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

\( \phi_e = \text{electron drift flux \ (s^{-1})} \)

\( \phi_i = \text{target ion flux \ (s^{-1})} \)

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

\( \rho = \text{neutral gas density} \)

\( \sigma = \text{electron impact ionization cross-section} \)

\( \gamma = \text{secondary electron electron emission coefficient} \)
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
Substituting and taking the limit gives

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

For Ar at 10 mT, \( \rho \sigma \sim 9.1 \text{ m}^{-1} \)

\( \gamma \) for Al sputtered in Ar is 0.09

\( \gamma \) for Al sputtered in Ar/O\(_2\) is \( \sim 0.5 \)

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

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

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 $\gamma$ greater than in Case 1
Model (continued)

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

- $10^{16}/m^3$ 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 $\phi$ 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 \( \phi 33 \text{ cm} \) 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\textsubscript{2}, AC

- Two $\phi$ 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

Equivalent to

Grounded Bar

AC

Equivalent to
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$_2$
Discussion

• Results show qualitative predictions of model are correct
  ▪ Buildup distance shortened for coupled cathodes
  ▪ Increase in $\gamma$ 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!