CHARACTERISTICS OF ASYMMETRIC CAPACITIVELY COUPLED PLASMA SOURCES OPERATING WITH CLEAN AND CONTAMINATED ELECTRODES*

Natalia Yu. Babaeva\textsuperscript{a)}, Jae Koo Lee\textsuperscript{b)} and Mark J. Kushner\textsuperscript{a)}

\textsuperscript{a)}Iowa State University
Ames, IA 50011, USA
natalie5@iastate.edu, mjk@iastate.edu
http://uigelz.ece.iastate.edu

\textsuperscript{b)}Pohang University of Science and Technology
Pohang, South Korea jkl@postech.ac.kr

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AGENDA

- Clean and contaminated plasma processing systems
- Energy dependence of secondary electron emission coefficient
- Consequences of SEEC
  - High voltage asymmetric discharges
  - Low voltage asymmetric discharges
  - MERIE (Magnetically Enhanced Reactive Ion Etching)
- Concluding Remarks
POLYMERIZING CHEMISTRIES IN PLASMA SOURCES

• Plasma processing reactors having different materials use chemistries that are purposely (e.g., c-C₄F₈) or incidentally polymerizing (e.g., Cl₂/HBr).

• The evolution of surfaces during a process change reaction rates. Example: Ar/Cl₂ ICP with quartz window.

• Increase in Cl* correlates with increasing thickness of Si-O film which is removed by a SF₆ plasma clean.

SECONDARY ELECTRON EMISSION COEFFICIENT

- The secondary electron emission coefficient (SEEC) from ion impact is a function of the incident ion energy.
- Capacitively coupled plasmas are sensitive to “contamination” due to dependence of SEECs on the cleanliness of the surface.
- Dirty metals generally have a large dynamic range of SEEC.
- SEECs for Ar⁺ on clean and contaminated metals can differ by factors of 10.
  - High voltage: $\gamma$ larger
  - Low voltage: $\gamma$ smaller

SEECs IN CAPACITIVELY COUPLED SYSTEMS

- The consequences secondary electron emission in clean and contaminated capacitively coupled discharges were computationally investigated.

- High voltage system: 1-d Particle in Cell-Monte Carlo Simulation

- Low voltage system: 2-d Plasma hydrodynamics model (“nonPDPSIM”)

- MERIE (Magnetically Enhanced Reactive Ion Etcher): 2-d Hybrid Model (“HPEM”)

- Argon, 20-100 mTorr, 10-30 MHz, 200-1500 V (peak-peak)
Self bias on the powered electrode produces higher ion energies than on the grounded electrode.

With contamination the SEEC for the powered electrode can be an order of magnitude larger (0.4 versus 0.07).

Ar, 30 mTorr, 27 MHz, 1500 V (p-p)
PLASMA DENSITY FOR HIGH VOLTAGE CCP

- **30 mTorr:**
  - On average, $\gamma$ is larger in dirty system.
  - Higher rate of beam ionization increases plasma density.

- **20 mTorr:**
  - Larger $\gamma$ in dirty system enables plasma to be sustained.
  - Clean system (lower $\gamma$) is likely below self-sustaining.
  - Processing with polymerization is not “constant” even with fixed voltage operation.
  - **Ar, 27 MHz, 1500 V (p-p)**

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LOW VOLTAGE CCPs: BEAM IONIZATION

- At low voltage, $\gamma$ is larger for clean electrodes.
- As the chamber is contaminated during the process, beam ionization decreases.
- Difference in location of ionization increases asymmetry, and produces more negative $V_{dc}$.
- Ar, 100 mTorr 10 MHz, 300 V
LOW VOLTAGE CCPs: ELECTRON DENSITY

- Higher beam ionization source with clean electrodes results in higher electron density.
- More uniform ionization source enabled by beam electrons produces more uniform plasma.
- Higher conductivity effects electron heating.
- Ar, 100 mTorr 10 MHz, 300 V
**LOW VOLTAGE CCPs: ELECTRON TEMPERATURE**

- Higher conductivity with clean electrodes reduces electron heating in bulk.
- Hot electrons are more localized near the sheaths.
- Ar, 100 mTorr, 10 MHz, 300 V
• Heating of bulk electrons scales with frequency while ionization by beam electrons decreases.

• Differences between clean and dirty systems at higher frequencies (> 10s MHz) are nominal.

• Ar, 100 mTorr, 30 MHz, 300 V

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CONSEQUENCES OF STOPPING POWER: MERIEs

- Low pressure CCPs at moderate voltages (100s eV beam electrons) typically do not have large contributions from beam ionization due to low stopping power of gas.

- MERIE (Magnetically Enhanced RIE) with transverse magnetic fields greatly increase stopping power of secondary electrons.

- Consequences of contamination and variation in SEEC in MERIE systems can be expected to be greater.
• $\gamma = 0.01$ (V = 330 V, $V_{dc} = -31$ V)

• With $B=0$, stopping power of gas is low. Large changes in $\gamma$ produce nominal changes in ion density and voltage.

• $\gamma = 0.45$ (V = 360 V, $V_{dc} = -38$ V)

• Ar, 100 mTorr, 10 MHz
• $\gamma = 0.01$ ($V = 450$ V, $V_{dc} = -76$ V)

• $\gamma = 0.45$ ($V = 330$ V, $V_{dc} = -37$ V)

• With $B=100$ G, beam electrons are totally confined in plasma. Changes in $\gamma$ produce larger changes in ion density and voltage.

• Ar, 100 mTorr, 10 MHz

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• Voltage adjusts to changes in $\gamma$ to keep power constant.
• Resulting changes in ion density, though larger with B-field, are not dramatic. Change in voltage does affect in energy distributions.
• Ar, 100 mTorr, 10 MHz
• Change in voltage with $\gamma$ produces change in ion energy distribution to wafer.

• Large B-field is more sensitive to $\gamma$.

• Ar, 100 mTorr, 10 MHz
• **B = 0**

  - B=0: Increasing $\gamma$ produces nominal increase in ion density and decrease in power as secondary electrons are poorly utilized.

• **B = 100 G**

  - B=100 G: Increasing $\gamma$ produces more ionization, larger ion density and increase in power.

• Ar, 100 mTorr, 10 MHz
CONCLUDING REMARKS

• Contamination of electrodes and changes in SEEC can produce significant changes in properties of CCPs.

• With contamination:
  • High powers: SEEC increases, plasma density increases.
  • Low powers: SEEC decreases and plasma may extinguish.

• Stopping power of gas for beam electrons denotes sensitivity of plasma to changes in SEEC. MERIE systems are particularly sensitive due to high stopping power.

• Effects are mitigated by keeping power constant and accentuated when keeping voltage constant.