Open Drift Path Magnetron Cathodes

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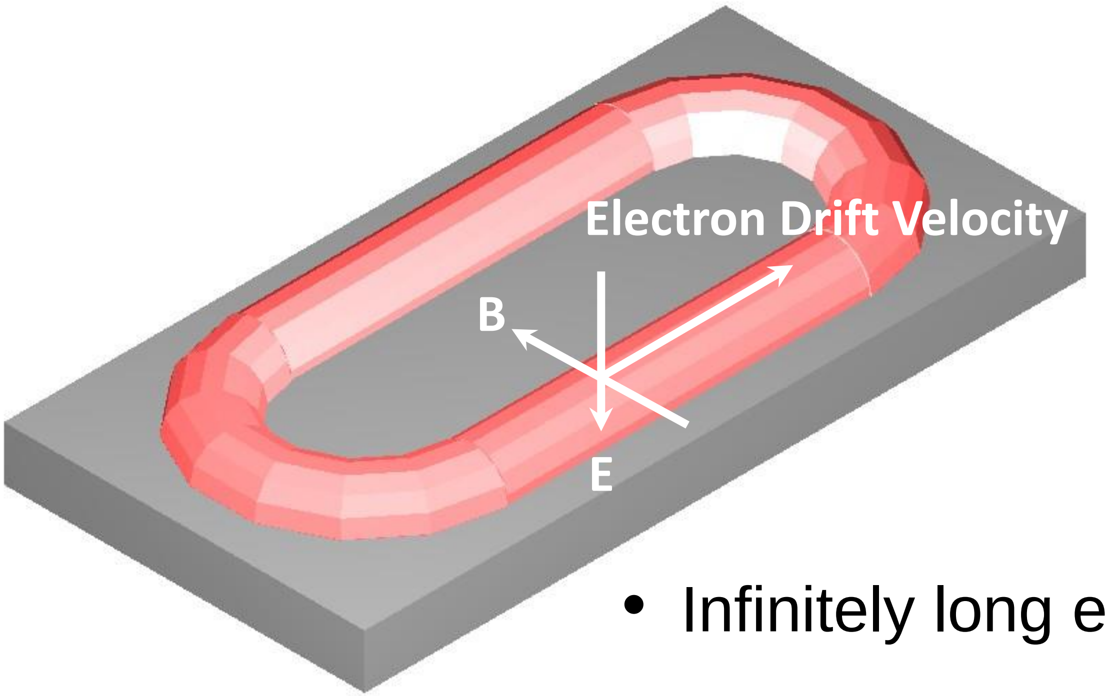
When the Surface Really Matters

Introduction

- **Purpose:** Investigate the performance of magnetron cathodes with open electron drift paths
- **Rationale:**
  - ODP cathodes could provide a significant improvement over rotatable magnetrons for large planar substrates
  - High target utilization with far simpler cathode and target designs resulting in lower cost, easier maintenance, higher reliability
- **Outline of the talk:**
  - Model calculations
  - Qualitative measurements

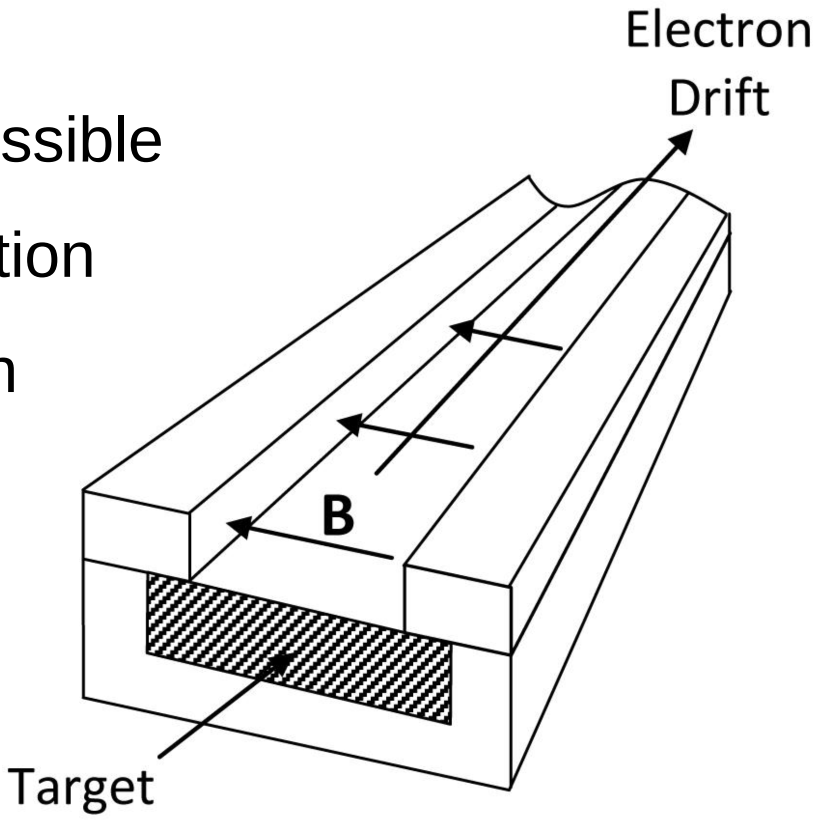
Conventional Closed Drift Path Planar Magnetron



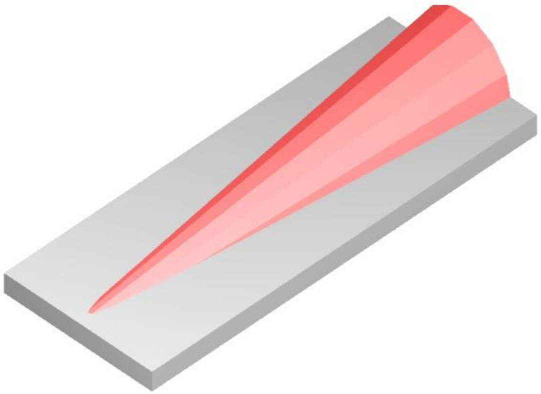
- Infinitely long electron drift path
- Uniform magnetic field not possible
- Reduced target utilization

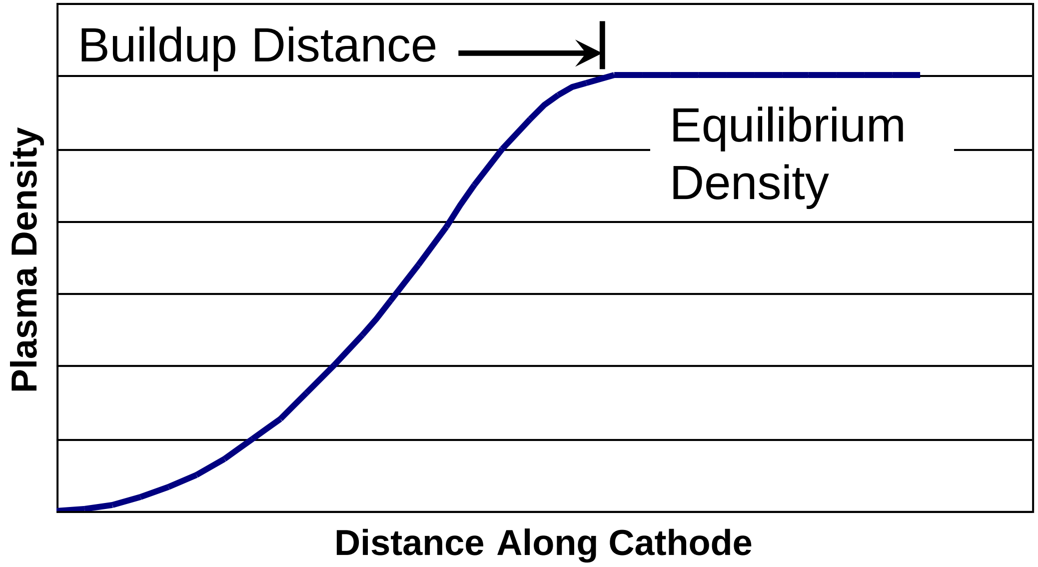
Open Drift Path Planar Magnetron

- Uniform magnetic field possible
  - Excellent target utilization
  - Simple cathode design
- Finite length drift path
  - Non-uniform plasma along length
  - Linear triodes



Open Drift Path Magnetron

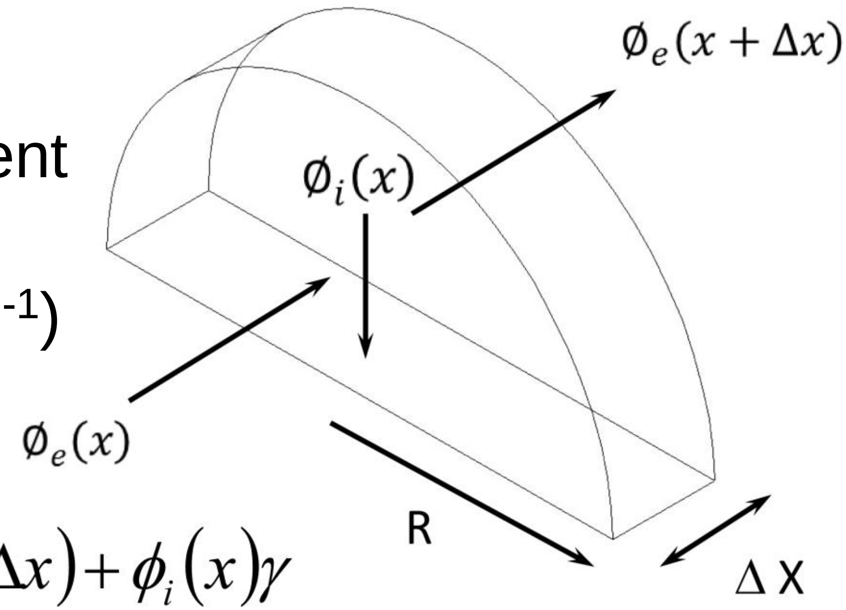




- What factors affect the buildup distance?
- Can it be made short enough for useful ODP cathodes?

Model

Drift path segment



ϕ_e = electron drift flux (s^{-1})

ϕ_i = target ion flux (s^{-1})

$$\phi_e(x+\Delta x) = \phi_e(x)(1+\rho\sigma\Delta x) + \phi_i(x)\gamma$$

ρ = neutral gas density

σ= electron impact ionization cross-section

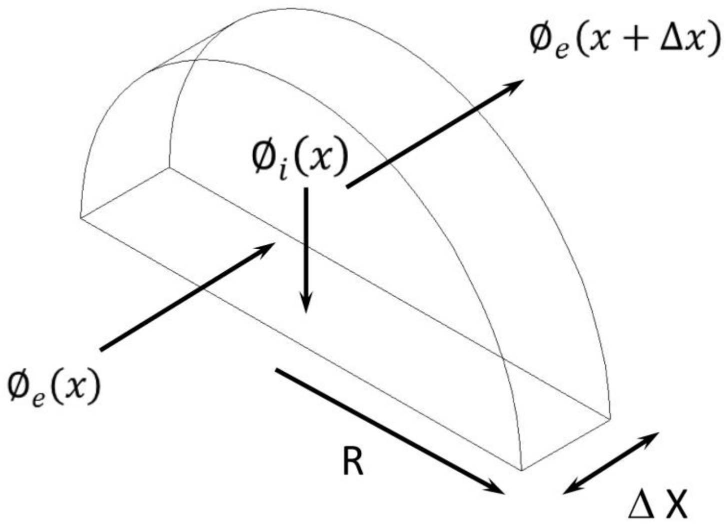
γ = secondary electron emission coefficient

Model (continued)

$$\phi_e(x+\Delta x) = \phi_e(x)(1+\rho\sigma\Delta x) + \phi_i(x)\gamma$$

$$\phi_e(x) = N_e(x)V\frac{\pi R^2}{2}$$

$$\varphi_i(x) = 0.6\sqrt{\frac{kT_e}{m_i}}N_e(x)(2R\Delta x)$$



$N_e(x)$ = electron density

V = electron drift velocity

kT_e = electron energy

m_i = ion mass

Model (continued)

Substituting and taking the limit gives

$$N_e(x) = N_e(0)e^{\left(\rho\sigma + 0.6\sqrt{\frac{kT_e}{m_i}\frac{4\gamma}{\pi RV}}\right)x}$$

For Ar at 10 mT, $\rho\sigma$ ~ 9.1 m^{-1}

γ for Al sputtered in Ar is 0.09

γ for Al sputtered in Ar/O_2 is ~0.5

$(kT_e/m_i)^{1/2}$ = ion velocity at the sheath edge

Assume $(kT_e/m_i)^{1/2} / V = 0.2$*

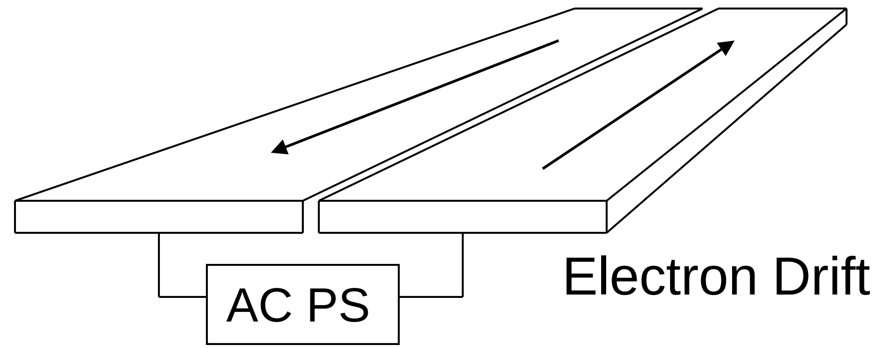
*S. M. Rossnagel and H. R. Kaufman, "Induced drift currents in circular planar magnetrons," J. Vac. Sci. Technol. A5 (1), 88, 1987

Model (continued)

Three Cases:

1) Single ODP cathode sputtering Al in Ar with DC power

2) Dual ODP cathodes sputtering Al in Ar with AC power:
residual plasma above instantaneous anode increases $N_e(0)$ when sheath expands



3) Dual ODP cathodes sputtering Al in Ar/O_2 with AC power: both $N_e(0)$ and γ greater than in Case 1

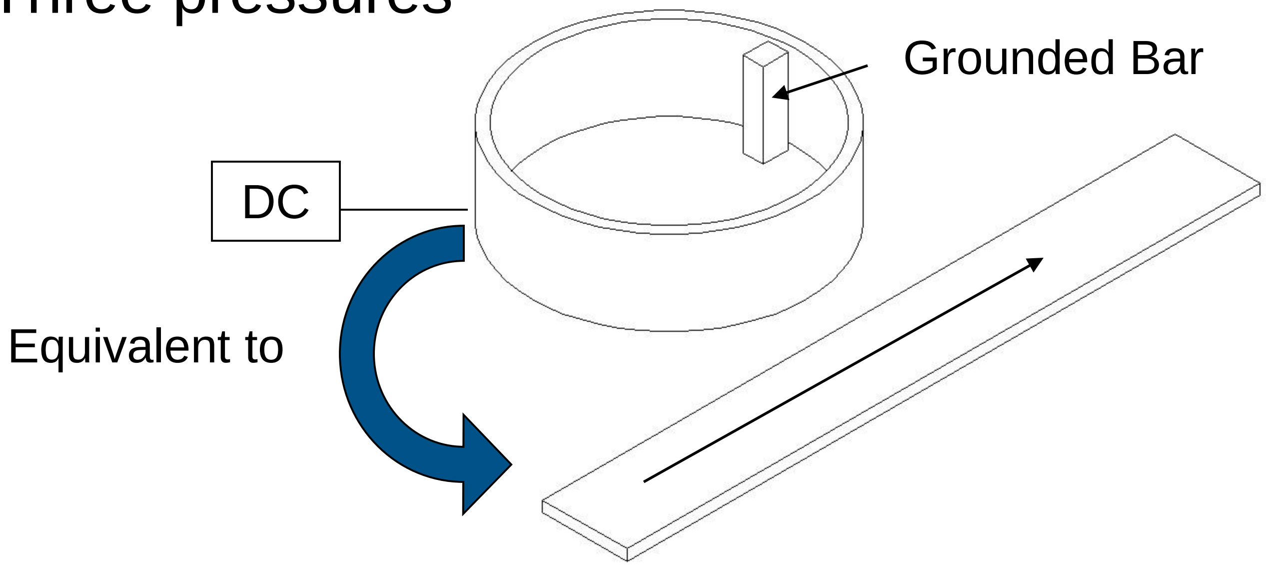
Model (continued)

	$N_e(0)$ (m^{-3})	$\rho\sigma$ @10mT (m^{-1})	$0.6\sqrt{\frac{kT_e}{m_i}\frac{4\gamma}{\pi RV}}$ (m^{-1})	x when $N_e(x) = 10^{16}/m^3$ (m)
Case 1	1	9.1	1.4	3.5
Case 2	10^{10}	9.1	1.4	1.3
Case 3	10^{10}	9.1	7.8	0.8

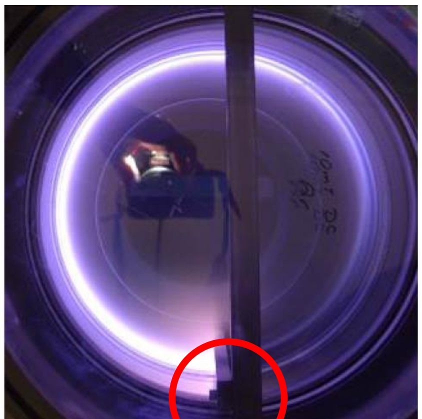
- $10^{16}/m^3$ typical of equilibrium plasma densities in magnetrons
- $N_e(0) = 10^{10}/m^3$ chosen to represent residual plasma as target goes negative and sheath expands

Experiment: Case 1, Al in Ar, DC

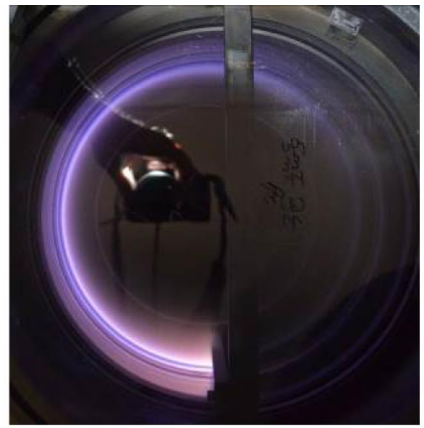
- One ϕ 33 cm by 10 cm high cylindrical magnetron with bar to interrupt racetrack
- 1 kW max total power, DC
- Three pressures



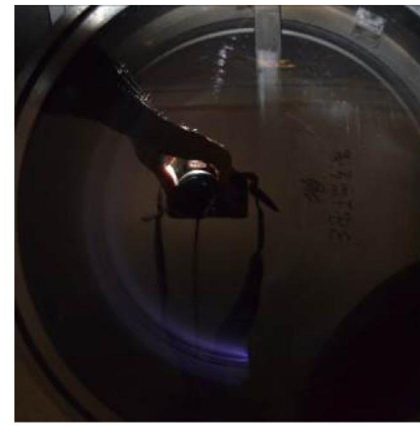
Experiment: Case 1, Al in Ar, DC



1 kW DC, 10 mT, Ar



250 W DC, 5 mT, Ar

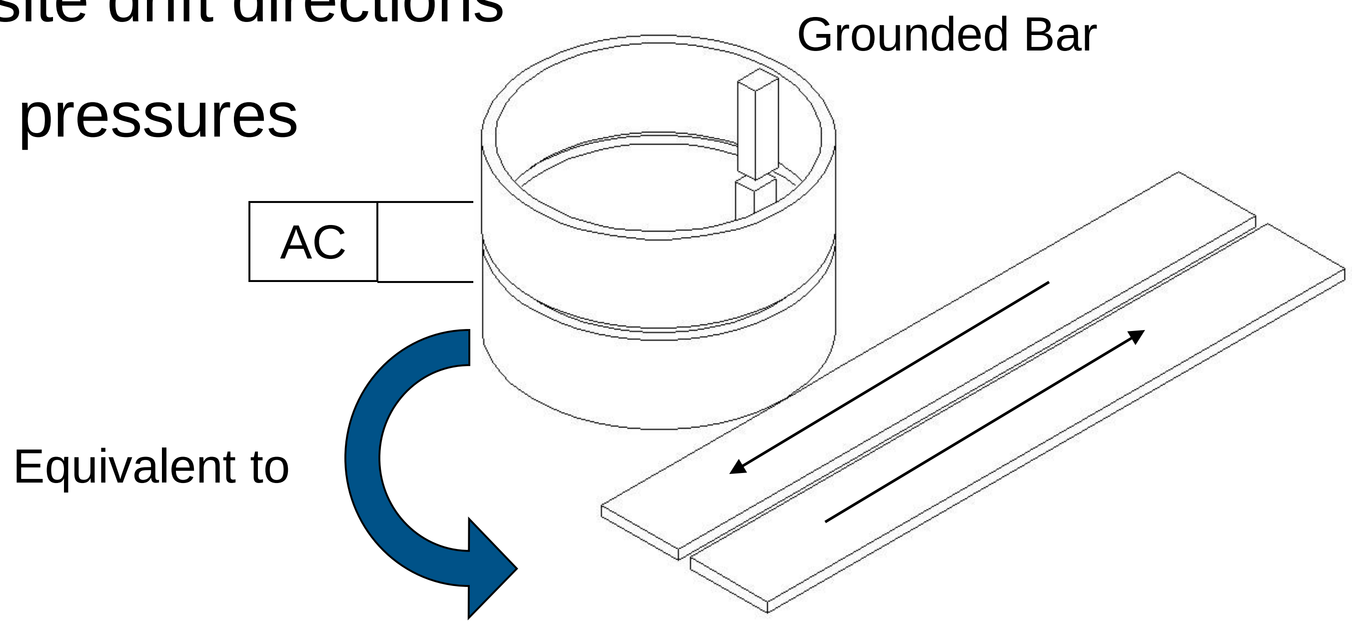


100 W DC, 3.5 mT, Ar

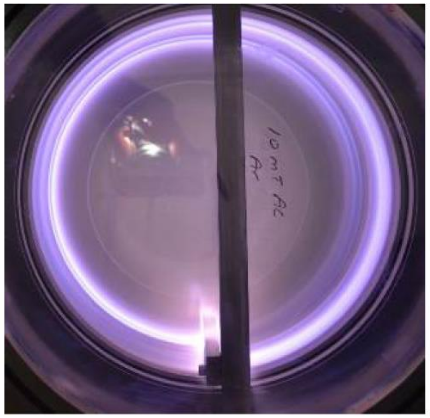
Grounded Bar

Experiment: Case 2, Al in Ar, AC

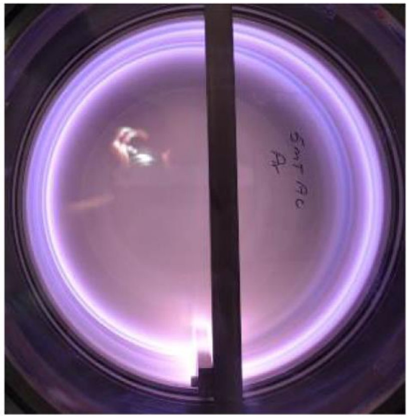
- Two ϕ 33 cm by 10 cm high cylindrical magnetrons with bar to interrupt racetracks
- 1 kW total power to both cathodes, 40 kHz
- Opposite drift directions
- Three pressures



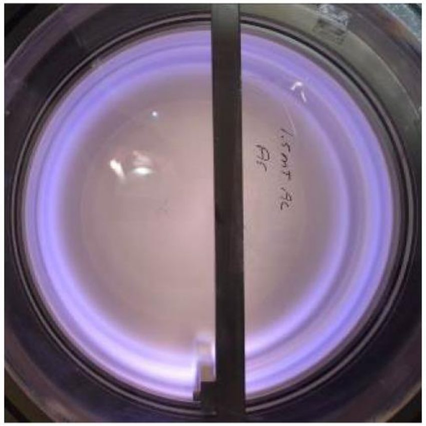
Experiment: Case 2, Al in Ar, AC



1 kW AC, 10 mT, Ar



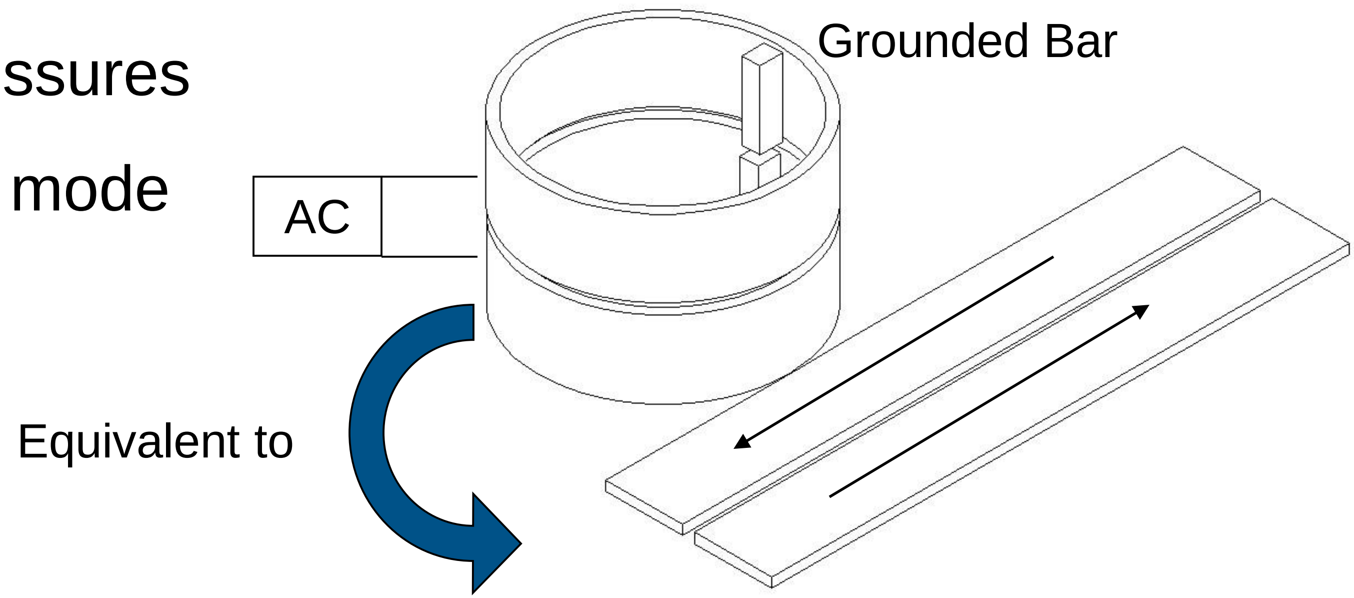
1 kW AC, 5 mT, Ar



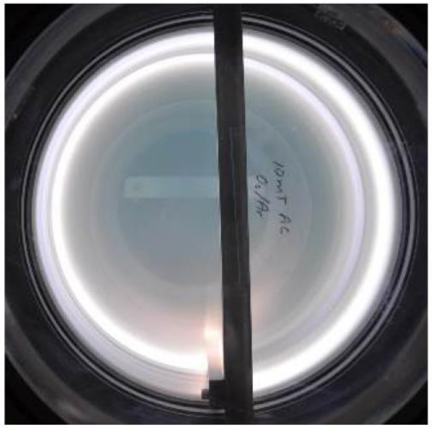
1 kW AC, 1.5 mT, Ar

Experiment: Case 3, Al in Ar/O_2, AC

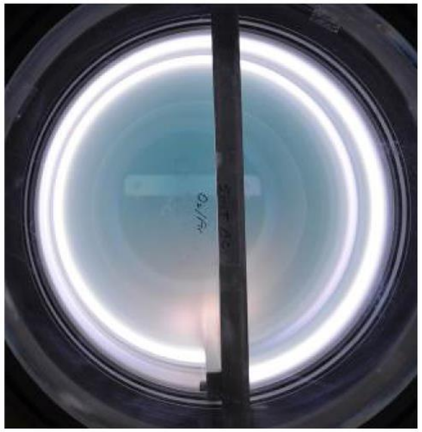
- Two ϕ 33 cm by 10 cm high cylindrical magnetrons with bar to interrupt racetracks
- 1 kW total power to both cathodes, 40 kHz
- Opposite drift directions
- Three pressures
- Poisoned mode



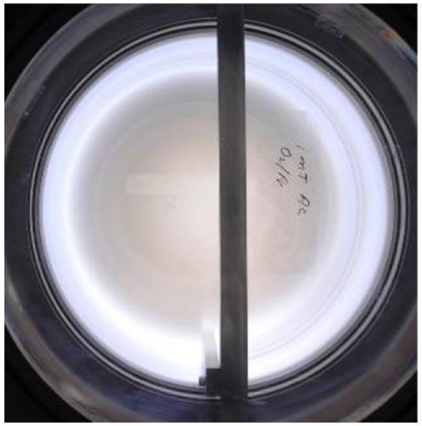
Experiment: Case 3, Al in Ar/O_2, AC



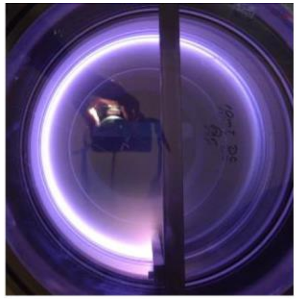
1 kW AC, 10 mT, Ar/O_2



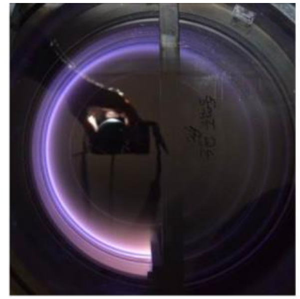
1 kW AC, 5 mT, Ar/O_2



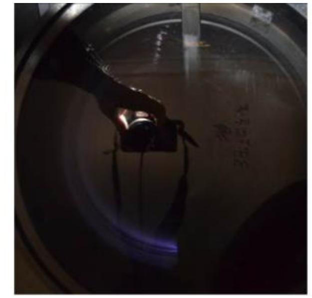
1 kW AC, 1 mT, Ar/O_2



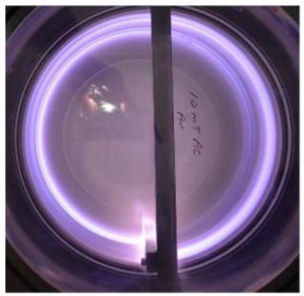
1 kW DC, 10 mT, Ar



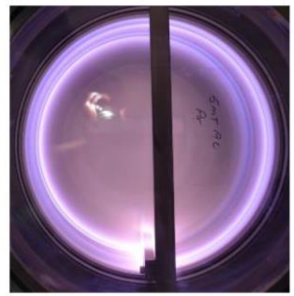
250 W DC, 5 mT, Ar



100 W DC, 3.5 mT, Ar

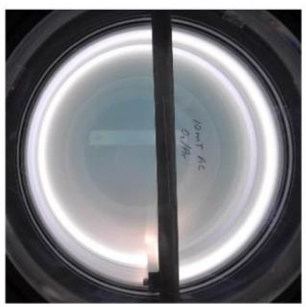


1 kW AC, 10 mT, Ar

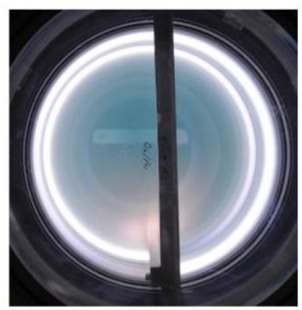


1 kW AC, 5 mT, Ar

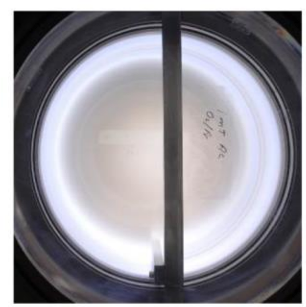
1 kW AC, 1.5 mT, Ar



1 kW AC, 10 mT, Ar/O_2



1 kW AC, 5 mT, Ar/O_2



1 kW AC, 1 mT, Ar/O_2

Discussion

- Results show qualitative predictions of model are correct
  - Buildup distance shortened for coupled cathodes
  - Increase in γ further reduces buildup distance
- Lower pressures appear to reduce buildup distance in Cases 2 and 3
  - $\mu_B/\mu_0 = [1+ C(B/\rho)^2]^{-1}$
- Distances less than a meter (much less?) possible in some cases

Discussion

- Dual cathodes several meters long widely used for AC reactive sputtering
- Open drift path cathodes may offer simple, inexpensive alternative to conventional and rotatable magnetrons
- Factors for further investigation
  - Frequency of AC power
  - Strength and geometry of magnetic field
  - Cathode termination

Thank You!