Properties of the electron sheath in low temperature plasmas

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I. Introduction

The study of sheaths has been an integral part of plasma physics from its foundation[1]. Given the tendency for plasmas to be electropositive, ion (or cathodic) sheaths have attracted much of the attention. As a result, the common understanding of electron (or anodic) sheaths has been largely based on intuition rather than close examination. This is in spite of the appearance of electron sheaths in a variety of situations, most frequently around Langmuir probes.

We report on several recent discoveries regarding the behavior of electron sheaths which represent the confluence of new theoretical insight, massively parallel kinetic simulations, and advanced optical diagnostics. In addition to these results, we identify promising opportunities upon which to build a better understanding of electron sheath behavior.

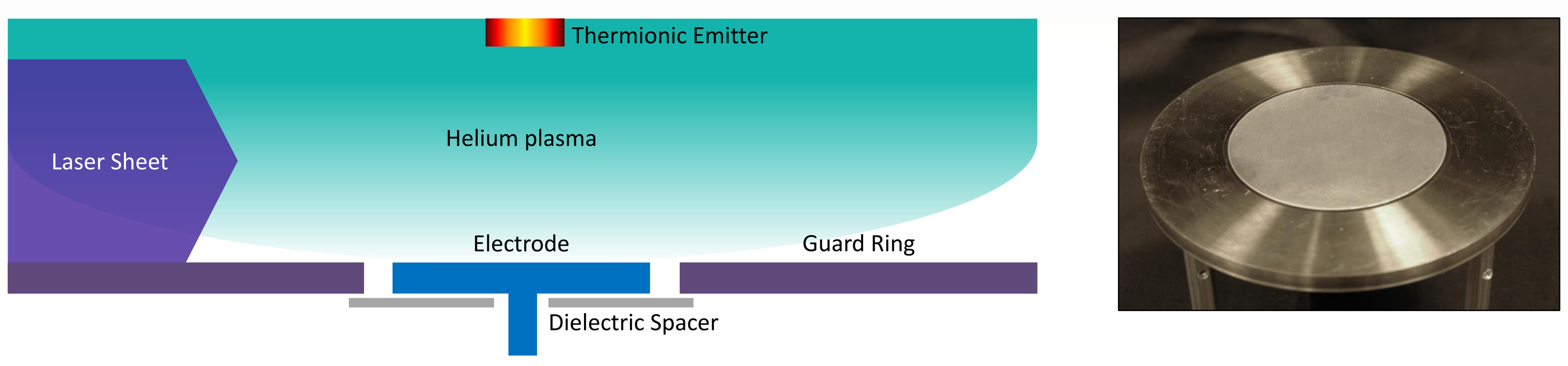

Figure 1. (left) Diagram of the LCIF interrogation of an electron sheath. (right) Embedded electrode used in studies

II. Experimental Setup

Electron sheath properties were studied in a GEC reference cell[2] in which the lower electrode was modified to accommodate a second embedded electrode. Helium was introduced into the system with operating pressures on the order of 10 mTorr. A plasma was initiated using a thermionic emitter operated at a constant discharge current of 300 mA (approximately 50 V). The embedded electrode diameter was chose to satisfy the anode-cathode area ratio necessary to obtain an electron sheath[3].

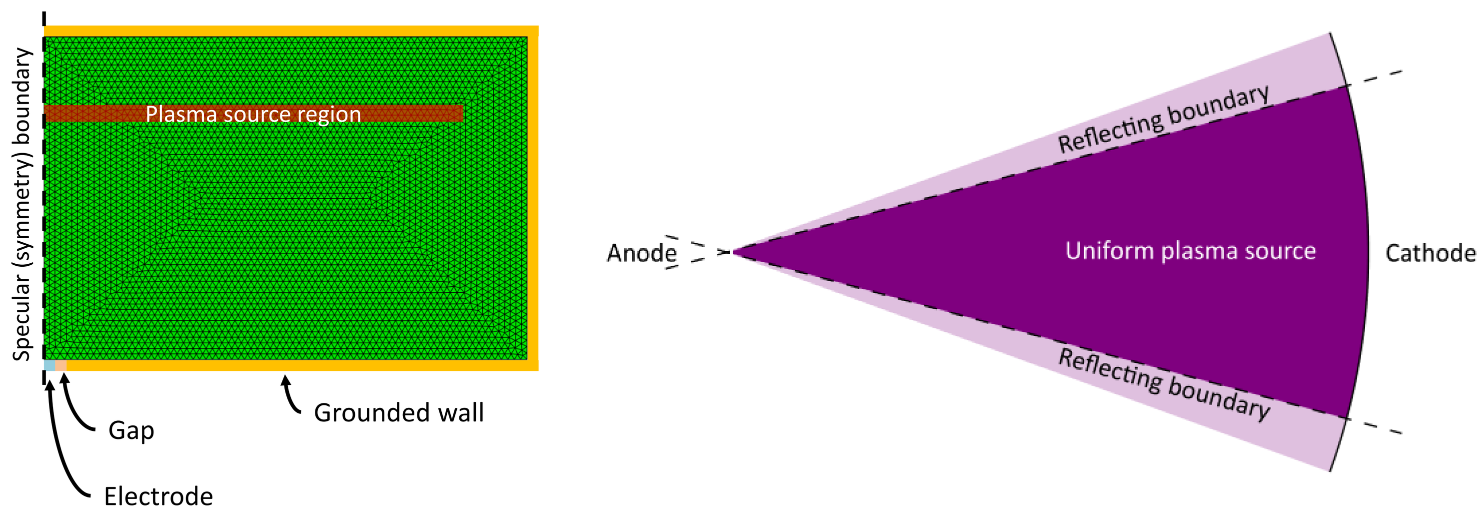

Figure 2. (left) 2D cartesian geometry for PIC/DSMC simulations. (right) Wedge geometry representative of a coaxial system.

III. Simulation Setup

Simulations were conducted in the PIC/DSMC code, Aleph[4]. Several geometries were used depending on the study. Comparisons to experiment were made with a 2D cartesian system utilizing a localized plasma source, closely matching the experimental setup. Later studies employed a wedge geometry with reflecting radial boundaries intended to mimic a coaxial discharge or Langmuir probe. The timesteps always resolved the fastest phenomena in question and common constraints for CFL and mesh resolution were met.

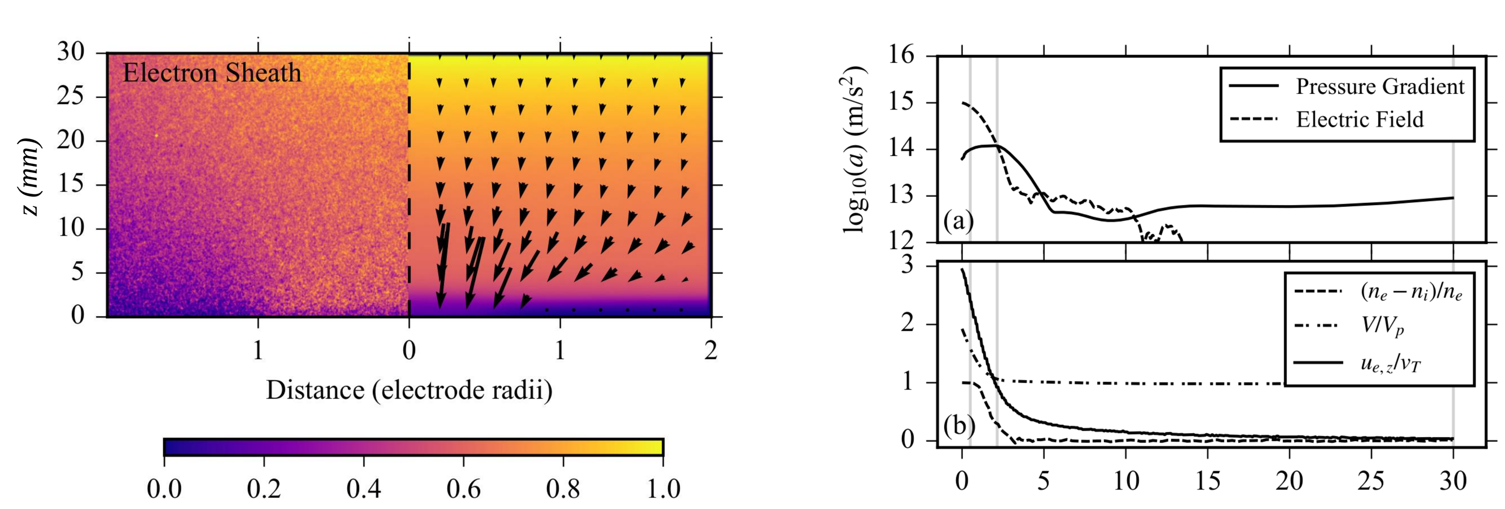

Figure 3. (left) Comparison of measured and simulated electron densities near an electron sheath with flow vectors from simulation. (right) Components of the electron momentum equation and on-axis sheath parameters.

IV. Electron Presheath Properties

Measurements using LCIF[5] revealed unexpected changes in the plasma properties far from the sheath edge when transitioning from an ion sheath to an electron sheath. Further investigation in theory, experiment, and simulation [6] confirmed that the presheath for the electron sheath was significantly from that of the ion sheath. First, the flow in the electron presheath is driven by the pressure-gradient, not the electric field. Second, the electron presheath is significantly larger than the equivalent ion presheath. Finally, as a consequence, electron sheaths can significantly alter the bulk properties of a plasma, both in density, flow field, and energy distribution.

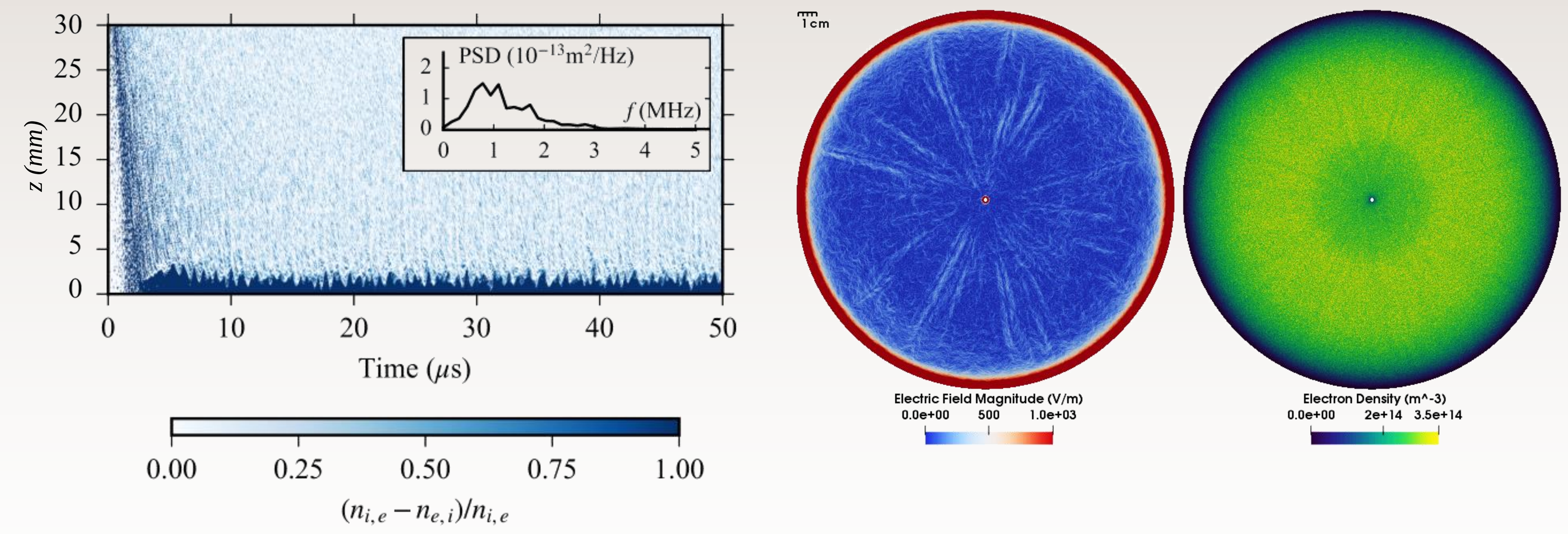

Figure 4. (left) Fluctuations in the electron sheath edge position. (right) Radial striations formed in the bulk due to an electron sheath.

V. Electron sheath-induced instabilities

Simulations of the electron sheath have revealed instabilities excited by the strong electron flow in the sheath and presheath regions. The first case of this was observed in the form of sheath edge fluctuations with a frequency comparable to the ion plasma frequency. Examination of the charge density changes showed these edge fluctuations extending through much of the presheath region. Coaxial simulations revealed an additional instability in the form of radial striations with length scales comparable to the whole of the plasma (~10 cm).

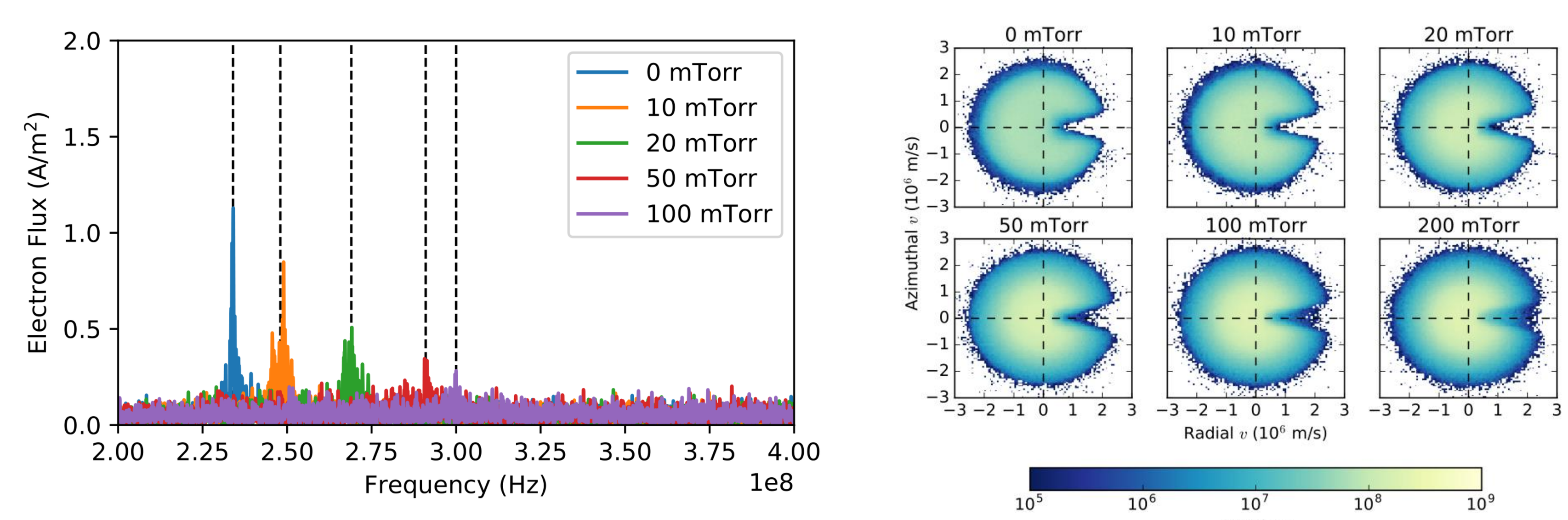

Figure 5. (left) Fourier transform of the electron flux at the anode. (right) 2D electron VDFs in a coaxial electron sheath simulation.

VI. Collisional Effects

Like ion sheaths, we expect that the properties of an electron sheath will be largely determined by the collisionality of the system[7]. For this reason, a computational study was conducted on the behavior of the electron sheath and presheath with respect to neutral gas pressure. The reaction set included electron-neutral ionization, excitation, and elastic scattering in addition to ion-neutral charge exchange. The frequency content of the electron flux to the anode was clearly tied to the bulk plasma frequency with damping determine by the neutral collision frequency. Examination of the two-dimensional electron VDFs[8] near the anode shows clear evidence of geometric effects in the form of a loss cone distribution. As the neutral pressure increases, collisions within the sheath scatter electrons into the loss cone region.

VII. Conclusions and Future Work

Electron sheaths exhibit a wide range of physical phenomena that are distinct from ion sheaths and have received relatively little attention. The electron presheath is comparatively large with flows driven by pressure gradients instead of electric fields. The strong flow of electrons drives instabilities in both the sheath edge and in the bulk plasma in the form of radial striations. Evidence from frequency analysis of electron flux shows evidence of electron plasma waves driven by instabilities within the electron sheath. Meanwhile, the two-dimensional velocity distributions bear a distinct loss cone associated with the geometry of the anode. Further work remains to be done on understanding of the presheath length scale, the precise nature of the instabilities driven by electron sheaths, and experimental verification of the instabilities and loss cone effects.

Acknowledgments

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