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Electric Field Measurements in a Ns Pulse Discharge in Atmospheric Air

Igor V. Adamovich
Ohio State University, adamovich.1@osu.edu

Quantifying the electric field in ns pulsed discharges is essential to understanding near-surface plasma phenomena. In this regard, time-resolved electric fields (E-field) were measured in a quasi-two-dimensional "curtain" ns discharge plasma in atmospheric air, sustained between a knife edge electrode and a dielectric plate (quartz, 100 μm thick) placed over a grounded electrode, with a 600 μm gap. The results were obtained using a ps four-wave mixing technique using a stimulated Raman shifting cell. For the first time, N_2 rather than H_2 was used as probe species. The knife edge electrode was powered by a 8 kV, ~100 ns pulse. Time-resolved E-field during the negative polarity pulse is shown in Fig. 1, ≈100 μm from the edge of the high-voltage electrode with resolution of 1 ns. The E-field before the pulse is fairly high, 15-20 kV/cm, due to charge accumulation on the surface from the previous, positive polarity pulse. When the voltage pulse is applied, the E-field (i) increases until "forward" breakdown occurs (≈45 kV/cm), (ii) decays rapidly after breakdown due to plasma self-shielding, (iii) reverses direction when the applied voltage is reduced, (iv) decreases during "reverse" breakdown, and (v) levels off at an asymptotic value of ≈20 kV/cm due to surface charge accumulation.

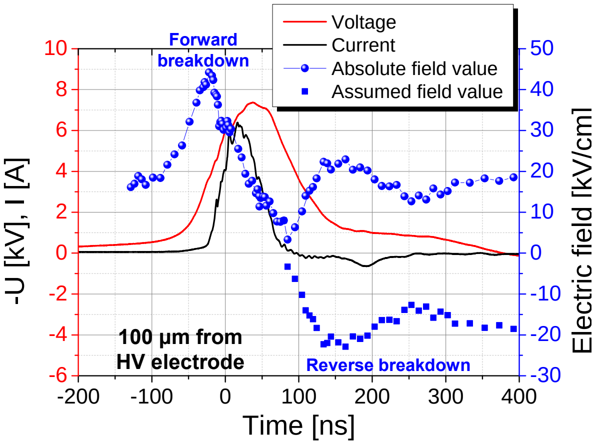


Figure 1 – Time-resolved electric field, voltage and current in a "2-D curtain", ns, dielectric barrier discharge plasma in atmospheric air, measured 100 μm from the high-voltage electrode edge.

The E-field near the dielectric surface (spatial resolution ≈100 μm), at t=70 ns, the momoment of field reversal, ≈150 μm from the surface is in Fig. 2. The discharge propagates as a surface ionization wave (SIW) with rapid E=field reduction behind the wave front. All features are consistent with plasma emission images taken with a 1 ns gate. These results provide quantitative insight into pulse breakdown kinetics and discharge energy partitioning in air. The ps four-wave technique is being used for accurate measurements of E-field vector in an SIW, ns pulse discharge in air over liquid water, to study kinetics and transport in plasmas used in biology and medicine.

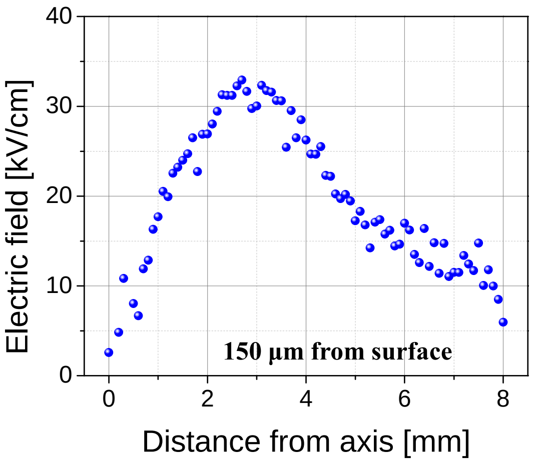
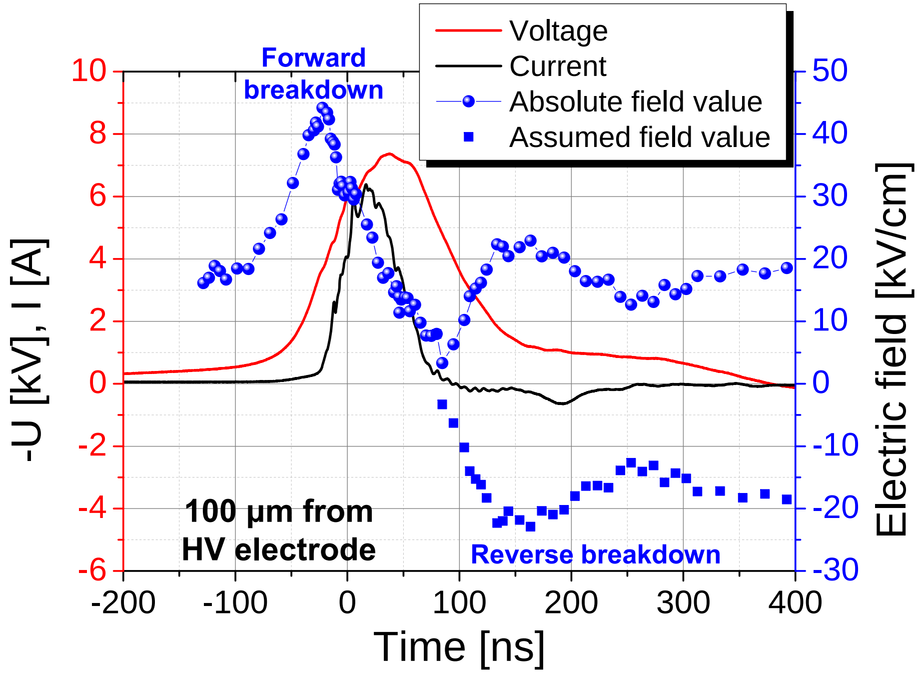


Figure 2 – Electric field in a "2-D curtain" plasma in atmospheric air. 150 μm from the dielectric surface during field reversal (t=70 ns).

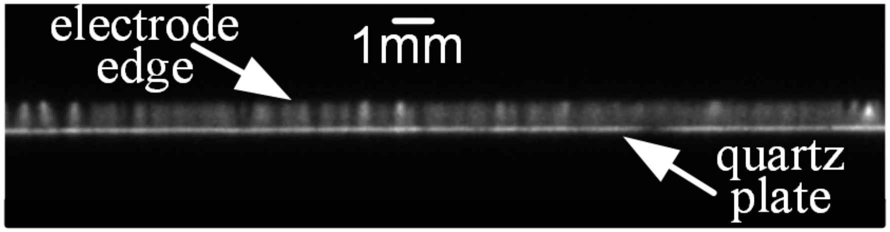
ELECTRIC FIELD MEASUREMENTS IN ns ATMOSPHERIC PRESSURE AIR PLASMA

- **Time-resolved, spatially resolved electric field is measured in a “2-D curtain” ns pulse dielectric barrier discharge in atmospheric air, by ps 4-wave mixing**
- **Quantitative insights are enable into discharge energy partition and reactive oxygen / nitrogen species generation in air plasmas used in biology and medicine.**

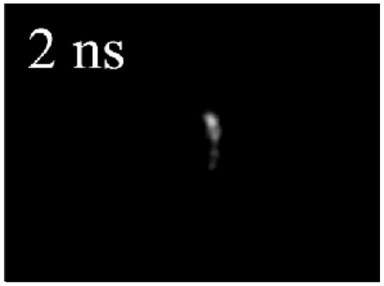


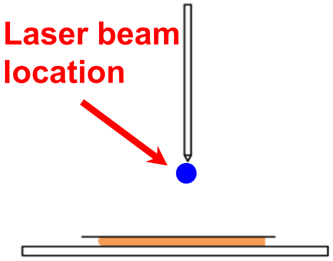
- **Time-resolved electric field near high-voltage electrode**

Front view, 100 ns gate



Side view, 2 ns gate





Animation (Click to play)

- **ns pulse “curtain” plasma images**

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HIGHLIGHT

DOE Plasma Science Center
Control of Plasma Kinetics

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New Insights on Potential of Emitting Wall with Applications for Emissive Probes

Brian Kraus and Yevgeny Raitses
Princeton Plasma Physics Laboratory (yraitses@pppl.gov)

Accurate measurements of plasma potential are challenging, especially for flowing, magnetized and collisional plasmas. Emissive probes are commonly used for plasma potential measurements in such complex plasma environments [1]. However, the interpretation of these measurements is not trivial as the emissive probe operation is directly associated with a fundamental question of the potential profile near an emitting surface. Recent theories on sheaths near emitting walls have proposed many sheath topologies other than the commonly accepted space-charge limited (SCL) regime [2]. In one case, an emitting sheath modelled in a particle-in-cell code showed oscillatory behavior [3]. Another theory predicted a new steady-state potential structure, the inverse sheath, which is formed near a strongly emitting wall if ions become trapped in the virtual cathode near the wall [4].

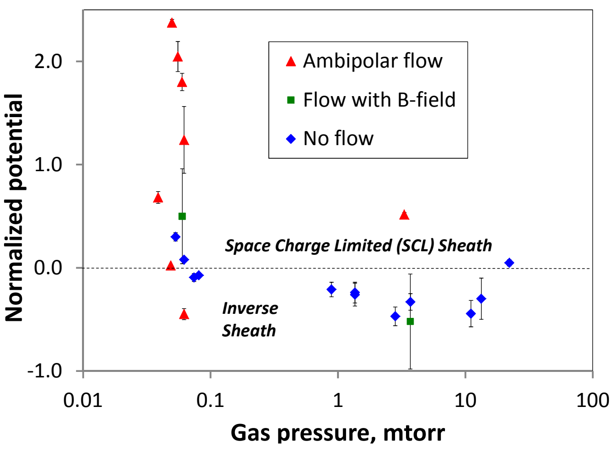

Figure 1 – Measured difference between plasma potential, V_p, and floating potential of the emissive probe, V_{em}, $(V_p-V_{em})/T_e$, where T_e is the electron temperature, for different plasmas.

Which emissive sheath theory is correct? The answer lies in results of our recent experiments with different low temperature plasmas produced at different gas pressures, with and without magnetic field, and with and without flow. In these experiments, a single probe filament was operated as a swept-biased probe to measure plasma potential and also as an emissive probe to measure the hot floating potential. Comparison of these measurements (Fig. 1) shows evidence for two sheath scenarios - SCL sheath for flowing plasmas and the inverse sheath for non-flowing plasmas.

A transition from a SCL sheath to the inverse sheath occurred with increasing gas pressure (Fig. 1). This result may validate the predicted effect of ion trapping near the emitting wall [4]. For an inverse sheath to develop, charge-exchange ion buildup in a double layer or so-called virtual cathode near the emitting wall must dominate over trapped ion losses near the probe. For our experimental conditions, ion losses are predicted to exceed the rate of ion trapping at gas pressures below 0.1 mTorr. Under such conditions, the measured sheath near a strongly emitting wall is in the SCL regime, consistent with [2]. Above this pressure threshold, the sheath is inverse, such that the emissive probe floats above the plasma potential as predicted in [4].

References

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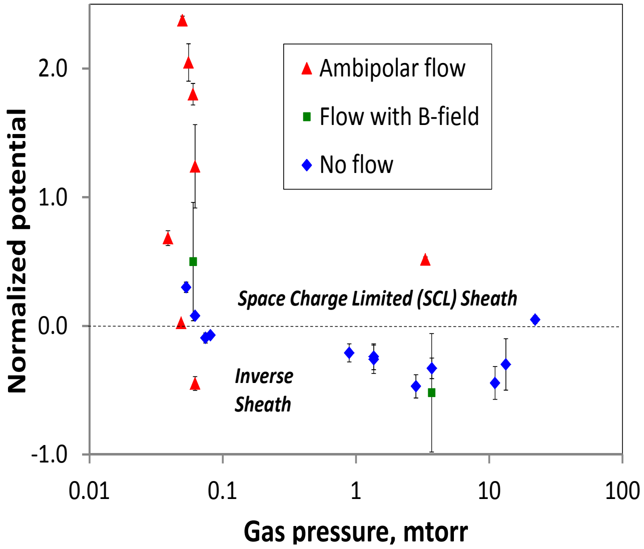
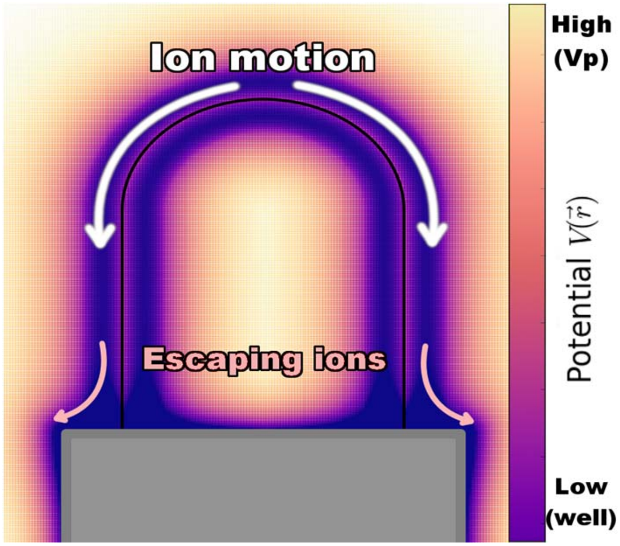
NEW INSIGHTS ON POTENTIAL OF EMITTING WALL WITH APPLICATIONS FOR EMISSIVE PROBES

- **Emissive probes are commonly used for plasma potential measurements in complex plasmas including flowing, magnetized and collisional.**
- **Recent theories proposed a diversity of sheath topologies near emitting walls, including space-charge limited (SCL) sheath and inverse sheath.**
- **Which emissive sheath theory is correct and can be applied for probes?**
- **Experiments at different gas pressures demonstrate both sheath regimes that may be due to tradeoff between ion trapping and ion loss near emitting wall.**





- **Two emissive sheath regimes: a) measurements, b) physical mechanism.**

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HIGHLIGHT

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

Department of Energy Plasma Science Center

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Control of Plasma Kinetics