Electron Densities and Electric Fields in High Pressure ns Pulsed Discharges

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The direct measurment of electric fields in atmsopheric pressure plasmas are critical to understanding fundamental plasma transport. Time-resolved electric fields were measured in a nanosecond pulsed discharge in atmospheric air, sustained between a knife edge electrode and a plane dielectric plate (quartz, 100 μm thick) placed over a grounded electrode, with 1 mm gap. The results were produced using a picosecond four-wave mixing technique using a stimulated Raman shifting (SRS) cell. The technique was adapted, for the first time, to use nitrogen, rather than hydrogen, as the probe species. The electrode is powered by a square shaped high voltage pulse with ≈50 ns rise time. The results, shown in Fig. 1, demonstrate that the electric field before the pulse is high, 25-30 kV/cm, due to charge accumulation on the dielectric surface. When the voltage pulse is applied, the electric field (i) reverses the sign, (ii) increases until breakdown limit (nearly 60 kV/cm for these conditions), (iii) decays rapidly during breakdown due to charge separation and plasma self-shielding, and (iv) levels off at an asymptotic value during surface charge accumulation. This technique can be used for accurate measurements of electric field in pulsed discharges in air, with sub-ns pulse resolution, to provide quantitative insight into pulse breakdown kinetics and discharge energy partition.

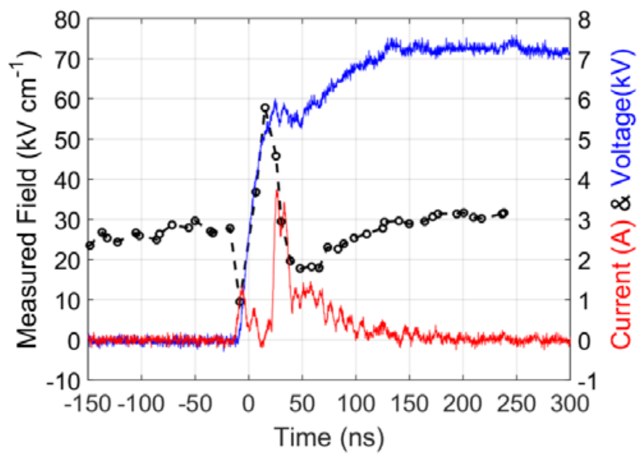


Figure 1 – Absolute electric field in a knife-edge-to-dielectric plane, ns pulse discharge in air, plotted together with pulse voltage and current waveforms.

Thomson / Raman scattering was used to measure time-resolved electron density, electron temperature, and gas temperature in a ns pulse discharge in helium and oxygen-helium mixtures, sustained as a diffuse filament discharge between a spherical high-voltage electrode and liquid water surface (see Fig. 2). A sharp metal pin is attached to the grounded electrode on the bottom of the water reservoir to enhance the electric field in center and help stabilize the discharge filament. The electron density and electron temperature increase rapidly during the ns pulse breakdown, peaking at $n_e \approx 4.5\cdot10^{14}$ cm^{-3} and $T_e \approx 2.5$ eV. After the discharge pulse, both electron density and electron temperature rapidly decay, over a few tens of ns, much faster compared to the discharge without water present. For the present conditions, the dominant electron decay mechanism is three-body electron attachment to water vapor. These measurements provide insight into discharge energy partition and rates of reactive oxygen species generation (such as O atoms) in plasmas sustained near liquid surfaces.

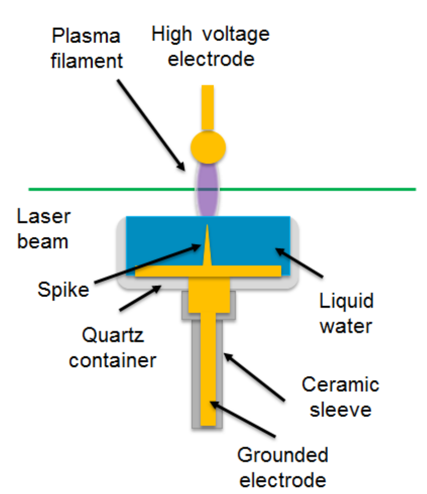
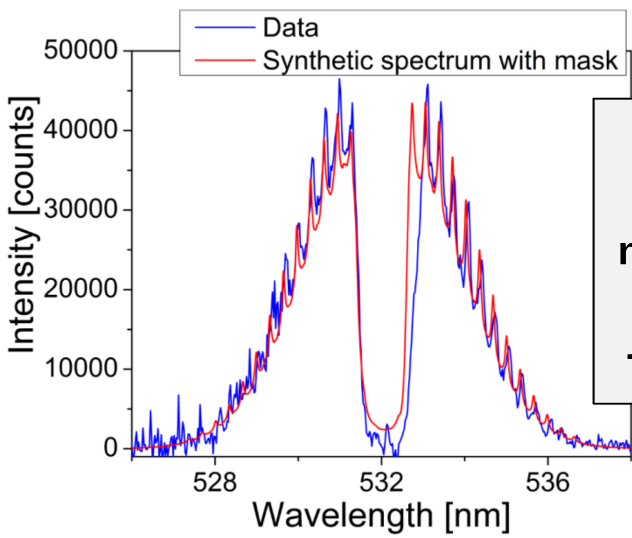


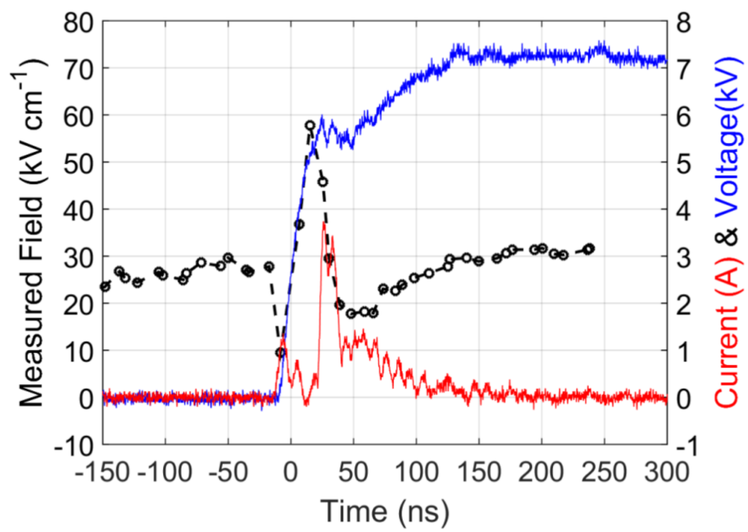
Figure 2 – Schematic of ns pulse discharge over liquid water surface

ELECTRON DENSITIES AND ELECTRIC FIELDS IN HIGH-PRESSURE ns PULSEd PLASMAS

- **Time-resolved electron densities and temperatures are measured in a pin-to-pin ns pulse discharge in O_2-He over liquid water by Thomson scattering**
- **Time-resolved electric fields are measured in a knife-edge-to-plane, ns pulse discharge in atmospheric air, by ps CARS-like 4-wave mixing**
- **Knowledge of $n_e(t)$, $T_e(t)$, and $E(t)$ are critical for quantitative insight into discharge energy partition and reactive oxygen / nitrogen species generation**



10% O_2-He
P=100 Torr
n_e=4.5·10^{14} cm^{-3}
T_e=2.5 eV,
T_{rot} = 350±20 K



- **Thomson / Raman scattering spectrum in O_2-He over liquid water**
- **Electric field ($|E|$) in a knife-edge-to-dielectric plane ns pulse discharge in air**

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HIGHLIGHT

THE OHIO STATE UNIVERSITY

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

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Magnetically Insulated Baffled Probe for Measurement of Plasma Potential in Medium-Pressure Magnetized Discharges

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Accurate measurements of steady state and fluctuating values of plasma potential are necessary to understand transport in magnetized discharges. The measurement accuracy of sweeping bias electrostatic probes can be affected by various plasma oscillations, which are common for magnetized discharges. The use of floating emissive probes are usually limited to low-density plasmas, $\approx 10^{13}$ cm^{-3}. In this work, we investigated a floating magnetically insulated baffled probe (MIB) for direct low-perturbative measurements of the plasma potential in both anomalous and quiescent magnetized plasmas at low (<1 mTorr) and moderate (>1 mTorr) pressures. The principle of operation of this probe is based on the dependence of the sheath voltage drop on the magnetic field [1]. The probe consists of a tube with a recessed collector. The tube acts as a baffle limiting the flux of magnetized electrons to the collector [2]. Unlike previous MIB probes [1,2], the tube shields the collector from plasma perturbations induced by E × B rotating spoke. The tube interior surface is conductive to avoid a charge buildup due to Hall effect.

Measurements with the MIB probe have been made in a E×B Penning discharge (Xe, $n_e \approx 10^{12}$ cm^{-3} $T_e \leq 5$ eV) with magnetized electrons and non-magnetized ions. Preliminary results of steady state measurements show that electron current drops by two orders of magnitude inside the tube (Fig. 1), and the MIB floating potential saturates to a value above the emissive probe floating potential. These results indicate measurement of an electric potential near the plasma potential (Fig. 2). Surprisingly the reduction of the electron current does not depend on the magnetic field. Simulations of the MIB probe are in progress to understand the probe operation and explain the above observations.

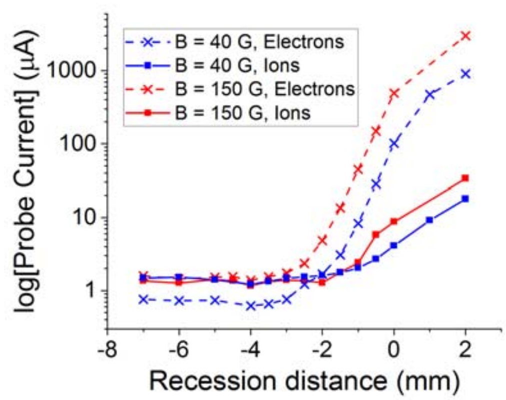


Fig. 1 – Ion and electron currents measured by the MIB probe collector vs recession distances and magnetic field.

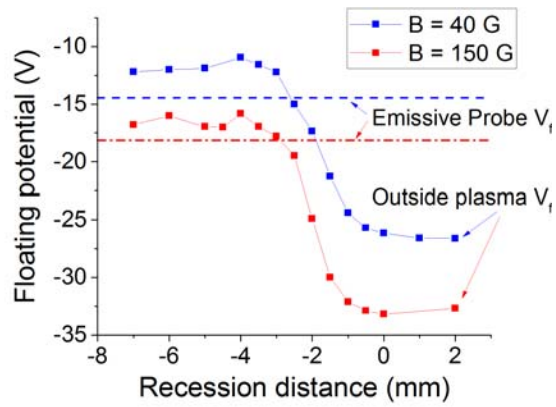


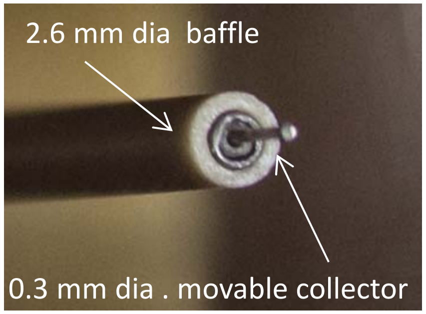
Fig. 2 – Floating potential of the MIB probe. Inside the tube, the collector floats at a potential above that from floating emissive probes.

References

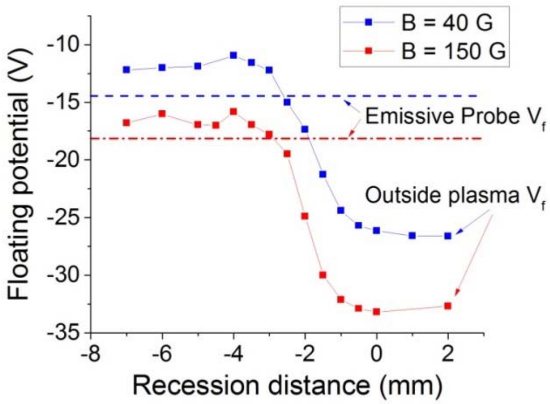
[1] V. I. Demidov, M. E. Koepke, and Y. Raitses, Rev. Sci. Instrum. **81**, 10E129 (2010).
[2] V. I. Demidov, S. M. Finnegan, M. E. Koepke, and E. W. Reynolds, Contrib. Plasma Phys. **44**, 689 (2004).

MEASURING PLASMA POTENTIAL IN NON-QUIESCENT MAGNETIZED DISCHARGES

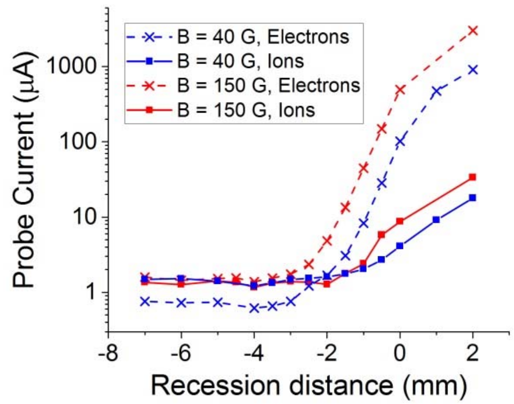
- **A Magnetically insulating baffled (MIB) probe was developed to measure plasma potential in magnetized discharges with rotating structures (spokes).**
- **MIB limits electron flux to the probe and reduces the sheath potential, so that the probe floats at or above the plasma potential while being non-emissive.**
- **In realistic plasma conditions, magnetic insulation worked only with a multi-layered baffle protecting against the spoke and charge buildup from Hall effect.**
- **Particle transport inside the probe is not fully understood – why is electron current reduction in the tube not affected by the magnetic field?**



- **A new multilayered MIB probe design.**



- **Comparison of MIB and floating emissive probes.**



- **Electron and ion currents to the biased MIB collector**

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