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

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AGENDA

- Clean and contaminated plasma processing systems

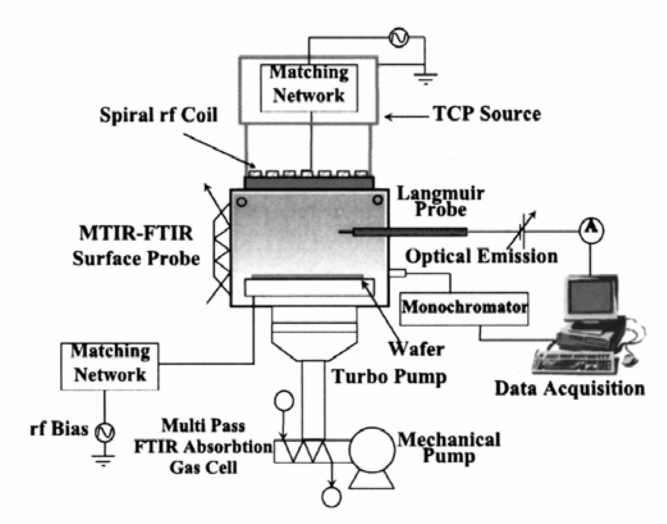
- Energy dependence of secondary electron emission coefficient

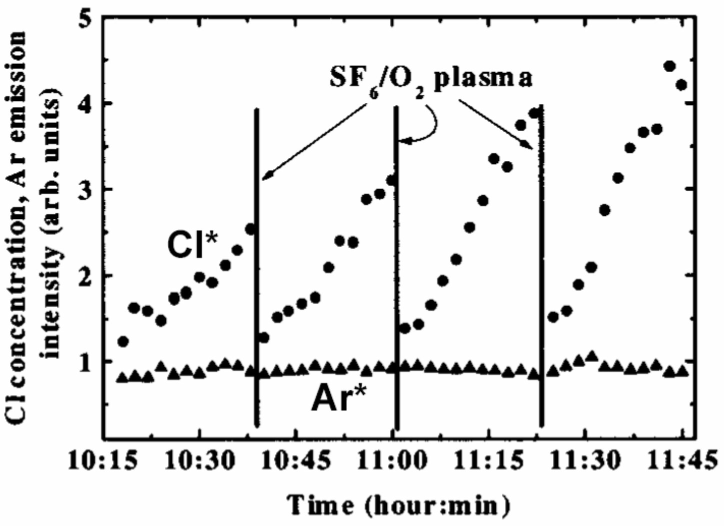
- Consequences of SEEC
    - High voltage asymmetric discharges
    - Low voltage asymmetric discharges
    - MERIE (Magnetically Enhanced Reactive Ion Etching)

- Concluding Remarks

POLYMERIZING CHEMISTRIES IN PLASMA SOURCES

- **Plasma processing reactors having different materials use chemistries that are purposely (e.g., c-C_4F_8) or incidentally polymerizing (e.g., Cl_2/HBr).**
- **The evolution of surfaces during a process change reaction rates. Example: Ar/Cl_2 ICP with quartz window.**



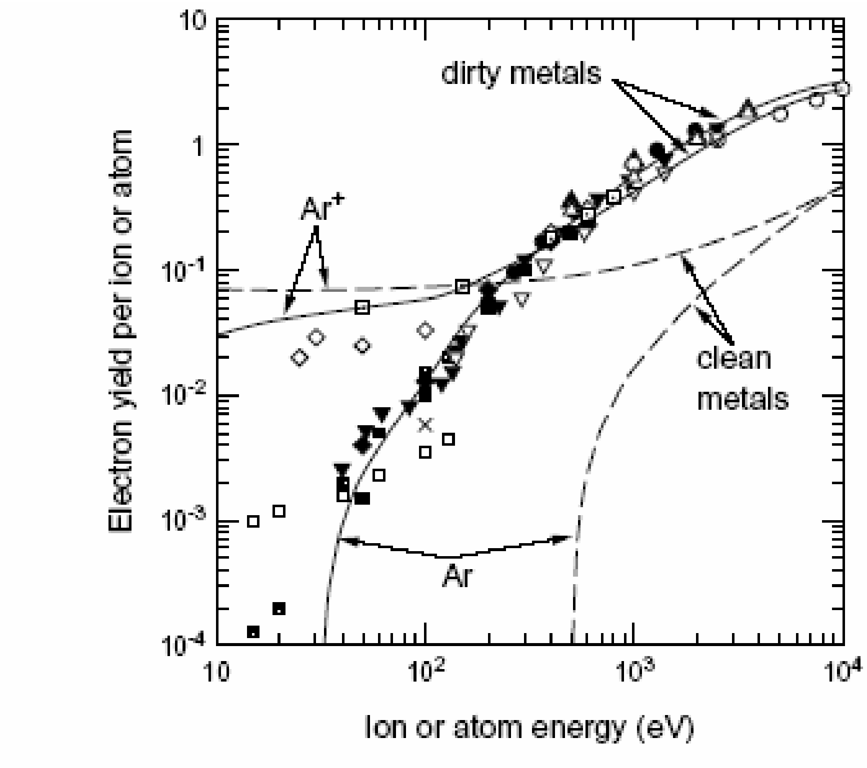


- **Increase in Cl* correlates with increasing thickness of Si-O film which is removed by a SF_6 plasma clean.**

- **Ref: Ullal et al, J. Vac. Sci. Technol. A v20, 43 (2002)**

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.**



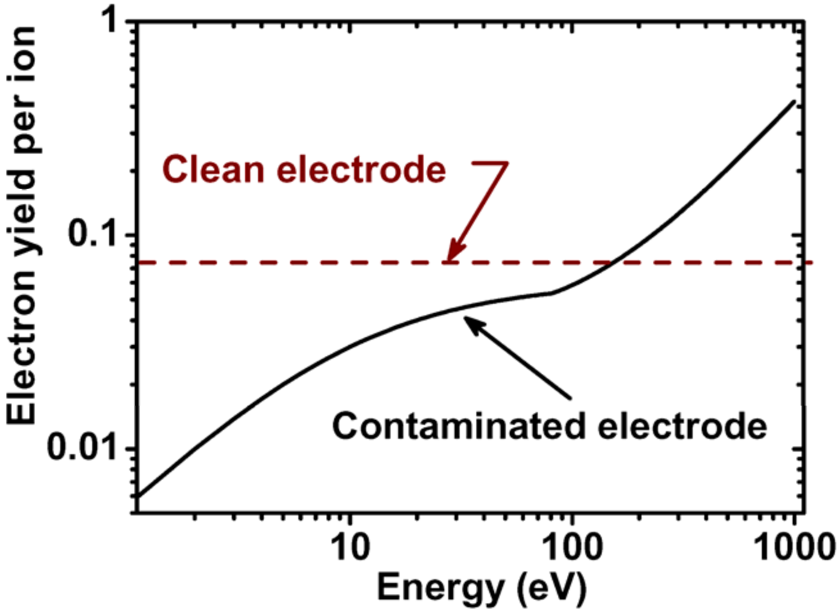
- **SEECs for Ar^+ on clean and contaminated metals can differ by factors of 10.**

- **High voltage: γ larger**
- **Low voltage: γ smaller**

- **A V Phelps and Z Lj Petrovic, Plasma Source Sci. Technol. 8, 21 (1999).**

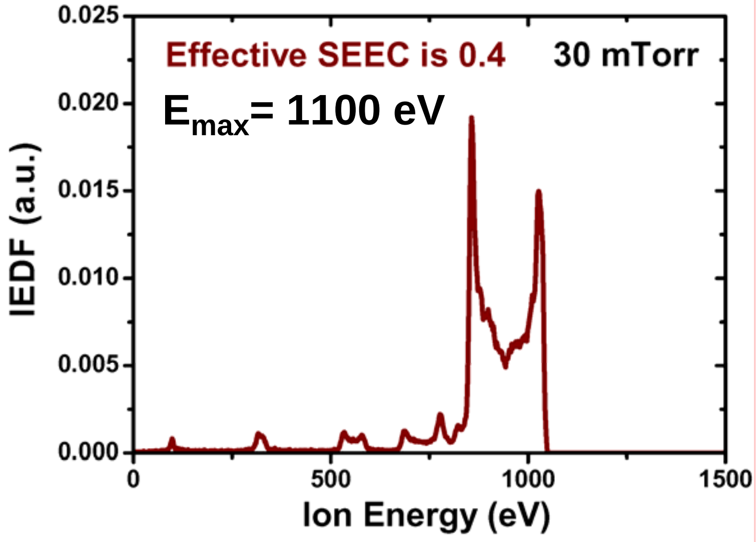
SEECs IN CAPACITIVELY COUPLED SYSTEMS

- **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")**

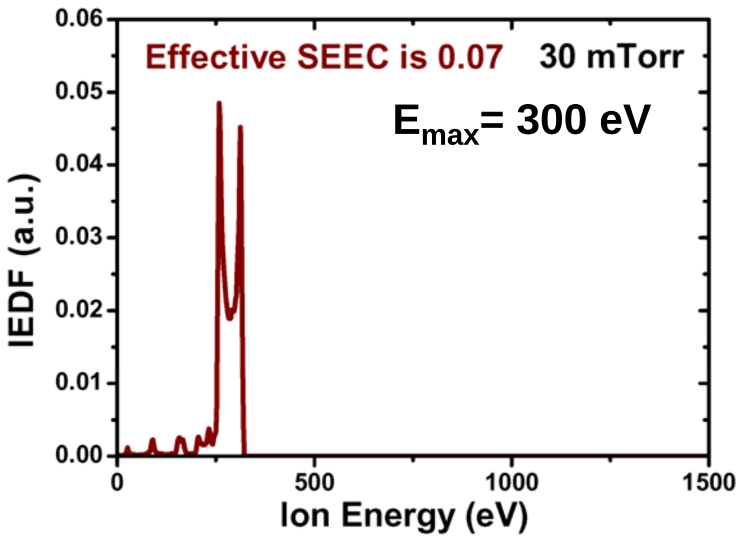


- **MERIE (Magnetically Enhanced Reactive Ion Etcher): 2-d Hybrid Model ("HPEM")**
- **Argon, 20-100 mTorr, 10-30 MHz, 200-1500 V (peak-peak)**

ASYMMETRIC “CONTAMINATED” HIGH VOLTAGE CCP



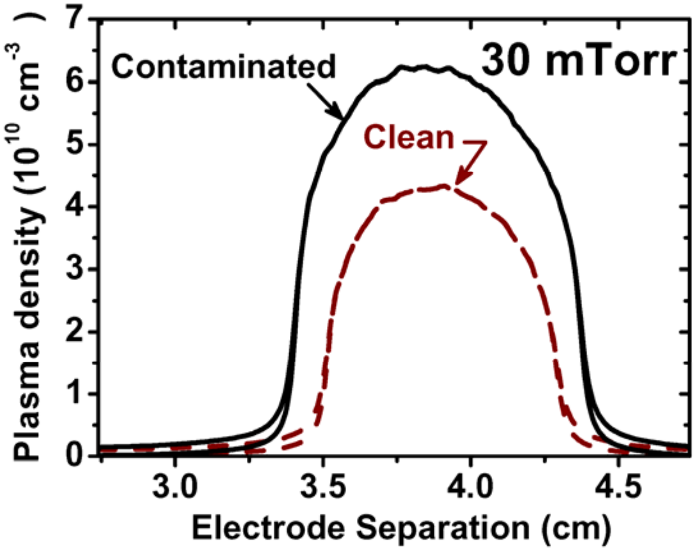
- **Powered Electrode**

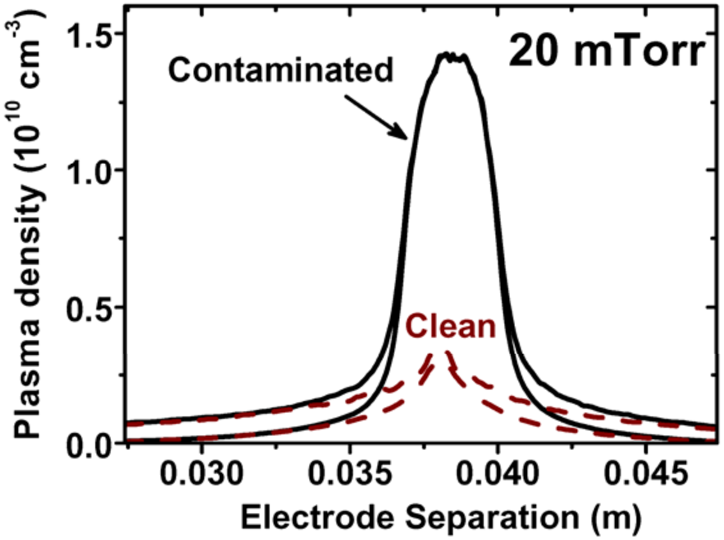


- **Grounded Electrode**

- **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)**

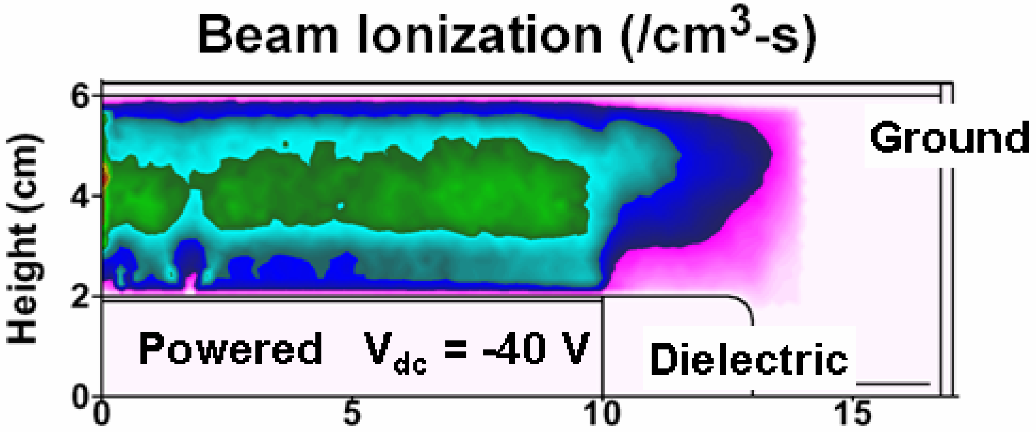
PLASMA DENSITY FOR HIGH VOLTAGE CCP



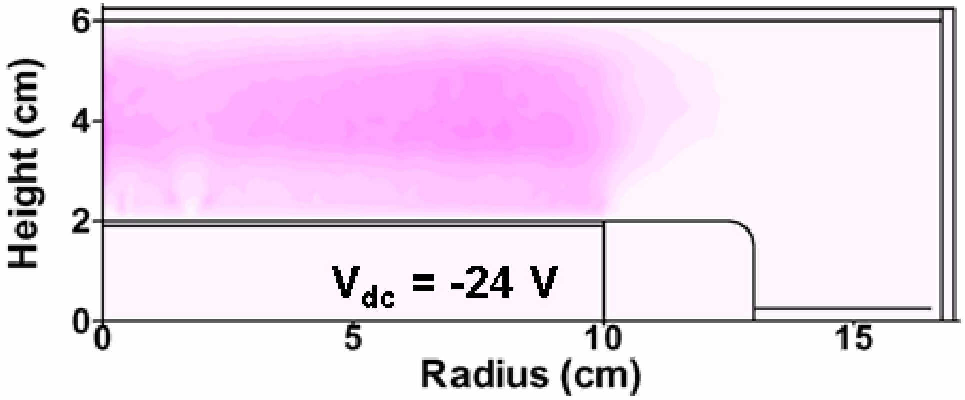


- **30 mTorr:**
  - **On average, γ is larger in dirty system.**
  - **Higher rate of bean ionization increases plasma density.**
- **20 mTorr:**
  - **Larger γ in dirty system enables plasma to be sustained.**
  - **Clean system (lower γ) is likely below self sustaining.**
- **Processing with polymerization is not "constant" even with fixed voltage operation.**
- **Ar, 27 MHz, 1500 V (p-p)**

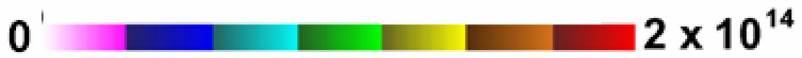
LOW VOLTAGE CCPs: BEAM IONIZATION



- Clean Electrodes

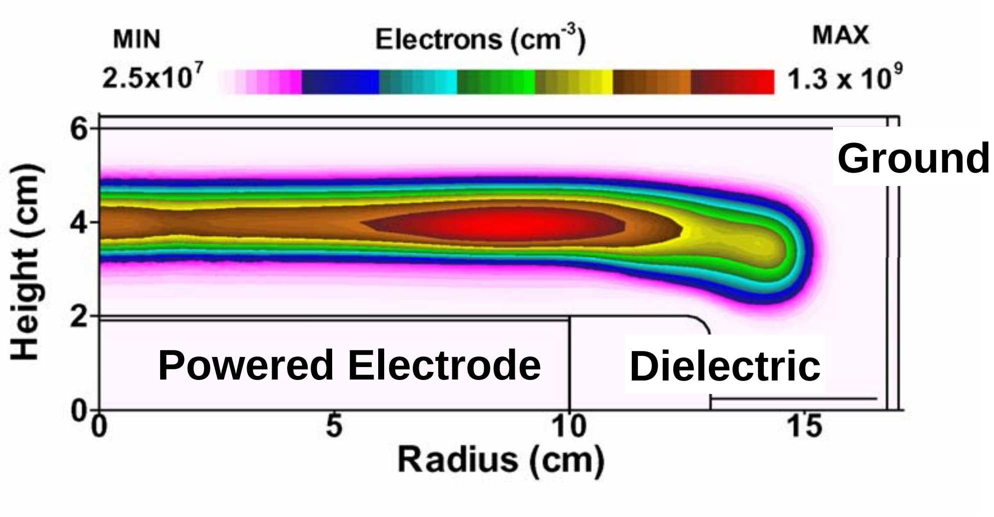


- Dirty Electrodes

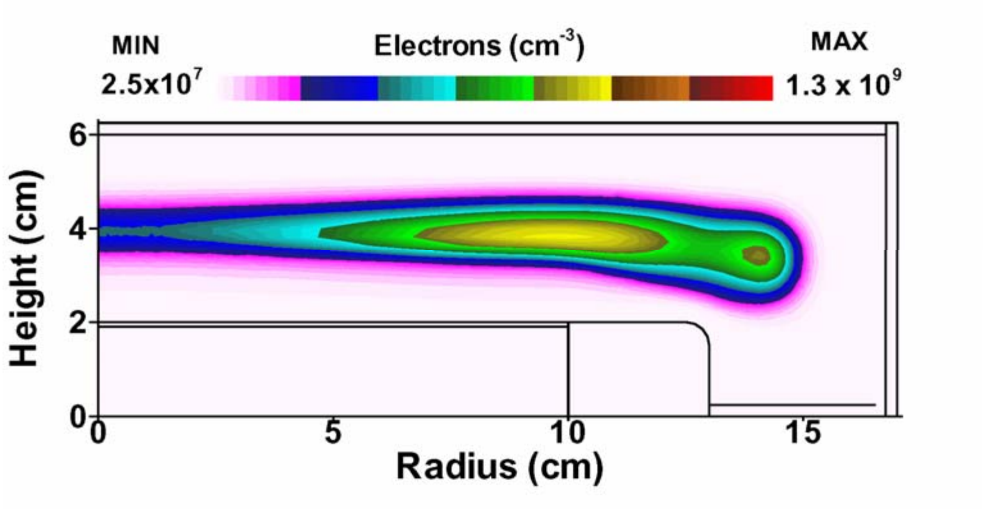


- At low voltage, γ is larger for clean electrodes.
- As the chamber is contaminated during the process, beam ionization decreases.
- Difference in location of ionization increases asymmetry, and produces more negative V_{dc}.
- Ar, 100 mTorr 10 MHz, 300 V

LOW VOLTAGE CCPs: ELECTRON DENSITY



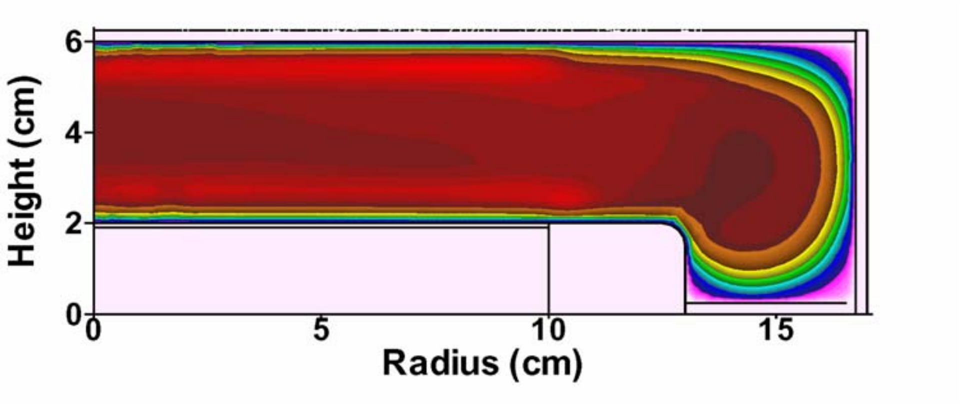
- Clean Electrodes



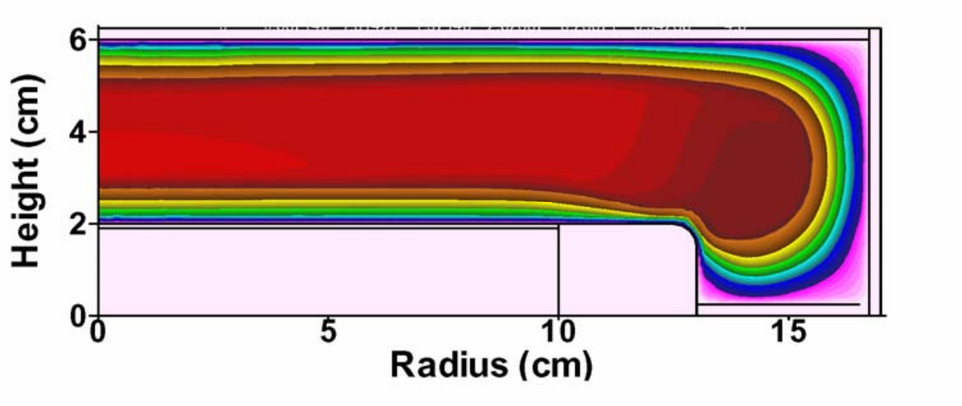
- Dirty Electrodes

- 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

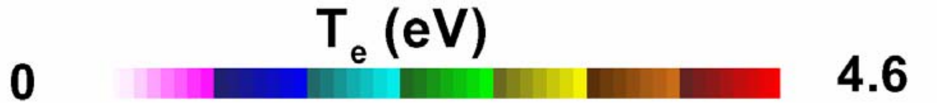
LOW VOLTAGE CCPs: ELECTRON TEMPERATURE



- Clean Electrodes

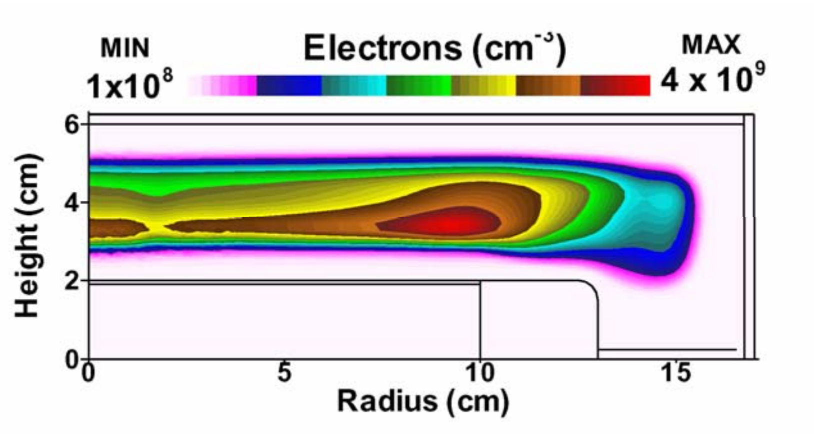


- Dirty Electrodes

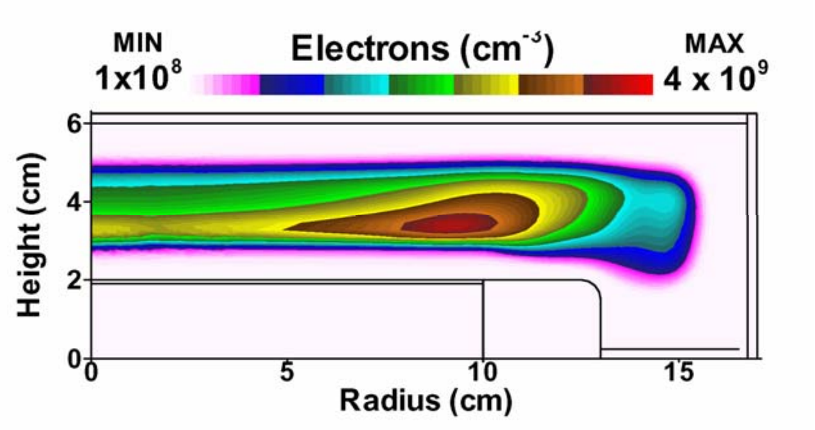


- Higher conductivity with clean electrodes reduces electron heating in bulk.
- Hot electrons are more localized near the sheaths.
- Ar, 100 mTorr, 10 MHz, 300 V

HIGH FREQUENCY CCPs: ELECTRON DENSITY



- Clean Electrodes



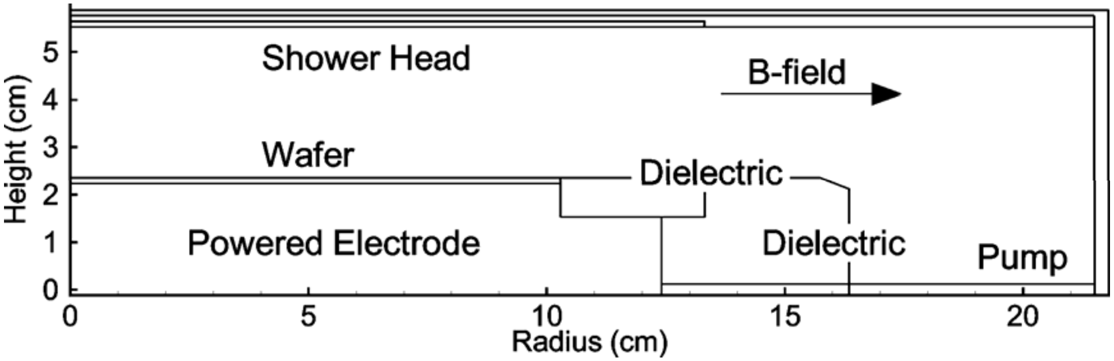
- Dirty Electrodes

- **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**

CONSEQUENCES OF STOPPING POWER: MERIEs

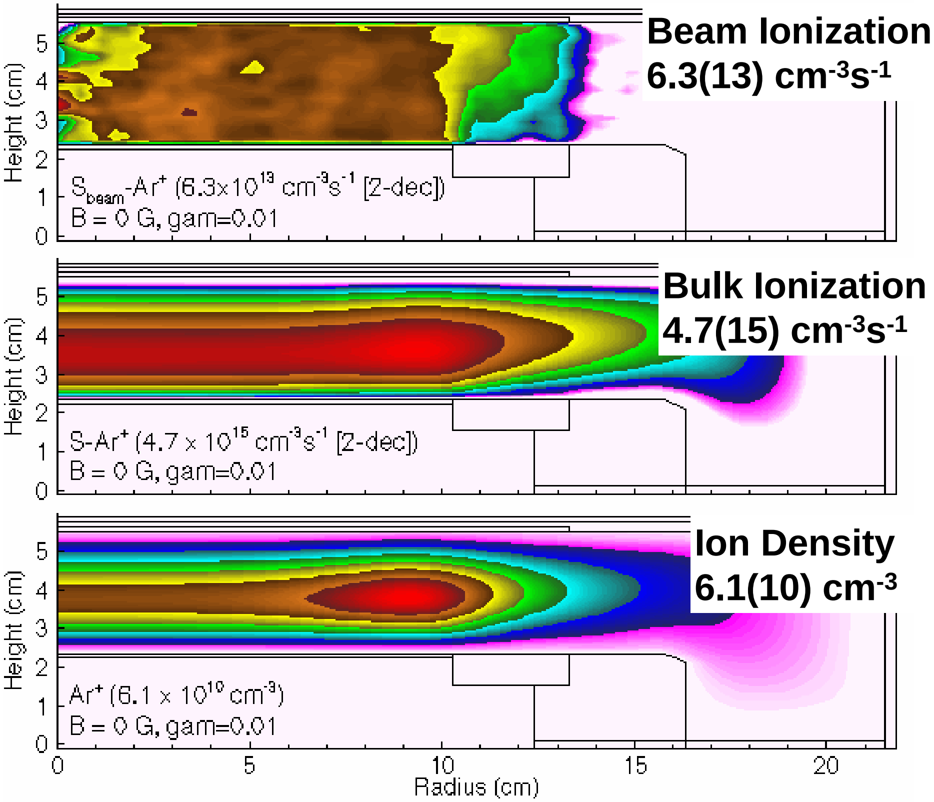
- Low pressure CCPs at moderate voltages (100s eV beam electrons) typically do not have large contributions from beam ionization due to low stopping power of gas.

- 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.

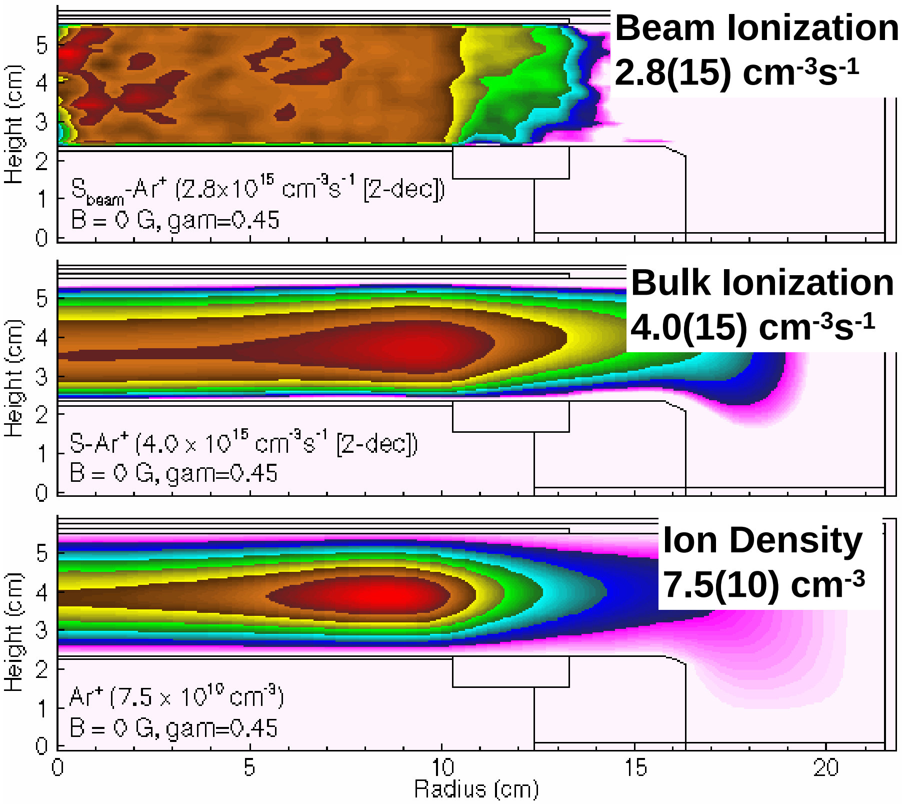
PLASMA PARAMETERS: MERIE, B=0, 250 W



Beam Ionization
6.3(13) $cm^{-3}s^{-1}$

Bulk Ionization
4.7(15) $cm^{-3}s^{-1}$

Ion Density
6.1(10) cm^{-3}



Beam Ionization
2.8(15) $cm^{-3}s^{-1}$

Bulk Ionization
4.0(15) $cm^{-3}s^{-1}$

Ion Density
7.5(10) cm^{-3}

- γ = 0.01 (V = 330 V, V_{dc}= -31 V)
- γ = 0.45 (V = 360 V, V_{dc}= -38 V)

- With B=0, stopping power of gas is low. Large changes in γ produce nominal changes in ion density and voltage.
- Ar, 100 mTorr, 10 MHz

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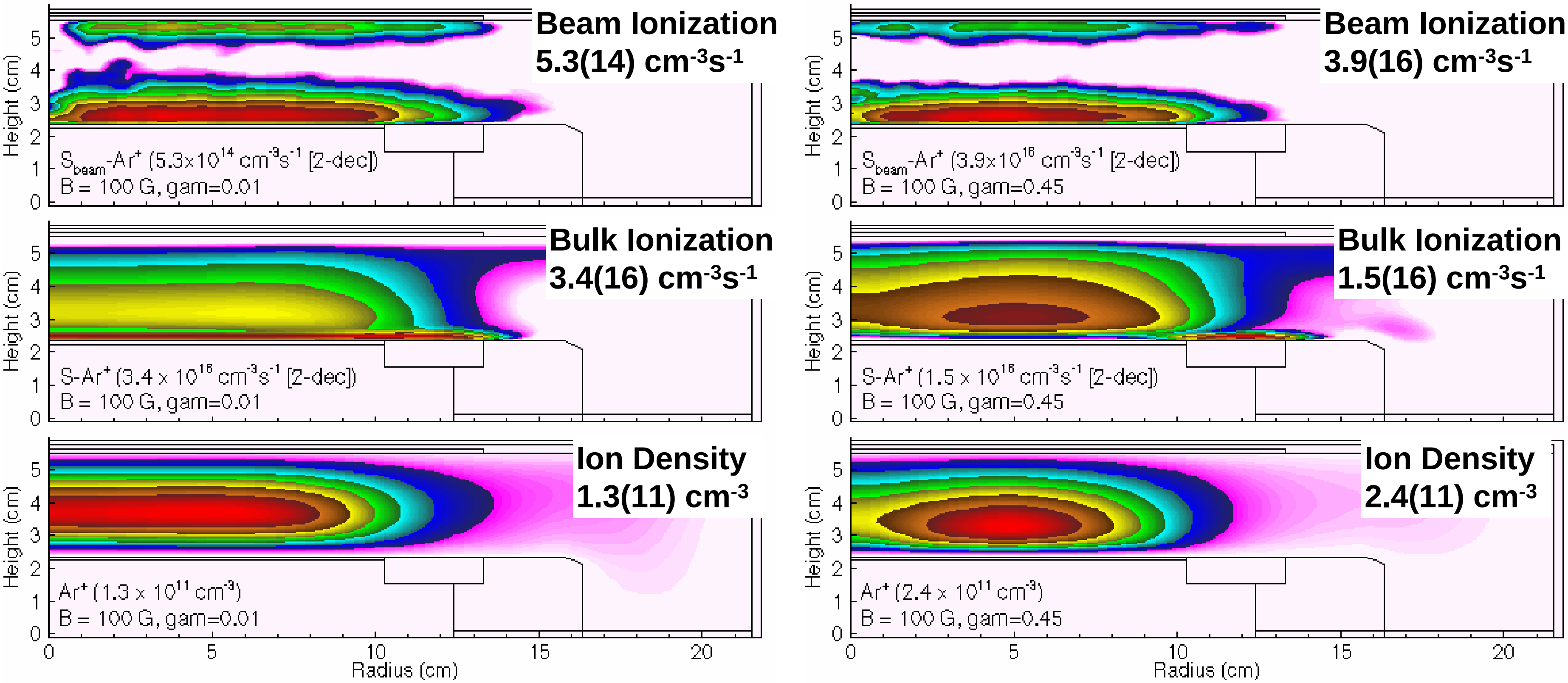
PLASMA PARAMETERS: MERIE, B=100 G, 250 W



Beam Ionization
5.3(14) cm^{-3}s^{-1}

Beam Ionization
3.9(16) cm^{-3}s^{-1}

Bulk Ionization
3.4(16) cm^{-3}s^{-1}

Bulk Ionization
1.5(16) cm^{-3}s^{-1}

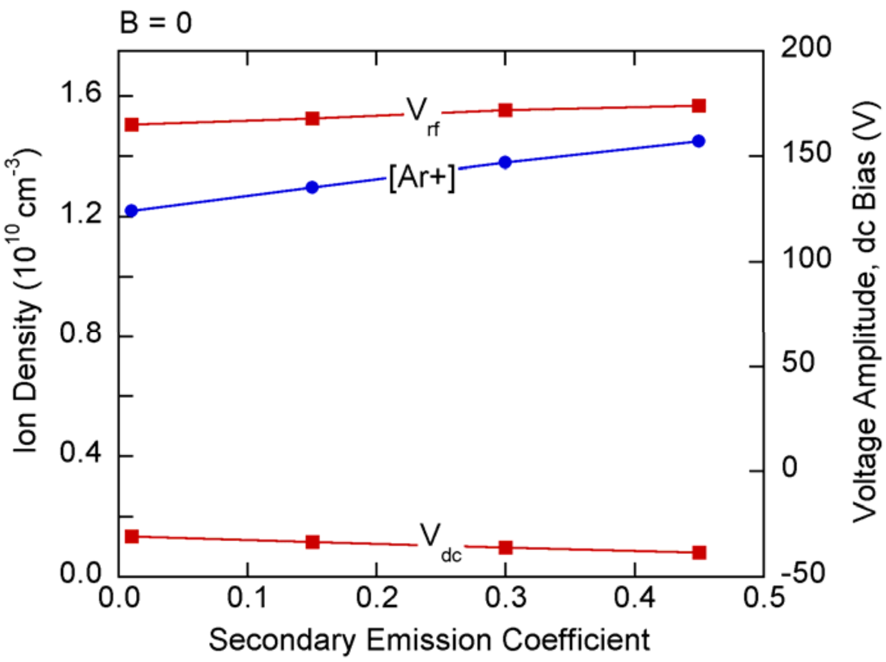
Ion Density
1.3(11) cm^{-3}

Ion Density
2.4(11) cm^{-3}

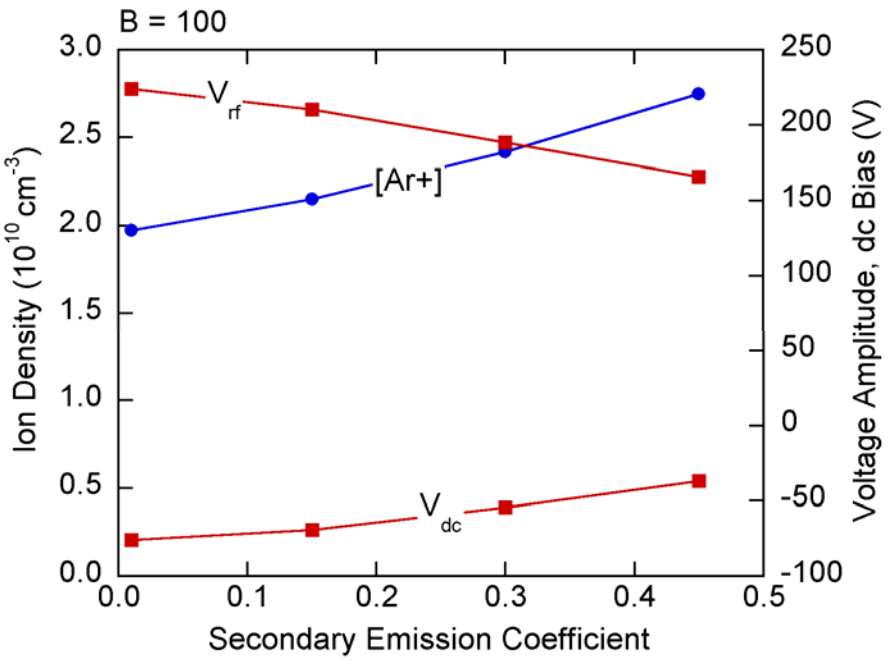
- **γ = 0.01 (V = 450 V, V_{dc}= -76 V)**
- **γ = 0.45 (V = 330 V, V_{dc}= -37 V)**

- **With B=100 G, beam electrons are totally confined in plasma. Changes in γ produce larger changes in ion density and voltage.**
- **Ar, 100 mTorr, 10 MHz**

PLASMA PARAMETERS: MERIE B=0, 100 G, 250 W



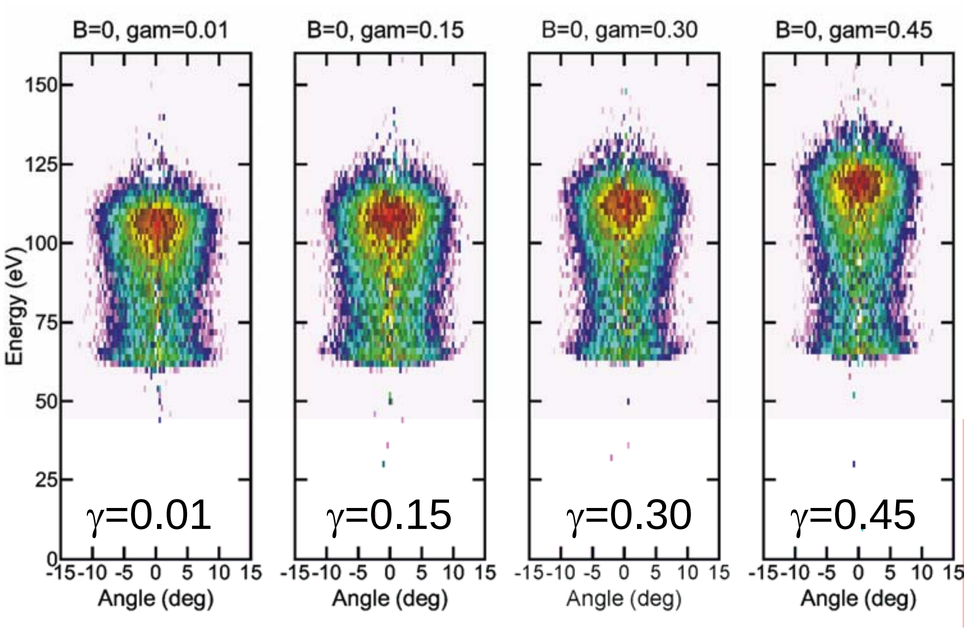
- **B = 0**



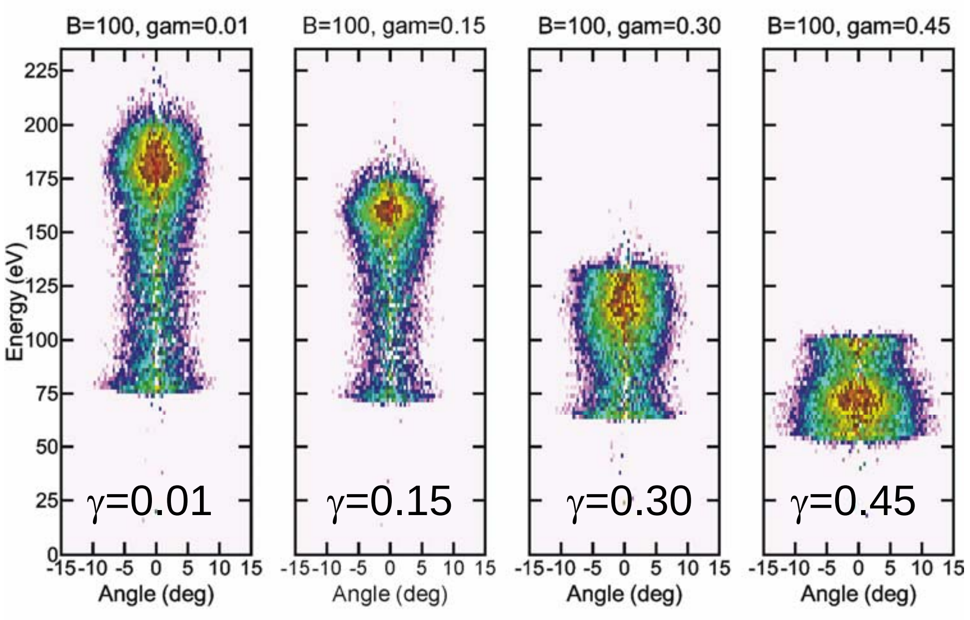
- **B = 100 G**

- **Voltage adjusts to changes in γ 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**

ION ENERGY DISTRIBUTIONS
B=0, 100 G, 250 W



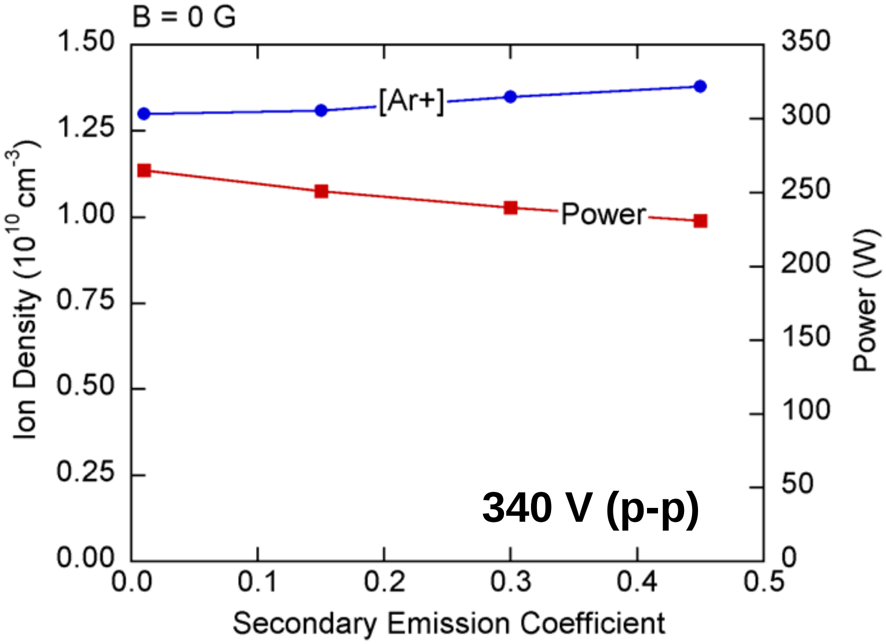
- **B = 0**



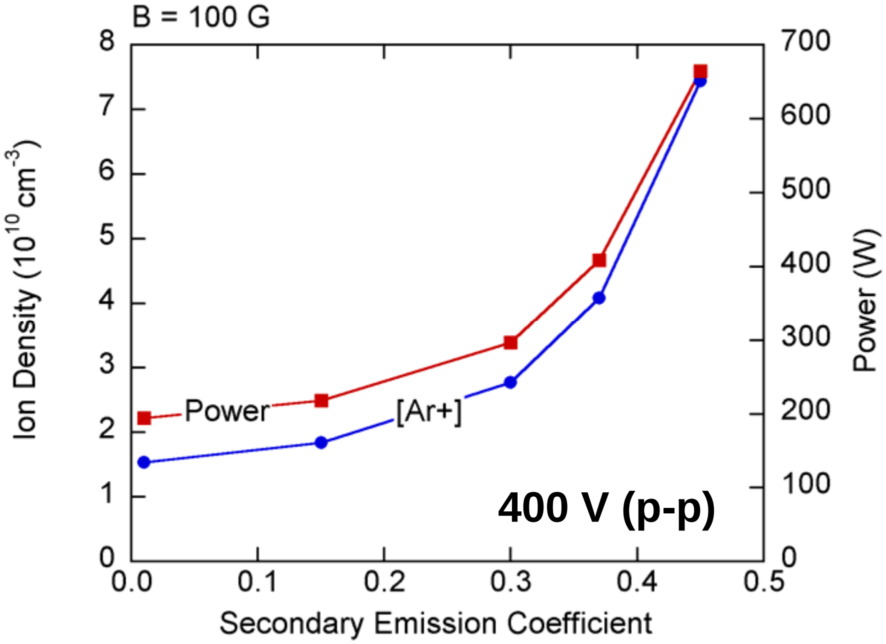
- **B = 100 G**

- **Change in voltage with γ produces change in ion energy distribution to wafer.**
- **Large B-field is more sensitive to γ.**
- **Ar, 100 mTorr, 10 MHz**

PLASMA PARAMETERS: MERIE B=0, 100 G, V=constant



- **B = 0**



- **B = 100 G**

- **B=0: Increasing γ produces nominal increase in ion density and decrease in power as secondary electrons are poorly utilized**
- **B=100 G: Increasing γ 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.