Nanosecond discharge ignited at the water-heptane interface: streamer-to-spark transition and time evolution of n_e and T_p

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Abstract: Nanosecond discharge is ignited at the water-heptane interface and propagated in water. Here, we study discharge characteristics using time-resolved OES. Emission spectra are acquired during ignition, propagation, and transition to spark. The data allowed the estimation of n_e and T_p from ignition to extinction. The findings provide new insights into the involved mechanisms such as the balance between ionization and recombination.

1. Introduction

Discharge in liquid is a fast transient and stochastic plasma and leads to the formation of a streamer that may transit to spark if the experimental conditions (voltage amplitude and duration, gap distance) allow. Both discharge modes, streamer and spark, exhibit interesting properties that make them attractive for applications such as liquid processing and nanomaterials synthesis [1]. To tailor the outcome of those discharges, it is necessary to understand, quantify, and control the involved processes during propagation. The achievement of these goals remains a challenge mainly due to the stochasticity and small size (a few hundred micrometers) of the discharge.

Recently, our group demonstrated that adding a liquid layer, that has low dielectric permittivity, at the top of another one, that has high dielectric permittivity, significantly enhances the discharge volume as well as its probability of occurrence [2]. This enhancement is due to the amplification of the electric field magnitude induced by the difference in the dielectric permittivity at the interface. The consideration of this property offers the opportunity to produce and characterize in-liquid discharges with time- and space-resolved techniques.

Herein, we apply pulsed high voltage to a pin positioned at the heptane-water interface, where a discharge ignites and propagates in water as a streamer before it transits to spark. Both modes, streamer and spark, are characterized by time-resolved optical emission spectroscopy (OES).

2. Experiment details and results

The discharges are ignited at the heptane-water interface using pulsed high voltage: amplitude of 20 kV, duration of 500 ns, and repetition rate of 1 Hz. The anode tip, made of copper, is placed at the interface, while the ground plate electrode (made of copper) is placed in distilled water at a distance that can be adjusted between 2 and 8 mm. Exposure time of the spectrometer's ICCD was 3 ns. The delay between the discharge and ICCD camera is controlled using a delay generator to reconstruct the temporal behavior. The OES spectra are analyzed using a Bayesian fitting procedure to determine n_e (from Stark broadening and shift of the Hα and O (777 nm) lines) and T_p from the continuum radiation (assumed to be dominated by Planck's radiation) [3].

Figure 1 shows the evolution of n_e and T_p for a gap of 4 mm. At the streamer's inception, n_e is high (~10^{25} m^{-3}) near the anode and decreases (to ~5×10^{24} m^{-3}) during propagation. During this stage, T_p is ~5000 ± 1000 K; the high uncertainty is due to the low intensity of the blackbody continuum. At the breakdown, i.e. streamer-to-spark transition, the power peaks to a few of 100s kW, which results in a rapid rise of n_e to a value that is unknown due to the only continuum radiation (no Hα line is detected). During this moment, T_p increases to 8000 ± 100 K. Beyond breakdown, n_e gradually decreases, while T_p rapidly (within 40 ns) drops by 1500 K before reaching a plateau at ~6000 K until extinction. The evolution of the spectral features suggests a strong energy transfer by radiative processes, including recombination [4]. This aspect will be further discussed.

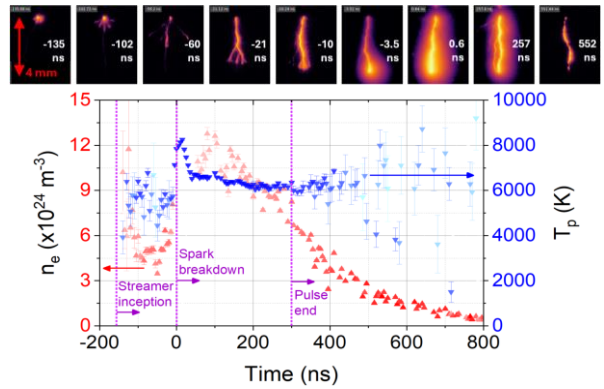

Fig. 1. Evolution discharge morphology (top) and of n_e and T_p (bottom) from ignition until extinction.

3. Conclusion

Analysis of time-resolved emission spectra emitted by in-water discharge allowed the detailed determination of $n_e(t)$ and $T_p(t)$ from ignition to extinction. The strong variation of these parameters may be linked to the balance between energy absorption at the breakdown and the energy loss through radiative processes.

References

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