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The Influence of a Positively Biased Electrode

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Introduction

An electrode biased positive in a plasma contained in a grounded chamber is typically expected to operate in one of two ways:

- (1) Probe mode. The anode is very small and expected to have negligible impact on the bulk plasma. Used to collect electrons and measure plasma characteristics, e.g., T_e . Example: Langmuir probes in the electron saturation regime.
- (2) Locking mode. The anode is large and the plasma potential increases to be positive with respect to this “wall”. If the anode potential is increased, the bulk plasma potential increases as well. Example: anode in a glow discharge.

We will examine the transition between the two limiting cases to answer:

- How small is small enough?
- How wide is the transition regime?
- How does the plasma description (e.g., fluctuations) vary across the regimes?

Anode Sheath Type Criteria

Reviewing from [1], if we define

A_W = area of grounded walls of chamber,

A_E = area of positively biased electrode, and

$$\mu = \sqrt{2.3m_e/m_i},$$

then balancing ion and electron currents to the two surfaces (under some model assumptions) leads to a plasma potential V_p ,

$$V_p = -\frac{T_e}{q_e} \ln \left[\frac{A_w + A_E}{A_w} \mu - \frac{A_E}{A_w} \exp \left(-\frac{q_e \Delta V}{T_e} \right) \right],$$

where $\Delta V = V_p - V_A$, and V_A is the anode voltage. For $V_p \gg T_e$, [1] indicates an ion sheath and

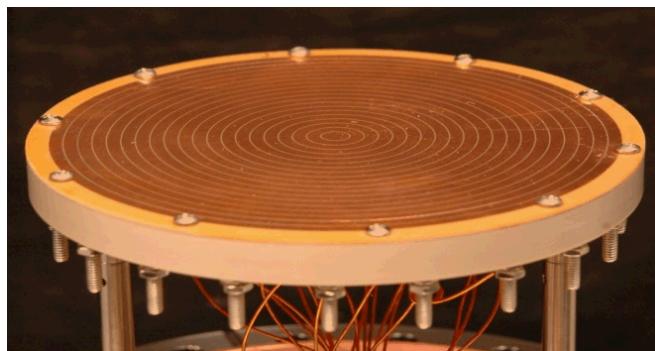
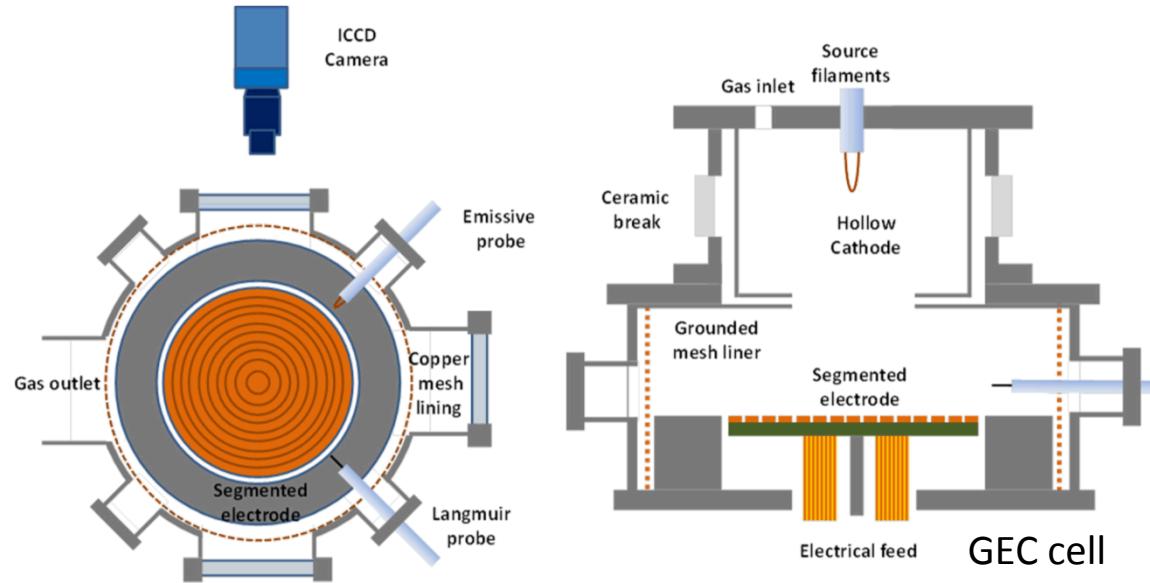
$$\frac{A_E}{A_w} \geq \left(\frac{0.6}{\mu} - 1 \right)^{-1} \approx 1.7\mu \quad (\text{ion sheath}).$$

In the other limit, where we assume $T_i \ll \Delta V$, [1] indicates an electron sheath,

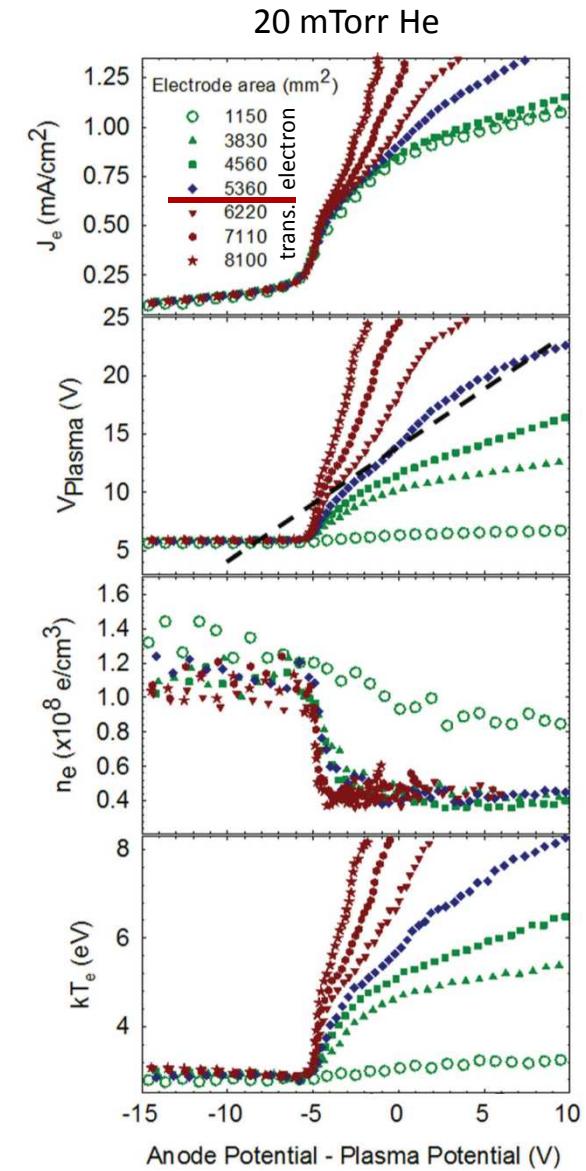
$$\frac{A_E}{A_w} < \mu \quad (\text{electron sheath}).$$

Experimental Results

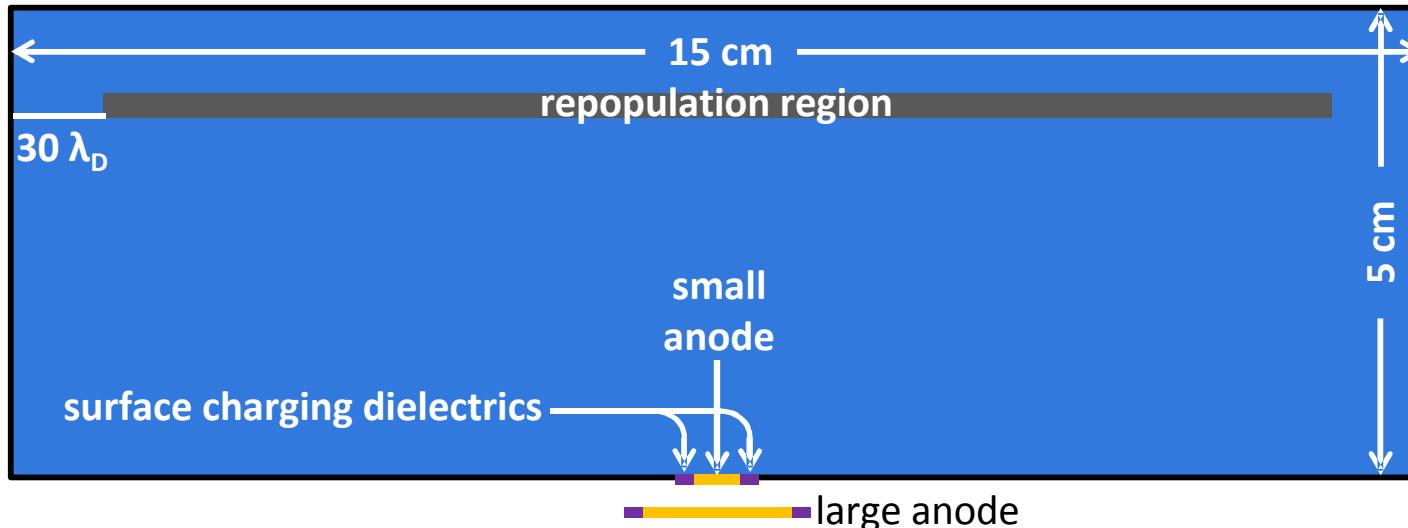
The full experiment is described in [2].



Segmented electrode



Computational Model



Neutral He plasma is generated in the repopulation region ($T_e = 4$ eV, $T_i = 0.1$ eV) at a rate to approximate experimental densities in the near-anode region ($\sim 2 \times 10^9/\text{cm}^3$ in the repopulation region).

Anode potential is $V_A = 20$ V. Other walls grounded.

Anode sizes were $(0.72, 1.00, 1.35, 1.46, 1.58, 1.70, 1.89, 2.08, 2.25) \times \mu$.

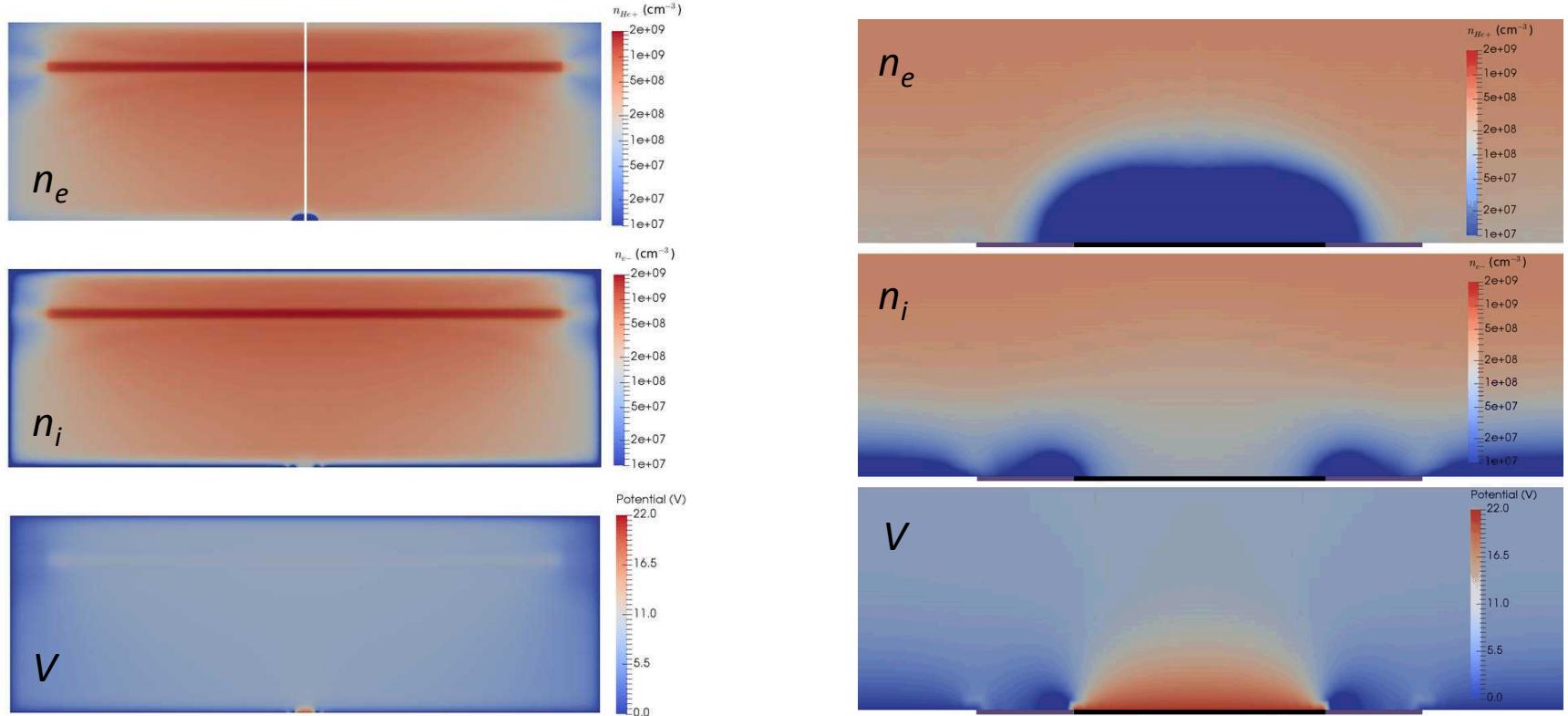
$$\lambda_D = 333 \text{ } \mu\text{m} \rightarrow \Delta x = 111 \text{ } \mu\text{m}$$

$$2/\omega_p = 793 \text{ ps} \rightarrow \Delta t = 100 \text{ ps}$$

Unstructured triangular mesh has $\sim 161,000$ cells (a half-domain was simulated).

Computational Results

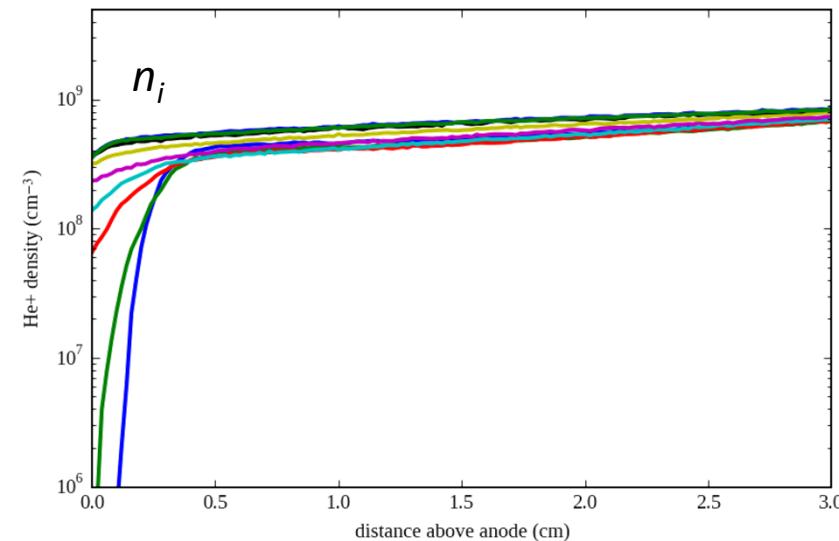
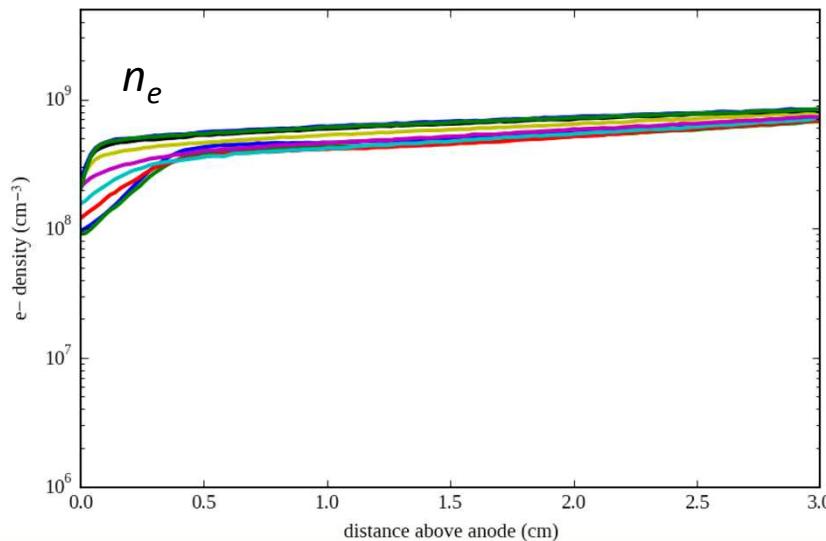
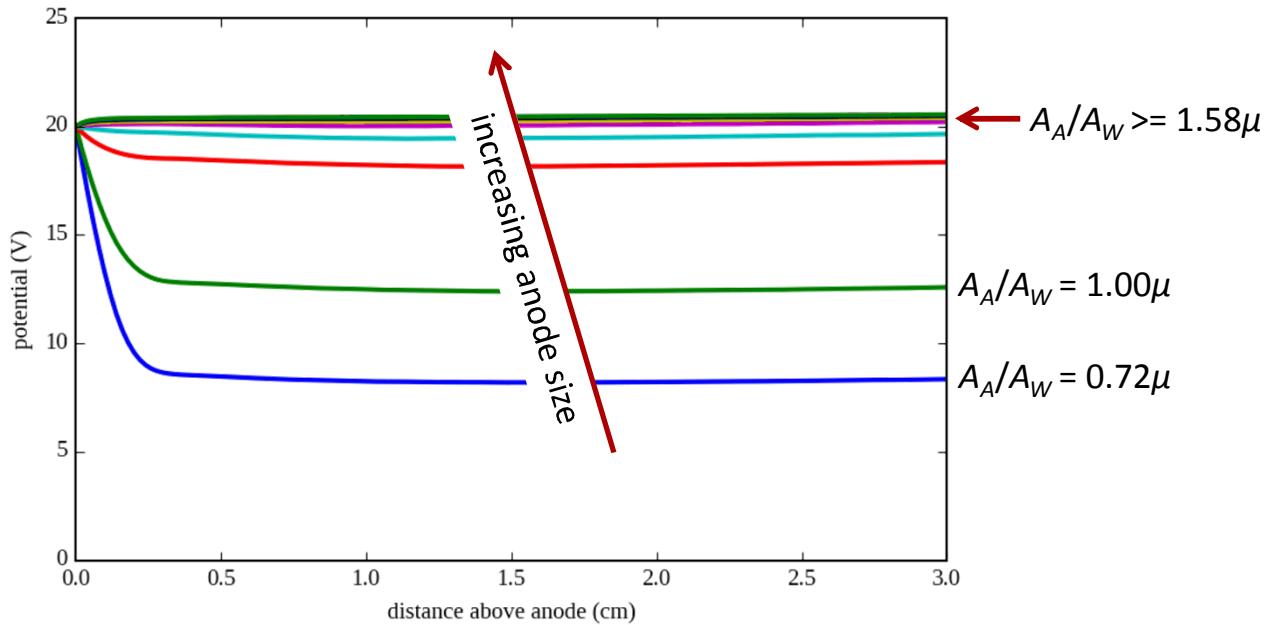
The full study is described in [3].



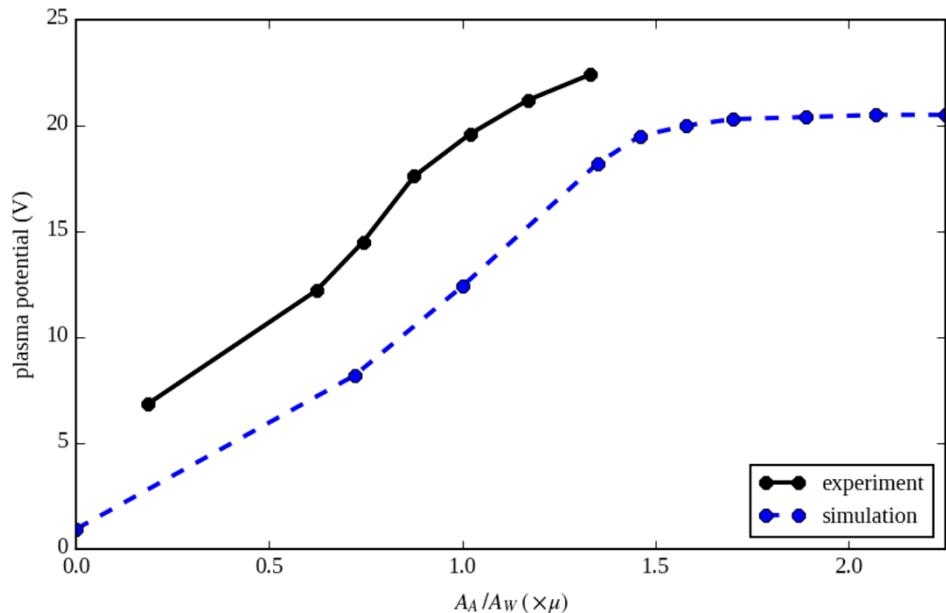
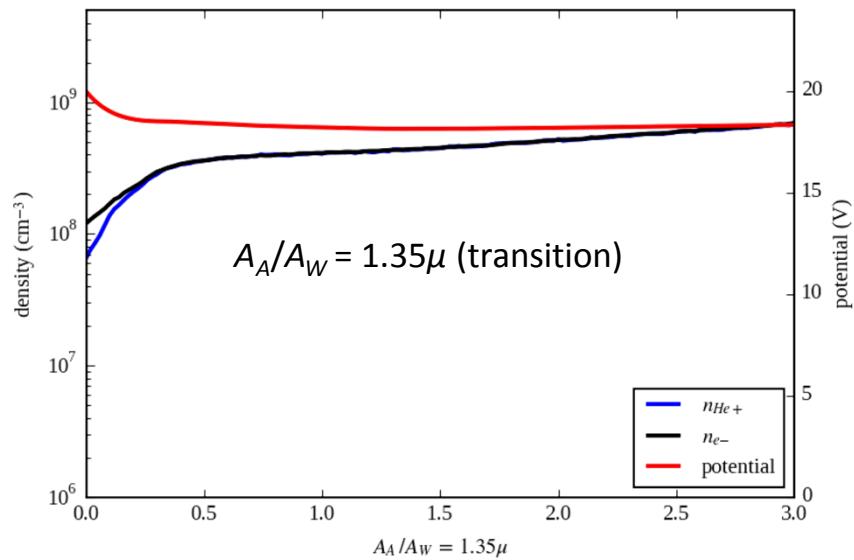
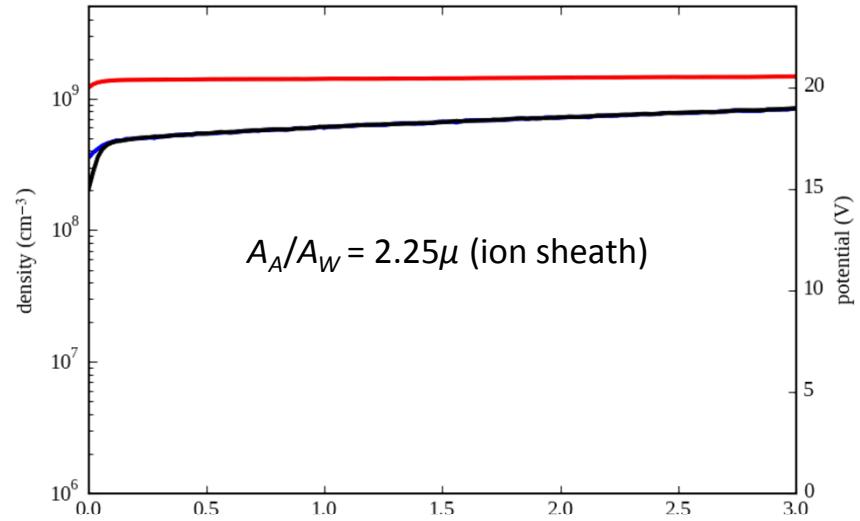
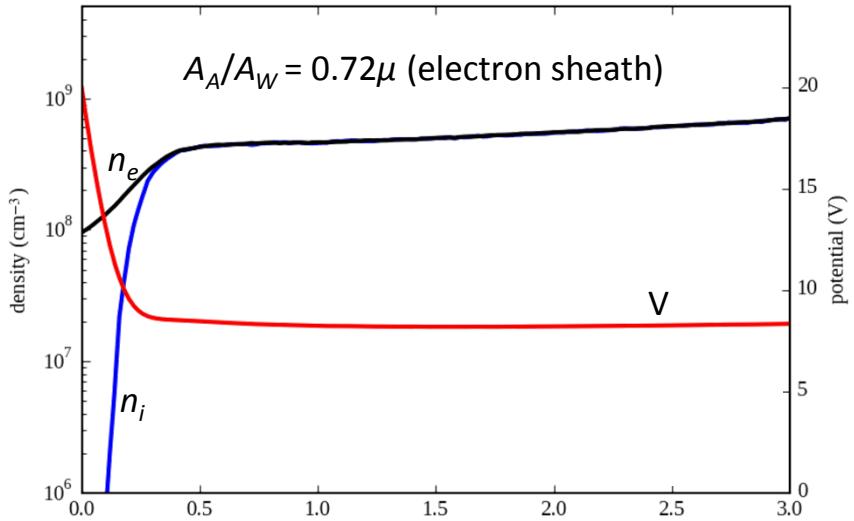
Solutions for $A_A/A_W = 0.72\mu$

The following data is taken along the centerline shown in the top left pane, averaged over 30 μs . Total physical simulation time is 50 μs and steady-state is achieved in $\sim 20 \mu\text{s}$. Simulations required ~ 36 hours on 128 cores.

Computational Results

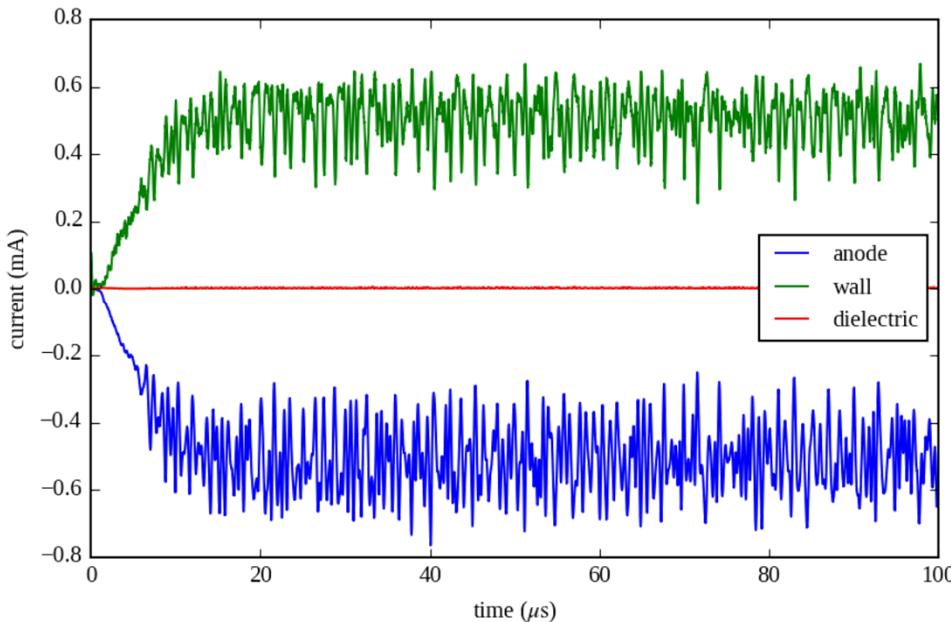


Computational Results

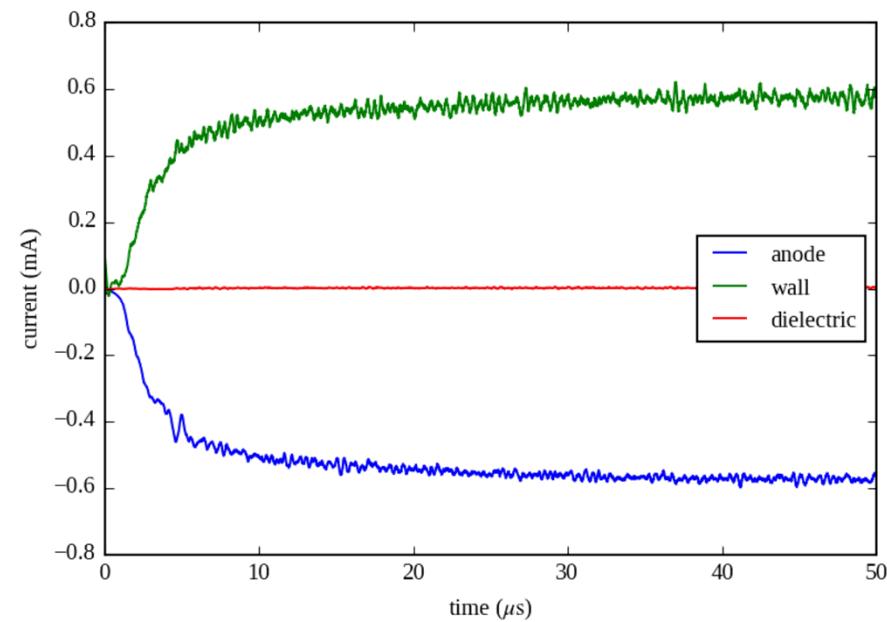


Sheath Stability

Currents for $A_A/A_W = 0.72\mu$



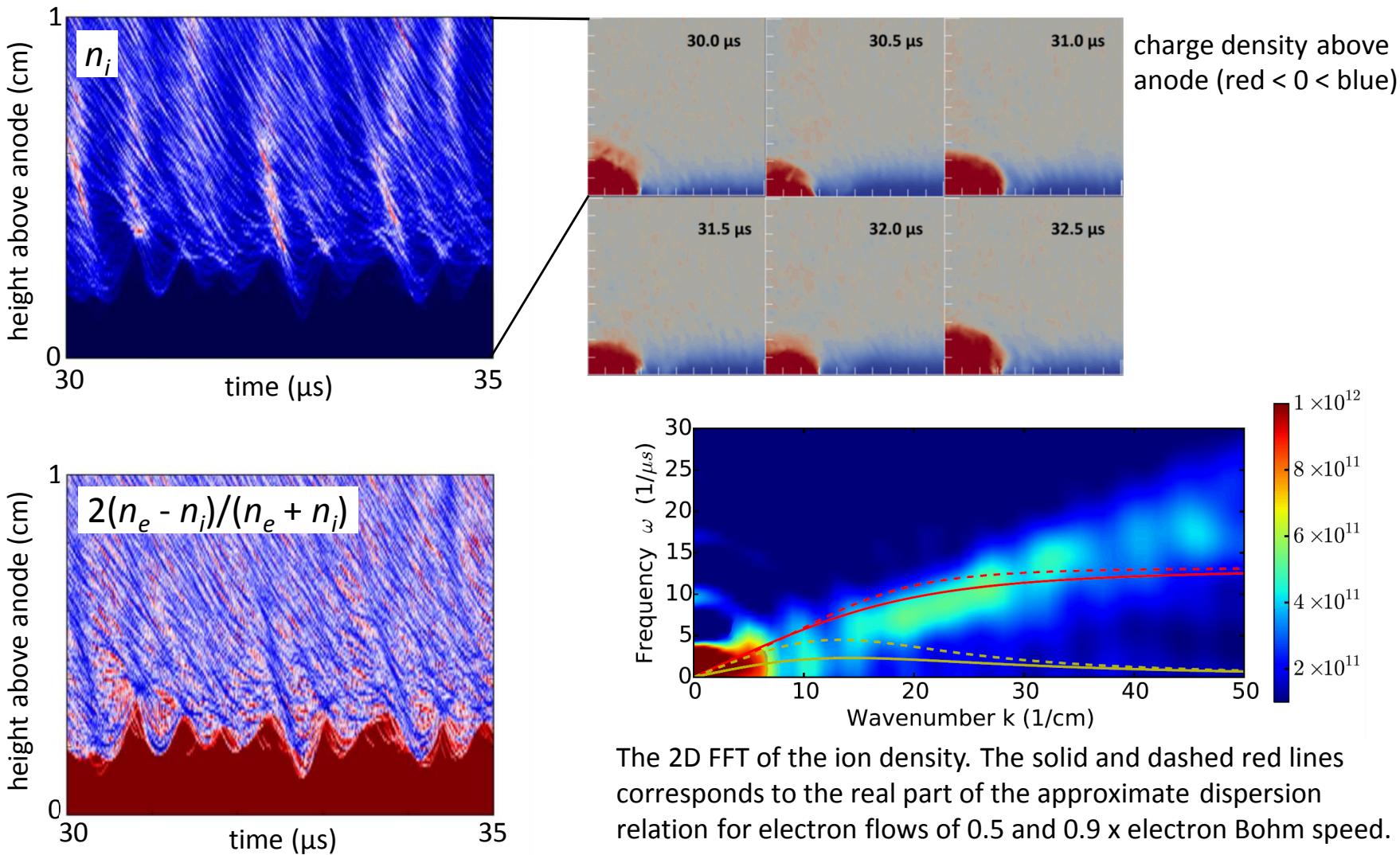
Currents for $A_A/A_W = 2.25\mu$



Clearly, the electron sheath is much noisier. We analyzed the fluctuations in terms of ion acoustic wave instabilities caused by differential flow of ions vs. electrons in the presheath region.

Electron Sheath Location Fluctuations

The full study is described in [4].



Conclusions

- Reasonable agreements between all of theory, experiment, and simulation.
- Transition region is narrow:
 - 1.7% of A_w for He (1.8% to 3.5%)
 - 0.44% of A_w for Ar (0.56% to 1%)
- Area of a grounded cylinder inside a GEC cell is $\sim 1.86 \times 10^5 \text{ mm}^2$. So positively biased surfaces $\geq \sim 10 \text{ cm}^2$ (for Ar) will have significant impact on plasma.
- 1 mm^2 probe size? Grounded chamber area limited to strictly above 180 mm^2 (again for Ar), or $\sim 7.6 \text{ mm}$ diameter sphere, to avoid impact (and experimental and computational results imply even larger).
- Electron sheaths exhibit ion acoustic wave instabilities.

References

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- [4] B. Scheiner, S.D. Baalrud, B.T. Yee, M.M. Hopkins, E.V. Barnat, *Phys. Plasmas* **22** (2015), 123520.

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