IGNITION CONDITIONS FOR PERIPHERAL PLASMA IN A GROUNDED CHAMBER CONNECTED TO A DUAL FREQUENCY CAPACITIVE DISCHARGE

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Acknowledgements:

Lam Research Corporation
National Science Foundation
UC Discovery/MICRO Programs

Thanks to: Doug Keil, Eric Hudson, and Reza Sadjadi
OUTLINE OF TALK

- Introduction
- Discharge confinement
  - Plasma diffusion into slot (completed)
  - Plasma maintenance in slot and periphery (main topic)
  - Berkeley experiment (in progress)
INTRODUCTION
PLASMA CONFINEMENT BY DIELECTRIC RINGS

Quartz confinement rings

Gas in

Pump

+ $V_{rf}$

- $V_B$

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DUAL FREQUENCY CAPACITIVE DISCHARGES

- $R \sim 15–30 \text{ cm}$, $l \sim 1–3 \text{ cm}$
- $p \sim 30–300 \text{ mTorr}$, $\text{C}_4\text{F}_8/\text{O}_2/\text{Ar}$ feedstock
- High frequency $f_{\text{rf}} \sim 27.1–160 \text{ MHz}$, $V_{\text{rf}} \sim 100–1000 \text{ V}$
- Low frequency $f_B \sim 2–13.56 \text{ MHz}$, $V_B \sim 500–3000 \text{ V}$
- Absorbed powers $P_{\text{rf}}$, $P_B \sim 500–3000 \text{ W}$

For independent control of ion flux and energy

$$\frac{\omega_{\text{rf}}^2}{\omega_B^2} \gg \frac{V_B}{V_{\text{rf}}} \gg 1$$

PLASMA TRANSPORT THROUGH SLOT
BASIC DIFFUSION MODEL

- $V_{rf} \Rightarrow$ plasma density $n_0$ at slot entrance
  $n_{\text{slot}}$ decays as plasma diffuses into slot
- $V_B + V_{rf} \Rightarrow$ dc plasma potential $\bar{V}_{\text{slot}}$ within slot
- Child law $\Rightarrow$ sheath width $s$ within slot
- As $n_{\text{slot}}$ decays, $s$ increases until $s = g/2 \Rightarrow$ plasma “pinch-off”
- Pinch-off length $x_{po} \sim 0.5$–1 cm for 0.5 cm gap $g$

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IMPROVEMENTS TO MODEL

• The sheath and the quartz ring form a capacitive voltage divider for the slot voltage
  ⇒ reduced sheath voltage and modest increase in pinch-off length

• Low pressure diffusion model in slot for \( \lambda_i \gtrsim (T_i/T_e) g \)
  ⇒ modest increase in pinch-off length

• Sheath width varies with position within the slot
  ⇒ slightly reduced pinch-off length

• Finite ionization rate within the slot
  ⇒ modest increase in pinch-off length

• Collisional (not collisionless) Child law sheath in the slot
  ⇒ slightly increased pinch-off length
MODEL RESULTS

(collisionless sheath without ionization in slot)

\[ p=50 \text{ mTorr}, \quad V_{\text{slot}}=100 \text{ V}, \quad g=0.5 \text{ cm}, \quad T_e=2 \text{ V} \]
PINCH-OFF LENGTH

• A good estimate of the pinch-off length is

$$x_{po} \sim \frac{2g}{\pi} \ln \left( 0.12 \frac{g^2}{\lambda_{D0}^2} \frac{T_e^{3/2}}{V_{slot}^{3/2}} \right)$$

where $$\lambda_{D0} = (\epsilon_0 T_e / e n_o)^{1/2}$$ = Debye length at slot entrance

• There is a weak pressure dependence at high pressures

• For typical plasma parameters

$$x_{po} \sim 2g < \text{slot width } w$$

$$\Rightarrow$$ plasma does not diffuse through slot into periphery
DISCHARGE MAINTENANCE
IN SLOT AND PERIPHERY
What are conditions for discharge maintained in slot?
("Maintenance curve")

“Breakdown” in slot not an issue with main discharge present

Discharge in slot $\implies$ discharge in periphery
For no discharge in slot, what are conditions for discharge maintained in periphery?

“Breakdown” of periphery (as opposed to maintenance) may be an issue (to be investigated)

Discharge in periphery $\not\implies$ discharge in slot
1D MODEL OF DISCHARGE MAINTENANCE

- Basic physics:
  - At low voltages (densities), total width of sheaths approaches gap spacing ⇒ bulk plasma becomes too thin
  - Ionization balance or power balance is lost

- Global model with additional physics at low rf voltages:
  - Account for a dc/low frequency sheath width in the absence of a high frequency sheath (Godyak/Sternberg, 1990)
  - Account for high frequency voltage drops across the dc/low frequency sheaths and the bulk plasma
  - Account for transition from ambipolar to free diffusion as bulk plasma becomes thin (Allis/Rose 1954)
BENCHMARK 1D MODEL AGAINST MEASUREMENTS

- Conventional capacitive discharge (argon)

![Graph showing model and measurements comparison](image-url)
2D RF CURRENT FLOWS IN SLOT

- Standard 1D global model has rf current transverse to plates
- Symmetric excitation of discharge in slot has 2D currents
  ⇒ enhanced ohmic heating, incorporated into model
- When periphery ignites, current drawn through slot increases
  ⇒ incorporated into model
• Solve for decay of electric field $E$ in dielectric region
• Decay depends on pinch-off length
  $\Rightarrow$ incorporated into model
NOMINAL PARAMETERS

Quartz confinement rings

$V_B = 0 + V_{rf} + V_d = 0$

$g = 0.5 \text{ cm}$

$w_{per} = 3 \text{ cm}$

$w = 3 \text{ cm}$

$l = 3 \text{ cm}$

• Plot $V_d$ versus pressure for maintenance in slot and periphery
MAINTENANCE FOR NOMINAL PARAMETERS

- At 100 mTorr, slot ignites, then periphery ignites
• Now at 100 mTorr, periphery ignites, then slot ignites
BERKELEY EXPERIMENT

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J.T. Gudmundsson
Sangsup Jeong
CONFINED AND UNCONFINED PLASMA

- 27 MHz, 5 ″ diameter powered electrode, 1/4 ″ slot gap $g$

(View through window along a diameter of the grounded electrode)

Main discharge only
(150 W @100 mTorr)

Main & peripheral discharge
(280 W @100 mTorr)
HYSTERESIS IN POWER CHARACTERISTICS

50 mTorr argon

Breakdown of periphery

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MAINTENANCE IN BERKELEY EXPERIMENT

- \( l = 2.54 \text{ cm}, \ g = 0.635 \text{ cm}, \ w = 3.8 \text{ cm}, \ w_{\text{per}} = 5.1 \text{ cm} \)
- 748.7 nm argon optical emission line in main discharge (the zero of $I$ is not calibrated)

80 W, 100 mTorr

202 W, 77 mTorr

High frequency (43.3 kHz) relaxation oscillation

Low frequency (4.2 Hz) relaxation oscillation
**FUTURE PLANS**

- Measure the rf voltage on main discharge plasma
- Experimentally characterize single frequency ignition (27 MHz) as a function of voltage, pressure, and gap spacing
- Experimentally characterize dual frequency ignition (27/2 MHz)
- Experimentally characterize instabilities and develop theoretical model
- Model effect of aspect-ratio of periphery on maintenance
- Model the effect of transport of electrons past pinch-off on peripheral ignition
- Model “breakdown” of periphery for no plasma in slot