Nanosecond pulsed discharges on levitated water droplet

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Abstract: Nanosecond pulsed discharges interacting with water droplets of different conductivities were studied using ICCD imaging. Initially, the discharges behave similarly, but later diverge based on conductivity. Low conductivity droplets cause plasma to propagate around them, while high conductivity droplets act as floating electrodes, facilitating charge transfer. These results underscore the impact of water droplets on plasma behaviour.

1. Introduction

Plasma-treated water has versatile applications, including wound disinfection, surface decontamination, and acting as a fertilizer to enhance plant growth. The high surface-to-volume ratio of small droplets promotes the generation of reactive oxygen and nitrogen species (RONS) at high concentrations when exposed to cold plasma [1]. When applied as a spray, plasma-treated liquids can access hard-to-reach areas and cover large surfaces efficiently.

Studies on discharges over single droplets have demonstrated that the droplet's conductivity significantly influences the discharge behavior [2]. In this work, we investigate the time-resolved evolution of nanopulsed discharges over water droplets with varying conductivity using an ICCD camera.

2. Methods

A pin-to-pin nanosecond pulsed (10ns, +40kV_{peak}) discharge in air was generated between two tungsten electrodes at 9 mm distance. The droplet (~10µL) was suspended between the pin in air using acoustic levitation, ensuring it remained stationary during the experiment. The surrounding air environment was regulated with an airflow of 3 slm, maintaining a relative humidity of 10% and a temperature of 20°C.

Two droplet conductivities were studied: pure water (1µS/cm) and a NaCl solution (16,000µS/cm). The discharge dynamics were captured using an ICCD camera (PI-MAX 3) positioned perpendicular to the discharge and acoustic levitator axis.

3. Results and Discussion

Figure 1 presents ICCD images capturing the temporal evolution of the discharge during the first nanoseconds. The discharge initiates from the high-voltage electrode (right side) and bridges the gap to the closest pole of the droplet. The discharge then reignites on the opposite side of the droplet and reach the ground electrode (left side). This behavior is attributed to the polarization of the droplet. The discharge evolution proceeds in the same manner for the first 1.5 ns.

At 2 ns, differences between the two droplets become apparent. For the low conductivity water droplet (Figure 1a), the plasma propagates around the droplet. This is because the droplet, being dielectric, prevents the charges from penetrating its interior. In contrast, for the saline droplet (Figure 1b), the charges go through the droplet due to its conductive nature.

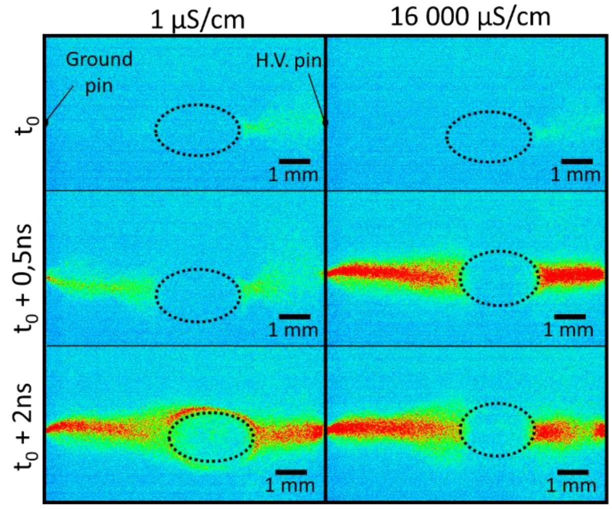

Fig. 1. ICCD images showing the temporal evolution of the discharge around the droplet (integration time = 480ps)

4. Conclusion

This study demonstrates the influence of droplet conductivity on the behavior of nanosecond pulsed discharges in air. Using ICCD imaging, we observed that the discharge dynamics are significantly affected by the droplet's electrical properties. For ultra-pure water droplets, the plasma propagates around the droplet due to its dielectric nature, which prevents the penetration of charges. Conversely, for saline droplets, the conductive nature allows the charges to go through the droplet. These findings highlight the critical role of droplet conductivity in shaping the interaction between plasma and liquids, which is essential for optimizing applications in areas such as plasma-based disinfection and surface treatment. Future work could explore the effects of varying droplet sizes and different plasma parameters to deepen our understanding of these interactions.

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References

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[2] Y.Chen et al., Suspended Droplets Discharge Characteristics (2024)