21PB-106P

Investigation of Heating Mode Transition in Atmospheric Pressure Dielectric Barrier Discharges Using a Particle-in-Cell Simulation

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During the last decade, a number of applications were introduced using micro atmospheric pressure plasmas such as vacuum ultraviolet lamps, plasma displays, surface treatment, and bio-medical devices. Among them, a dielectric barrier discharge (DBD) is widely used as the simplest device which can sustain normal or abnormal glow discharge under one millimeter gap size. In this study, a one-dimensional particle-in-cell (PIC) simulation was utilized to understand the discharge characteristics of a planar micro DBD with the variation of driving frequency from 13.56 MHz to 600 MHz. Transition of two different heating modes (α and γ modes) and the change of electron energy distribution functions (EEDFs) were investigated for both the argon and the helium plasma. The sheath heating by secondary electron emissions increases the number of hot electrons coming into the bulk-sheath boundary and the EEDF at the center shows a bi-Maxwellian profile in γ mode. On the other hand, Ohmic heating increases a temperature of the warm electron group in α mode, and the increment of driving frequency changes the number ratio of two electron groups through the relationship between the energy relaxation time and the driving period. Therefore, it is possible to control the interactions between plasmas and neutral gas for the generation of preferable radicals in the given device by the variation of driving frequency through the change of heating mode. The same phenomena were also investigated with the change of gap distance from the precedent experiment.

1. Introduction

Atmospheric pressure plasma has long been an area of significant interest for a large number of applications such as surface modification and materials processing, thin film deposition, water purification and biomedical. Moreover, advanced micro-processing technology rapidly developed atmospheric micro plasma technology such as plasma display panels, micro-fabrication using micro discharge devices in silicon, and others using dielectric barrier discharge (DBD) structures, due to a great advantage of stability and uniformity. It is well-known that three fundamental DBD modes can be classified: the Townsend mode, the filamentary mode and the uniform glow discharge mode. The Townsend mode is characterized by very low current density and maximum radiation intensity, observed near the anode without plasma properties. A filamentary discharge has lots of narrow conducting plasma channels which form patterns between the electrodes. Recently, the channel radius of plasma is an important parameter for surface irradiation. Larger radius plasma channel enables to improve surface treatment quality. In the glow discharge mode, which also known as uniform glow discharge mode, can be heated by high frequency external (input) voltage (V_{in}). The maximum ultraviolet radiation flux can be generated by the alpha process and the gamma process. The local electric field in the sheath is dominated by the space charge.

2. The simulation condition

A one-dimensional particle-in-cell simulation code XPDP1 with Monte Carlo Collisions (MCC) was used for this study. This simulation code is made by the Plasma Theory and Simulation Group in UC Berkeley [1]. In this simulation code, there are no assumptions on the distribution functions [2]. It uses time dependent phenomena and compares with theoretical estimates from radio frequencies to ultra-high frequency in DBD plasmas across a range of controllable input parameters.

Peak driving voltage (V_{in}) of 380V and an RF frequency ($f = \omega/2\pi$) in the range $13.56 < f <$ 600MHz are used for this simulation as shown in Fig. 1.

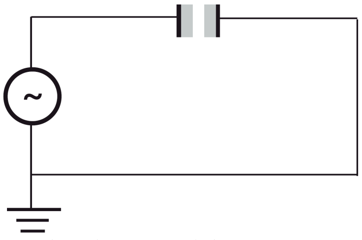

Fig. 1. Schematic Diagram of the system. RF sinusoidal voltage is applied to the anode, and the cathode is grounded.

The DBD plasma source used in this simulation consists of dielectric layers with 10 μm at each planar electrode, and two planar electrodes separated by a gap distance (L) of 80 μm, where the current path is formed for discharge initiation [3]. The effective electrode surface area (A) which is set for calculated external current is 1e-4 m^2. The gas considered in this investigation is pure helium or argon, which is the simplest gas to model a uniform glow discharge at atmospheric pressure [4]. The breakdown voltages using noble gas are low at RF frequency [5] at atmospheric pressure compared with discharges using other gas species. The secondary electron emission coefficient is set to 0.1 at the dielectric surfaces for closing helium ions on this simulation.

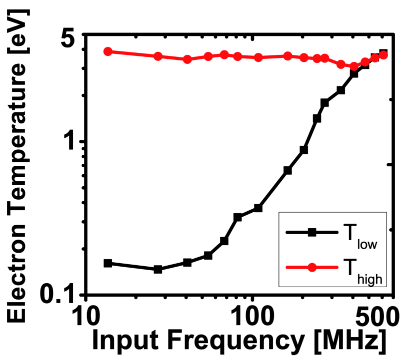

Fig. 2. plot of electron temperature for the low energy (T_{low}) and high energy parts (T_{high}). Both (T_{low}) and T_{high} are based on two-temperature EEPF. However, If $T_{low} = T_{high}$, These EEPFs are Maxwellian distribution.

3. The Result

Electron energy probability functions for the low energy and high energy parts with helium gas are measure at the center of the gap, which shows that anisotropic temperature of high energy part ($5\text{ eV} < \varepsilon < 19.8\text{ eV}$) becomes equal to isotropic temperature ($5\text{eV} > \varepsilon$) when the frequency is above 406.8 MHz. Fig. 1 shows electron temperatures for low energy part (T_{low}) and high energy part (T_{high}). The lowest L_{ow} is observed about 0.168 V at near 40.68 MHz. During T_{low} has continuous increment, T_{high} decreases slightly and rebounds at 339 MHz.

As can be seen in Fig. 2, Electron energy probability functions (EEPFs) at the center have two-temperature (bi-Maxwellian) distribution at low frequency, but it becomes Maxwellian in the condition of driving frequency larger than 400 MHz. The maximum value of energy relaxation mean free path is about 100 μm when electron kinetic energy is 19.8 eV. It shows that this mean free path is greater than both gap length and plasma depth.

Time-varied Electrical field in plasma (E_p) can accelerate electron drift motion which mainly loses energy through elastic collisions with neutral species in low energy part. This process makes Ohmic heating which mainly increases with square of driving frequency. However, low energy electrons seem to be kept by E_p. It shows that EEPF is a function of position according to anode potential fall and non-local kinetic.

References

[1] J. P. Verboncoeur, M. V. Alves, V. Vahedi, and C. K.Birdsall, *J. Comput. Phys.* **104**, 321 (1993).
[2] V. Vahedi, G. Di Peso, C. K. Birdsall, M A Lieberman and T D Rognlien, *Plasma Sources Science and Technology* **2**, 4 (1993).
[3] U. Kogelschatz, *Plasma Chemistry and Plasma Processing* **23**, 1 (2003).
[4] F. Massines, R. Messaoudi, and C. Mayoux, *Plasmas Processes and Polymers* **3**, 43 (1998).
[5] M. Moravej, X. Yang, G. R. Nowling, J. P. Chang, R. F. Hicks, and S. E. Babayan, *J. Appl. Phys.* **96**, 7011 (2004).