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Plasma Potential Locking

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Introduction

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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 thee two limiting cases to answer:

- How small is small enough?
- How wide is the transition regime?

Thresholds from Global Current Balance

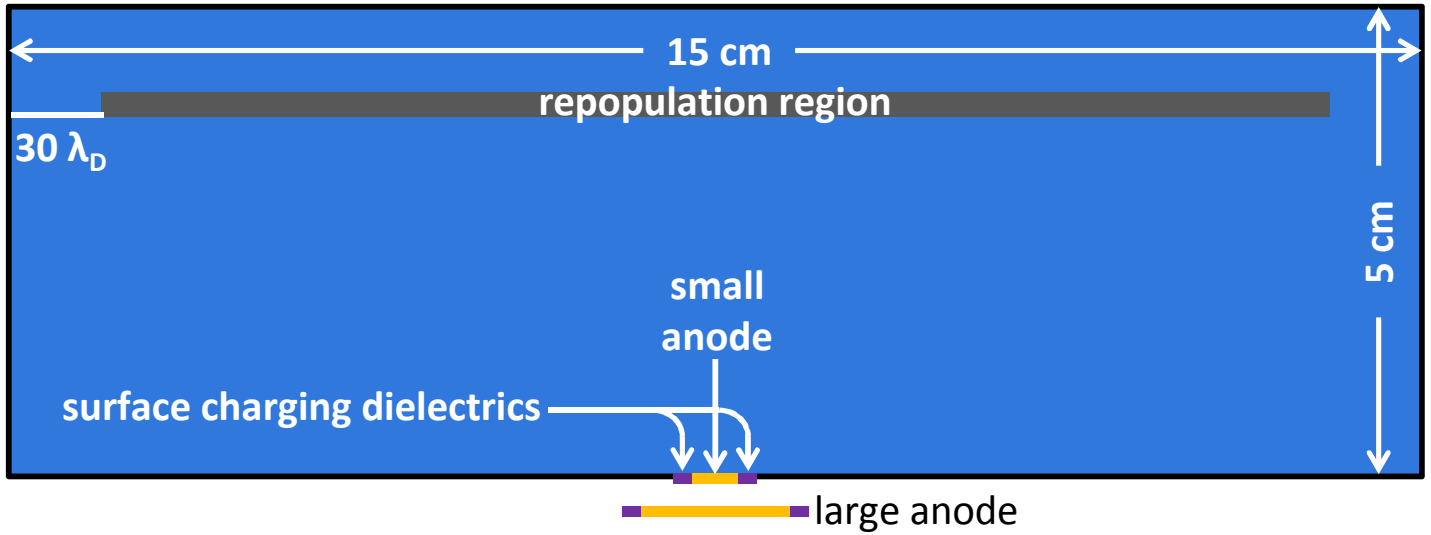
From (Baalrud, Phys. Plasmas 042109, 2007), we have theoretical estimates of the transitions. Setting A_W = area of grounded wall, A_A = area of anode surface, and $\mu = 1.5\sqrt{m_e / m_i}$,

$$A_A/A_W < \mu \quad \rightarrow \text{electron sheath}$$

$$\mu < A_A/A_W < 1.7\mu \quad \rightarrow \text{transition}$$

$$1.7\mu < A_A/A_W \quad \rightarrow \text{ion sheath}$$

Computational Model



Neutral He plasma is generated in the repopulation region (T_e = 4 eV, T_i = 0.1 eV) at a rate to match experimental densities in the near-anode region, $n_i = n_e$ ~10^9/cm^3 (~2 x 10^9/cm^3 in the repopulation region).

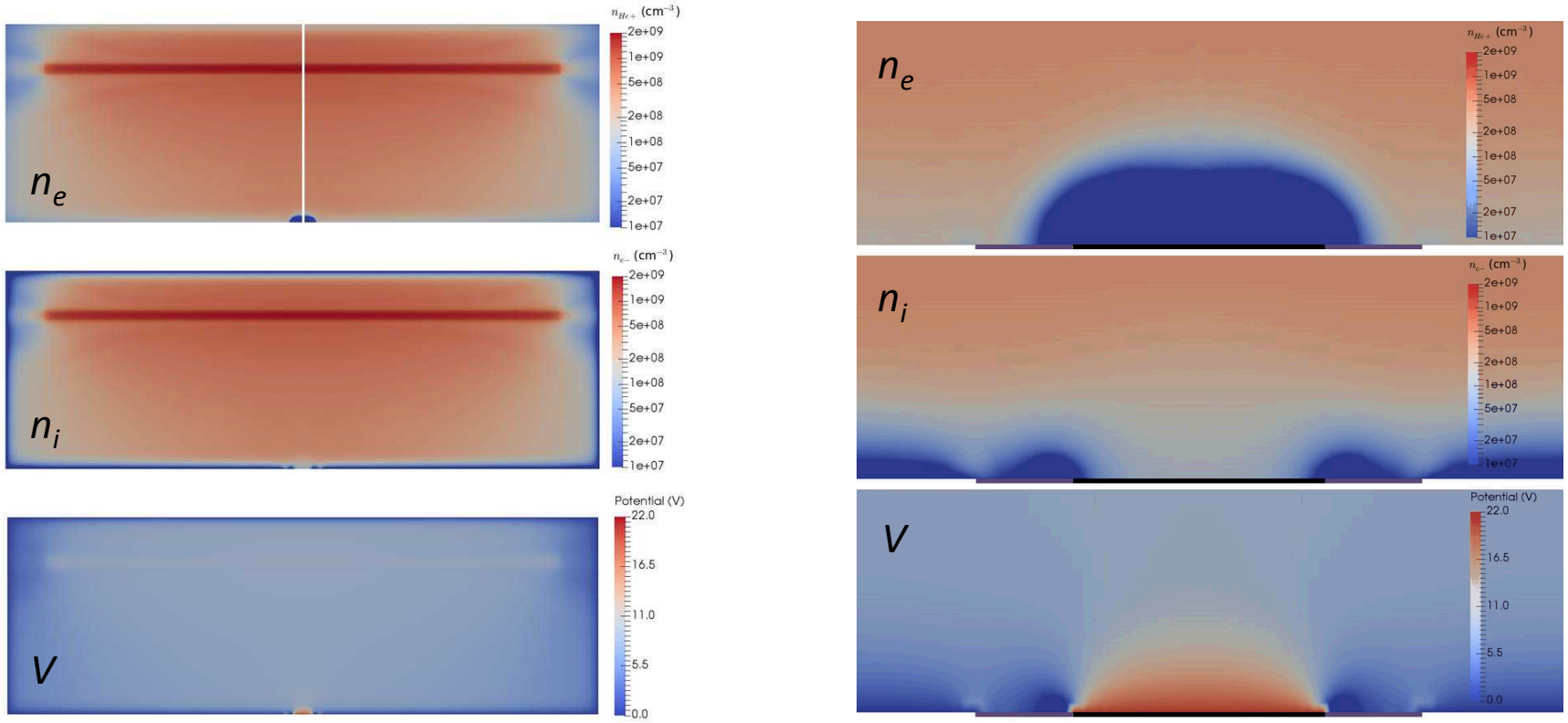
Anode potential is V = 20 V. Other walls grounded.

Anode sizes were (0.72, 1.00, 1.35, 1.46, 1.58, 1.70, 1.89, 2.08, 2.25) x μ.

λ_D = 333 μm → Δx = 111 μm
$2/\omega_p$ = 793 ps → Δt = 100 ps

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

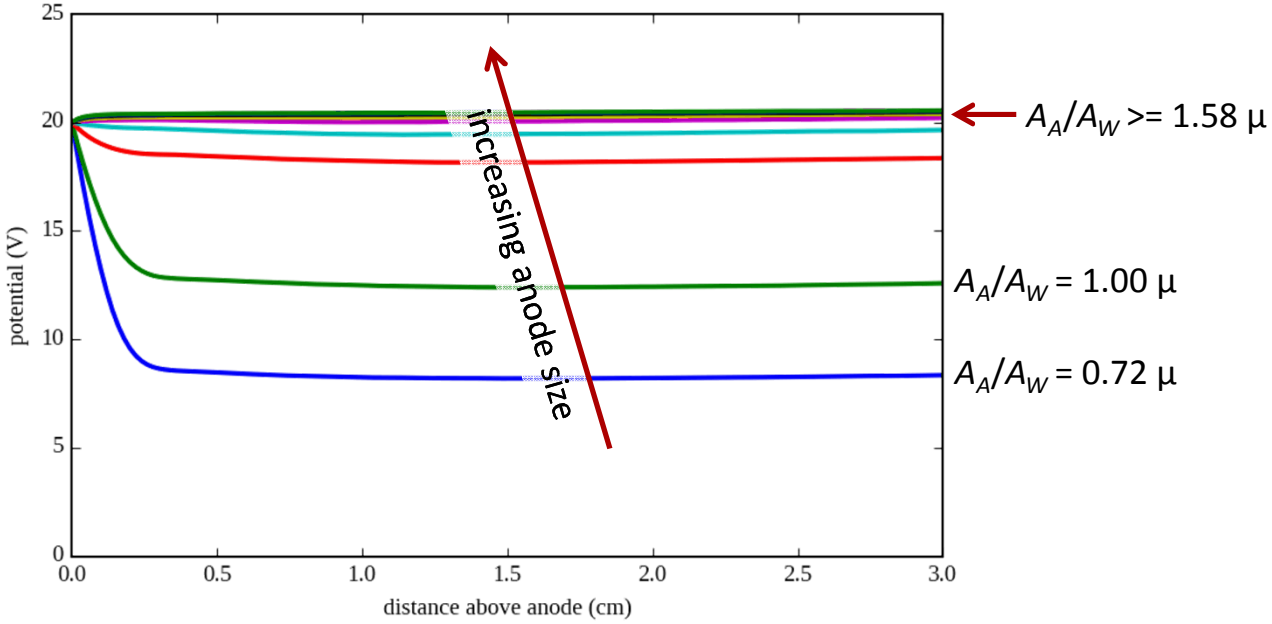
Computational Model

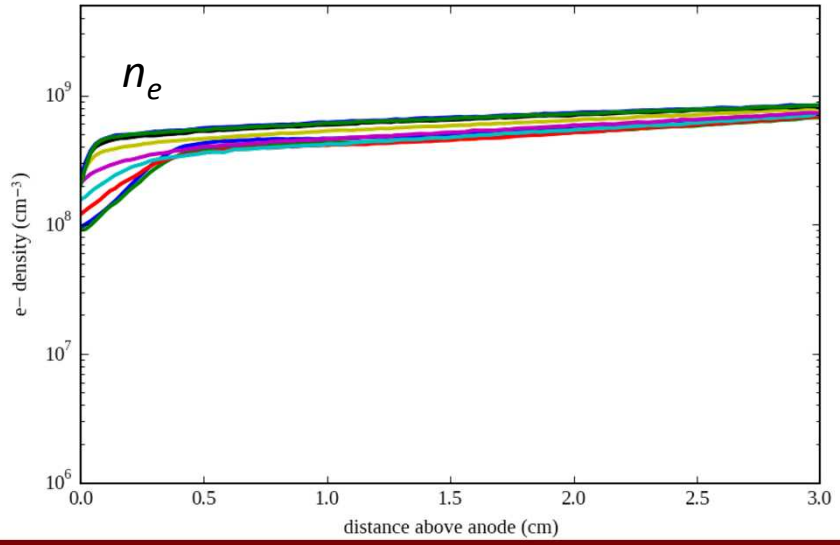


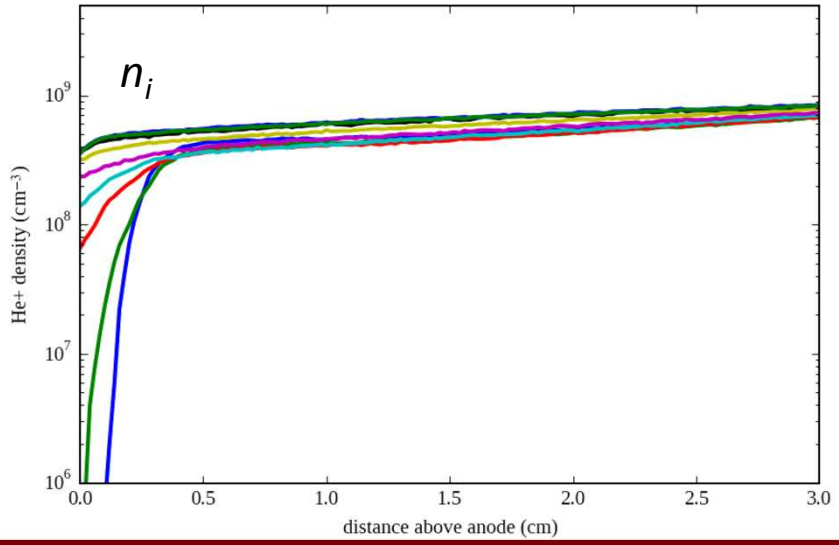
Solutions for A_A/A_W = 0.72 µ

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

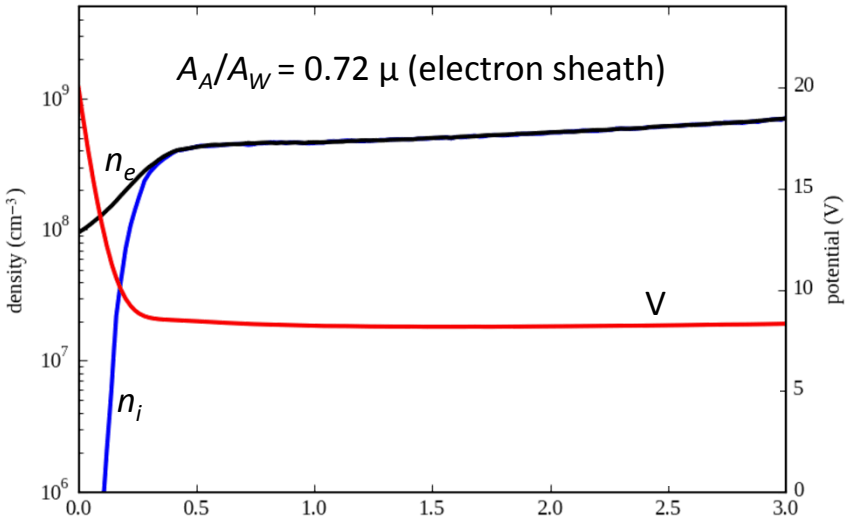
Results

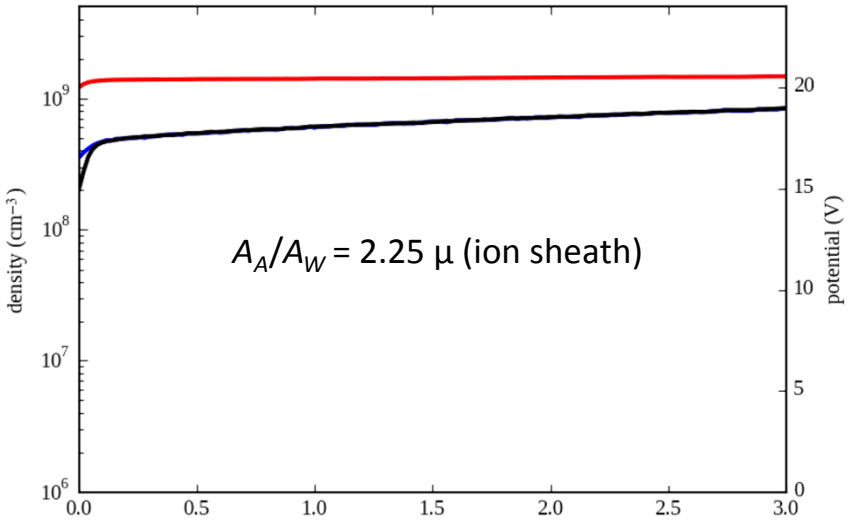

potential (V)
distance above anode (cm)
increasing anode size
A_A/A_W >= 1.58 µ
A_A/A_W = 1.00 µ
A_A/A_W = 0.72 µ

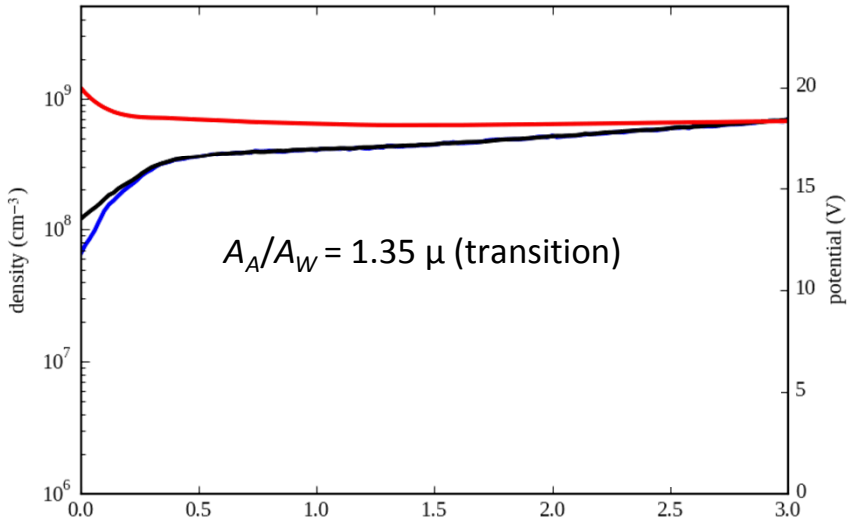

n_e
e– density (cm⁻³)
distance above anode (cm)


n_i
He+ density (cm⁻³)
distance above anode (cm)

Results

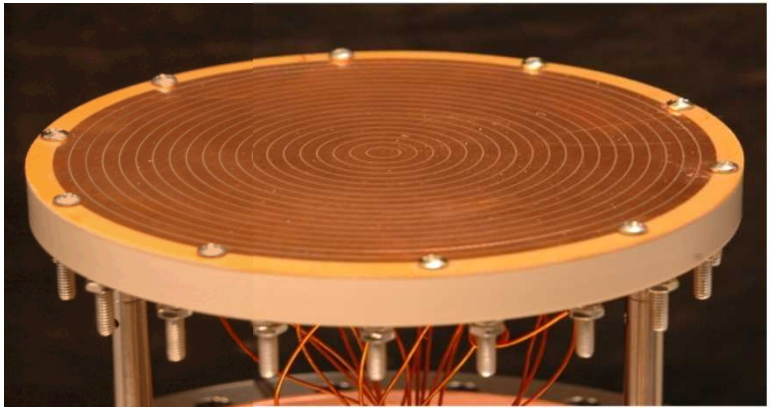

A_A/A_W = 0.72 μ (electron sheath)
n_e
n_i
V
density (cm^{-3})
potential (V)

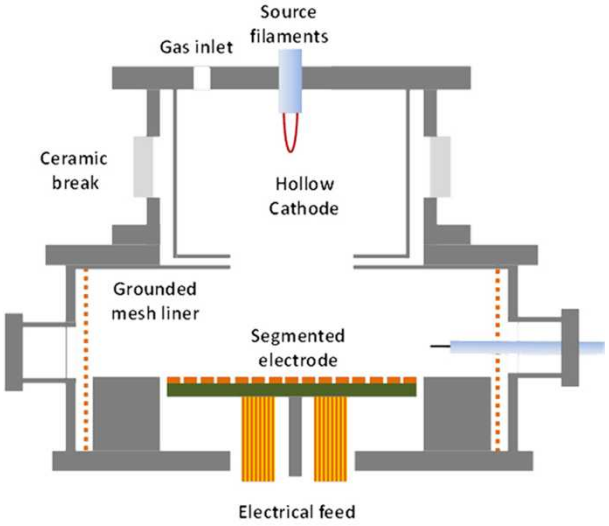

A_A/A_W = 2.25 μ (ion sheath)
density (cm^{-3})
potential (V)

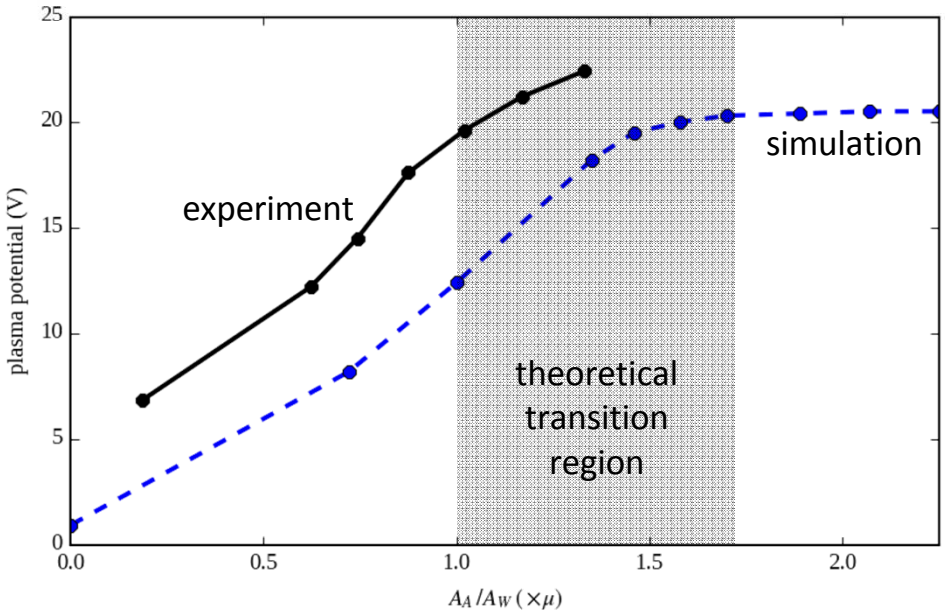

A_A/A_W = 1.35 μ (transition)
density (cm^{-3})
potential (V)

Comparison to Experiment and Theory

From (Barnat, Phys. Plasmas 103512, 2014)







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 ~1.86 x 10^5 mm^2. So positively biased surfaces >= ~10 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 ~7.6 mm diameter sphere, to avoid impact (and experimental and computational results imply even larger).

Thank you for your attention!