Instability and Striations in Water Vapor Discharge

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Abstract: This study characterized a moderate-pressure DC-driven glow discharge in pure water vapor. Voltage-current characteristics are measured over a broad range of discharge currents, and oscillations in current and voltage are found. An ionization wave traveling from cathode to anode, as well as striations in the positive column that disappear and reappear, are observed to be in sync with the current oscillations.

1. Introduction

Nonthermal plasma (NTP) discharges in the presence of water are essential in a wide range of research areas, including environmental, biomedical, and catalysis applications [1]. The primary reason for this broad impact is the production of reactive oxidizing species from NTP discharges in a humid medium, particularly OH, H_2O_2, and O_3, which play active roles in physicochemical processes. In this investigation, we studied the characteristics of a moderate-pressure DC-driven water vapor discharge with the intention of measuring spatial OH and H_2O_2 species profiles at steady-state conditions. However, the experiments showed some very unique and unexpected behavior over a wide range of discharge current conditions, which included not only a striated positive column but also transient ionization waves. The phenomenon of striations has been studied for different gases, power supplies, and configurations [2]. They are driven by ion-acoustic waves, vibration kinetics, and Soret and Dufour effects of electron and electron energy. Due to the wide regimes in which striations appear and the complexity of the physics involved, understanding of this phenomenon is limited and to our best knowledge striations in water vapor has not been reported in the past.

2. Experimental Method

The plasma cell consists of two solid cylindrical copper electrodes housed inside a cylindrical glass tube. A Teflon insulation coating is provided on the outer periphery of the electrodes. The inter-electrode separation is typically maintained at 5 cm. The pressure inside the plasma chamber is varied utilizing a two-stage mechanical vacuum pump and is measured with a digital pressure gauge. The discharge cell is vacuumed to ~ 0.05 Torr, and then liquid water is injected into the cell, which flash vaporizes. Liquid water is injected till a desired pressure of 8 Torr is achieved in the discharge cell. An oscilloscope was used to measure current waveforms and to trigger a high-speed ICCD camera (Stanford Computer Optics, 4Picos). The high-speed camera was used to take images of the plasma structure throughout the current waveform period, characterizing the change of the plasma structure over time.

3. Results and Discussion

Low amplitude oscillations in current and voltage were observed despite the plasma discharge operating in normal glow mode. The oscillations' amplitude was higher at higher average discharge currents, ranging from ~ 6 to 15 mA. These oscillatory waveforms got distorted as the discharge current increased. FFT of the current signals reveals the presence of multiple frequencies harmonics of each other. The oscillation frequency is found to decrease with increasing discharge current. A striated column appears at a discharge current of ~4.5 mA. High-speed imaging revealed the strata to sequentially disappear and reappear in sync with the current oscillations. The number of strata in the striations also decreased with increasing discharge current, which is typical of other observed striations in DC systems. An ionization wave was also observed traveling from cathode to anode at 6 to 11 km/s in sync with the current oscillations. The brightness of this wave increased with the discharge current while the velocity decreased with the same.

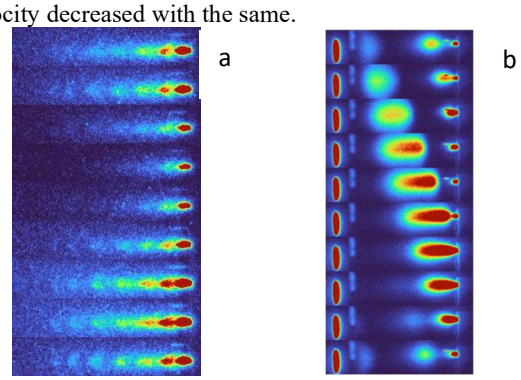

Figure 1: Temporal evolution of a) positive column I_d = 8 mA, V_d = 1.02 kV b) ionization wave I_d = 14 mA, V_d = 0.98 kV

4. Conclusion

Disappearing and reappearing striations, current and voltage oscillations, and a moving ionization wave front were all observed in a medium pressure DC driven plasma discharge. It is likely that the ionization wave is due to the negative ions, as the wave velocities were found to be within roughly a factor of 2 of the drift velocities of H^-, O^-, O_3^-, and OH^- ions.

Acknowledgments

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References

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