimation is found nearly equal to the estimated value.

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