SCALING OF MICRODISCHARGE DEVICES: PYRAMIDAL STRUCTURES*

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AGENDA

- Introduction of pyramidal microdischarge devices.
- Description of model.
- Fundamental properties of MDs sustained in neon.
- Transition from Townsend to negative glow.
- Scaling of MDs
- Concluding remarks.

MICRODISCHARGE PLASMA SOURCES

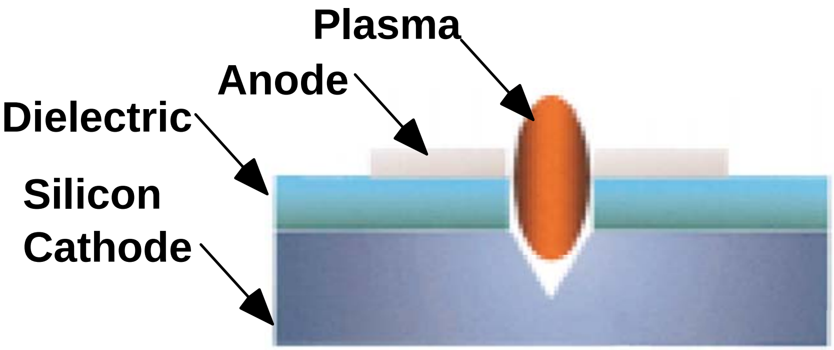
- **Microdischarges are plasma devices which leverage pd scaling to operate dc atmospheric glows 10s –100s μm in size.**
- **MEMS fabrication techniques enable innovative structures for displays and detectors.**
- **Although similar to PDP cells, MDs are dc devices which largely rely on nonequilibrium beam components of the EED.**
- **Electrostatic nonequilibrium results from their small size. Debye lengths and cathode falls are commensurate with size of devices.**

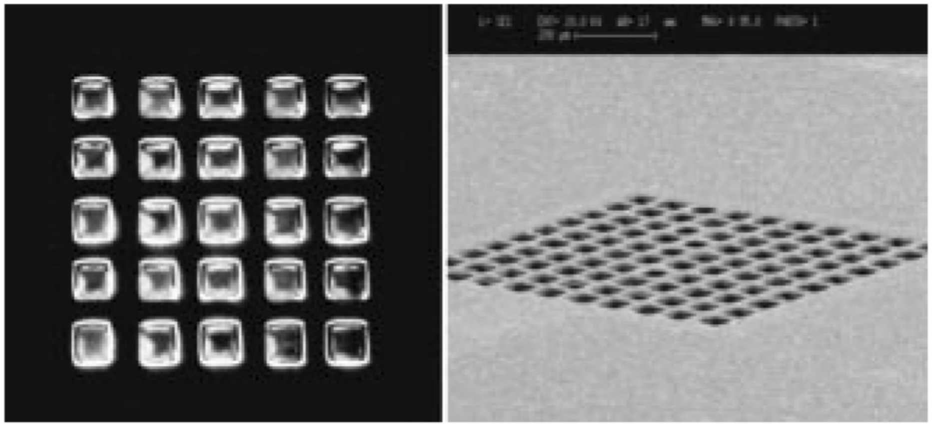
$$L_{cathodeFall} = \left(2V_c\varepsilon_0 / \left(qn_I\right)\right)^{1/2} \approx 10 - 20\mu m$$

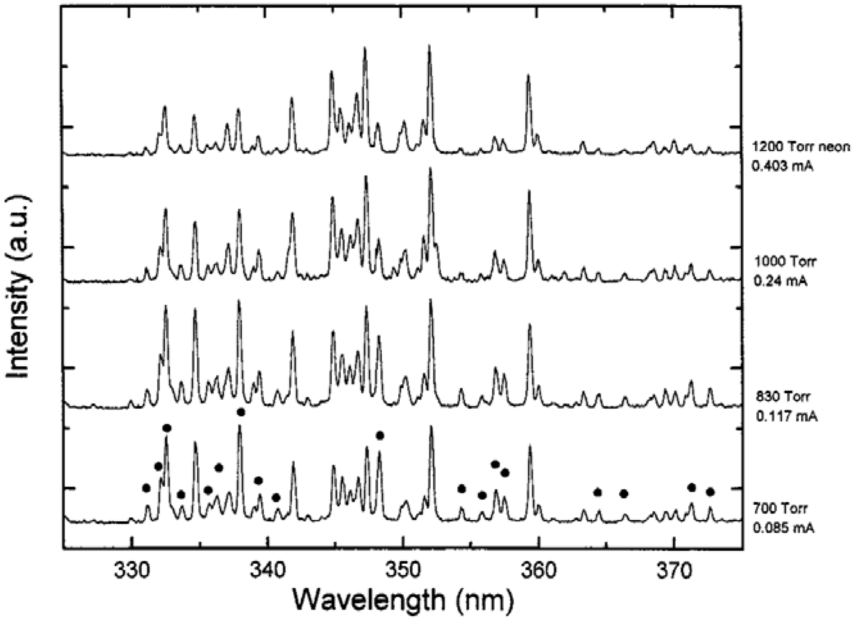
$$\lambda_D \approx 750\left(\frac{T_{eV}}{n_e(cm^{-3})}\right)^{1/2} cm \approx 10\mu m,$$

PYRAMIDAL MICRODISCHARGE DEVICES

- Si MDs with 10s μm pyramidal cavities display nonequilibrium behavior: Townsend to negative glow transitions.
- Small size also implies electrostatic nonequilibrium.







- S.-J. Park, et al., J. Sel. Topics Quant. Electron 8, 387 (2002); Appl. Phys. Lett. 78, 419 (2001).

2-D MODELING OF MICRODISCHARGE SOURCES

- **Charged particle continuity (fluxes by Sharfetter-Gummel form)**

$$\frac{\partial N_i}{\partial t} = -\vec{\nabla}\cdot\left(qN_i\mu_i\left(-\vec{\nabla}\Phi\right) - D_i\nabla N_i\right) + S_i$$

- **Poisson’s Equation for Electric Potential**

$$-\nabla\cdot\varepsilon\nabla\Phi = \rho_V + \rho_S$$

- **Bulk continuum electron energy transport and MCS beam.**

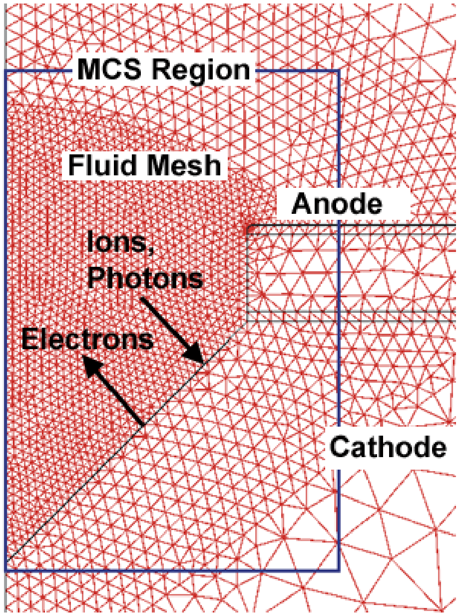
$$\frac{\partial\left(n_e\varepsilon\right)}{\partial t} = \vec{j}\cdot\vec{E} - n_e\sum_i N_i\kappa_i - \nabla\cdot\left(\frac{5}{2}\varepsilon\varphi - \lambda\nabla T_e\right), \quad \vec{j} = q\vec{\phi}_e$$

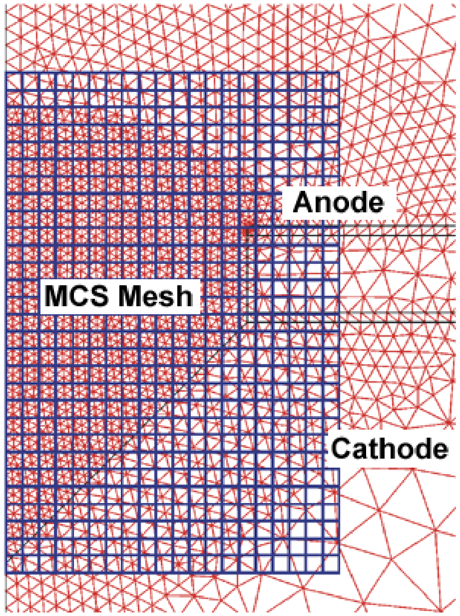
- **Neutral continuity and energy transport.**

$$\frac{\partial N_i}{\partial t} = -\nabla\cdot\left(\vec{v} - DN_o\nabla\left(\frac{N_i}{N_o}\right)\right) + S_i, \quad \frac{\partial\left(\rho cT\right)}{\partial t} = -\nabla\cdot\kappa\nabla T + P_g$$

DESCRIPTION OF MODEL: MCS AND MESHING

- Transport of energetic secondary electrons is addressed with a Monte Carlo Simulation.

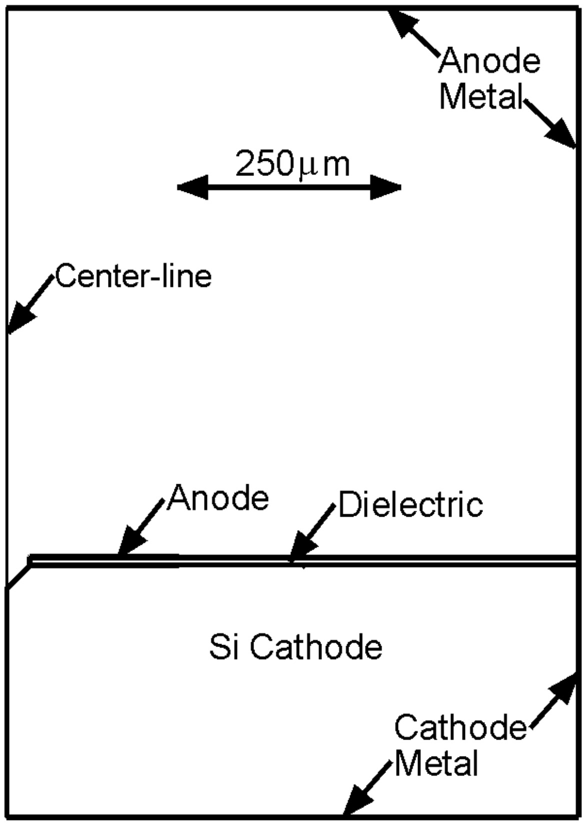


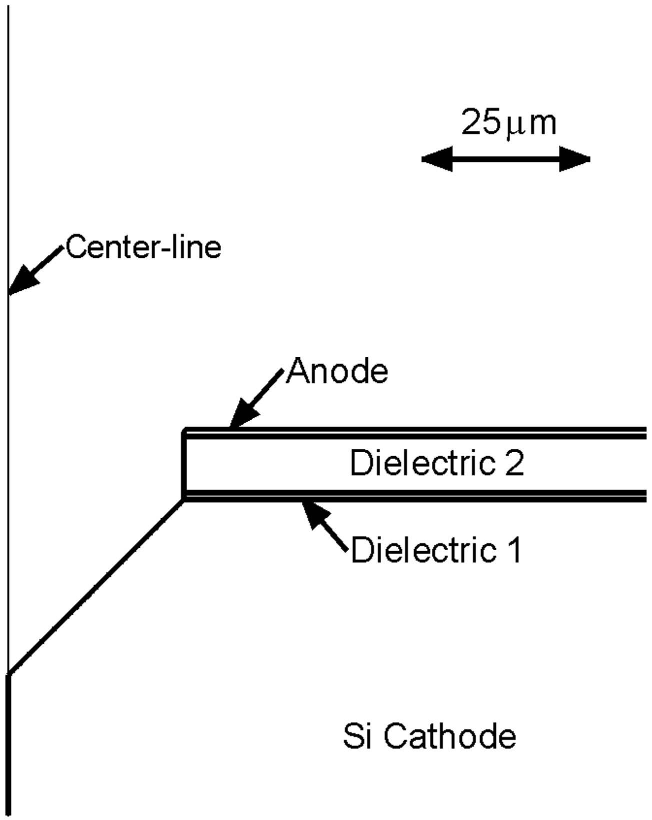


- Superimpose Cartesian MCS mesh on unstructured fluid mesh. Construct Greens functions for interpolation between meshes.
- Electrons and their progeny are followed until slowing into bulk plasma or leaving MCS volume.
- Electron energy distribution is computed on MCS mesh.
- EED produces source functions for electron impact processes which are interpolated to fluid mesh.

MODEL GEOMETRY: Si PYRAMID MICRODISCHARGE

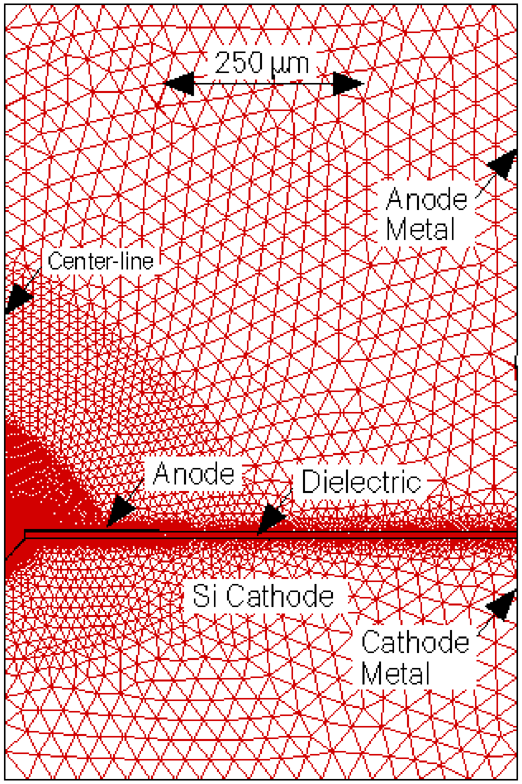
- **Investigations of a cylindrically symmetric Si pyramid microdischarge were performed.**

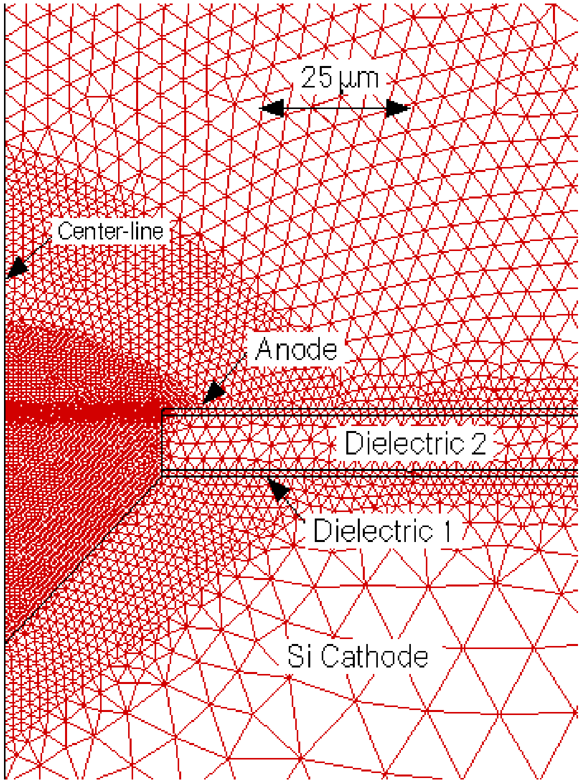




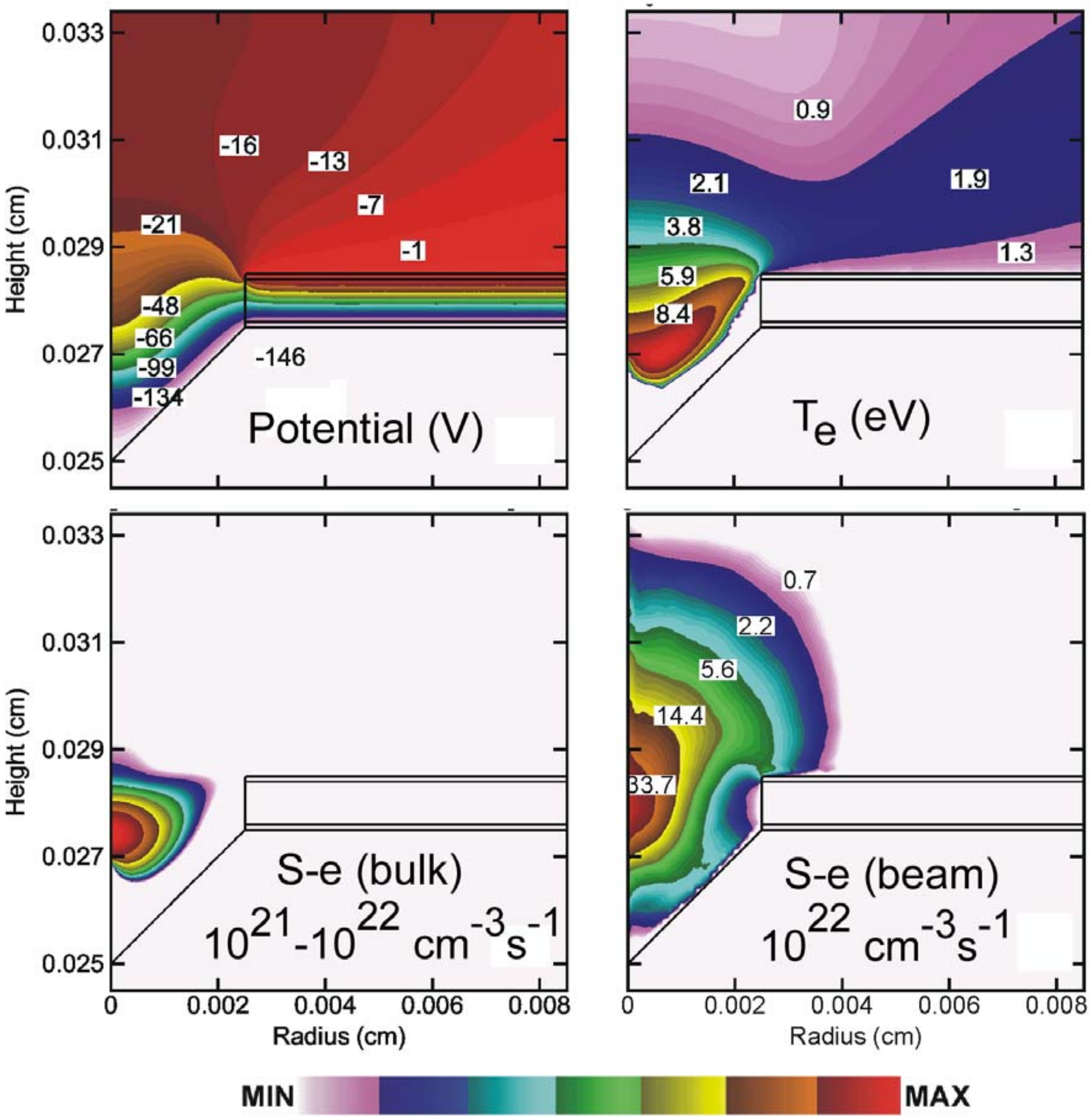
MODEL GEOMETRY: Si PYRAMID MICRODISCHARGE

- **Meshing is absolutely critical to resolve small structures and distant boundaries.**
- **Typical Mesh: 5,000-10,000 nodes, 10^2-10^3 dynamic range**





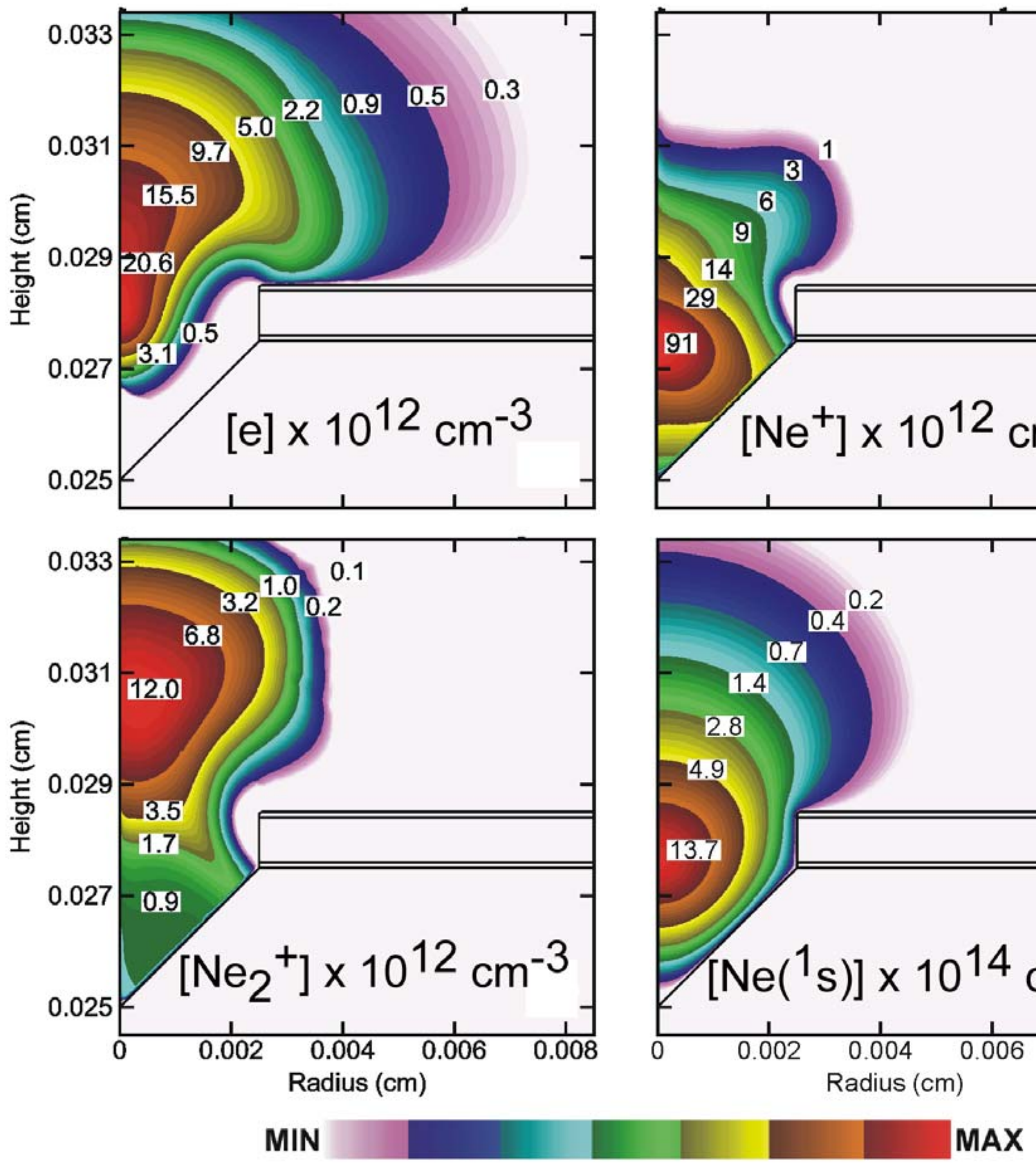
BASE CASE: Ne, 600 Torr, 50 μm DIAMETER



- Optimum operation produces large enough charge density to warp electric potential into cathode well.
- Inspite of large T_e, ionization is dominated by beam electrons

  - Ne, 600 Torr, 50 μm, 200 V, 1 MΩ

BASE CASE: Ne, 600 Torr 50 μm DIAMETER

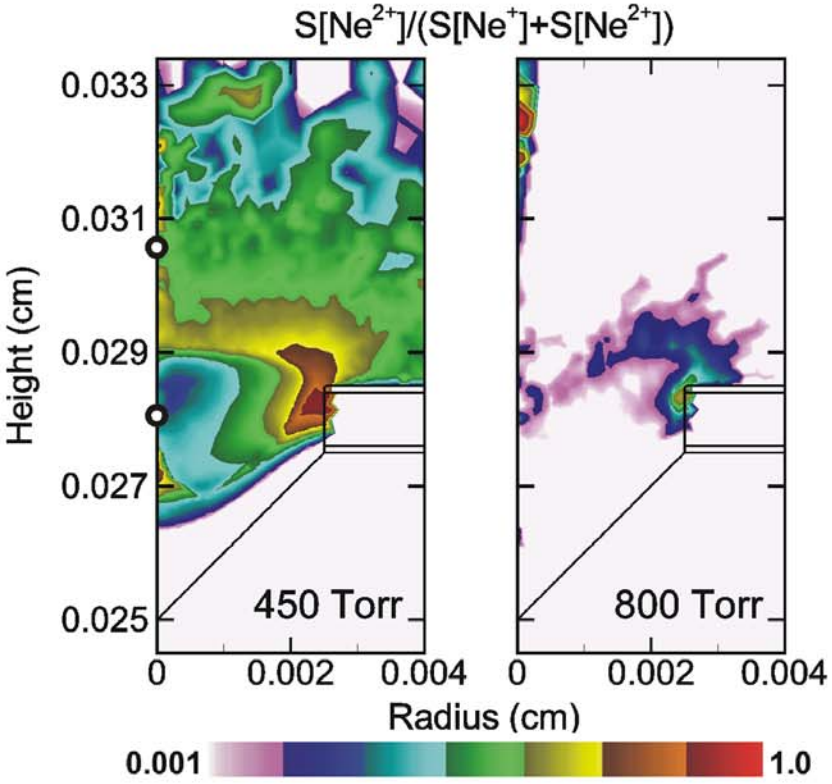


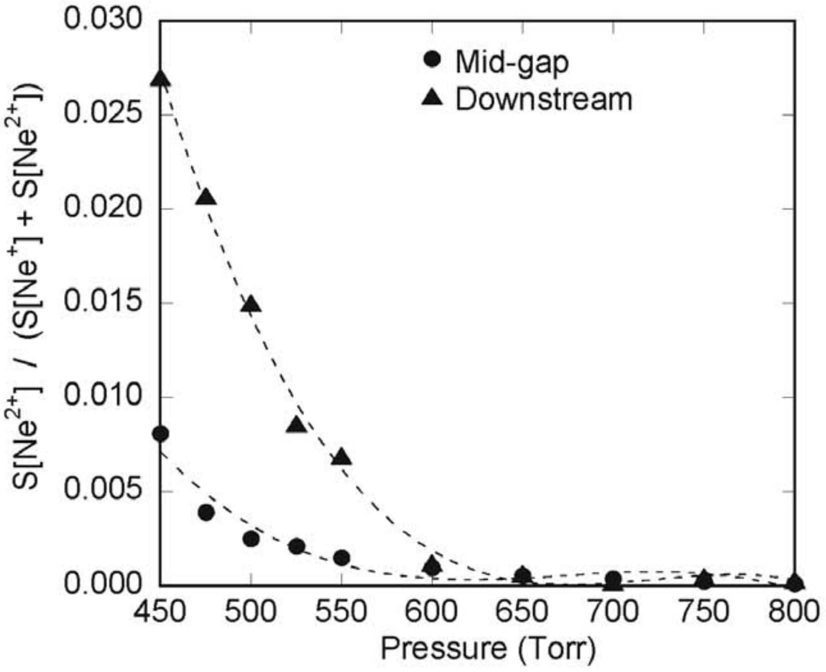
- **There is essentially no region of quasi-neutrality or which is positive column-like.**
- **Monomer and dimer ions are segregated.**
- **Excited state densities > 10^{15} cm^{-3} rival macroscopic devices**

  - **Ne, 600 Torr, 50 μm, 200 V, 1 MΩ**

TRANSITION TO NEGATIVE-GLOW BEHAVIOR

- **Although geometry precludes true hollow cathode behavior, negative glow behavior sets in a lower pressures.**
- **Characterize negative glow by $S[Ne^{2+}] / (S[Ne^{+}] + S[Ne^{2+}])$**

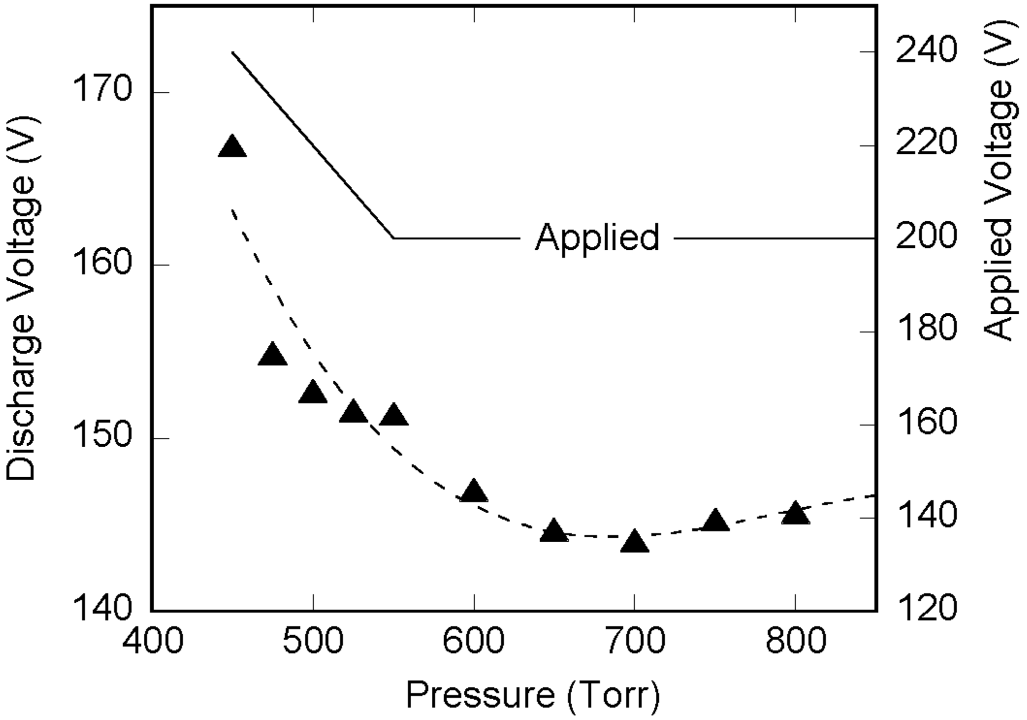




- **Ne, 50 μm diameter, 200 V, 1 MΩ**

SCALING WITH PRESSURE: PASCHEN BEHAVIOR

- **With pd=1-10 Torr-cm, these microdischarge devices display Paschen behavior.**



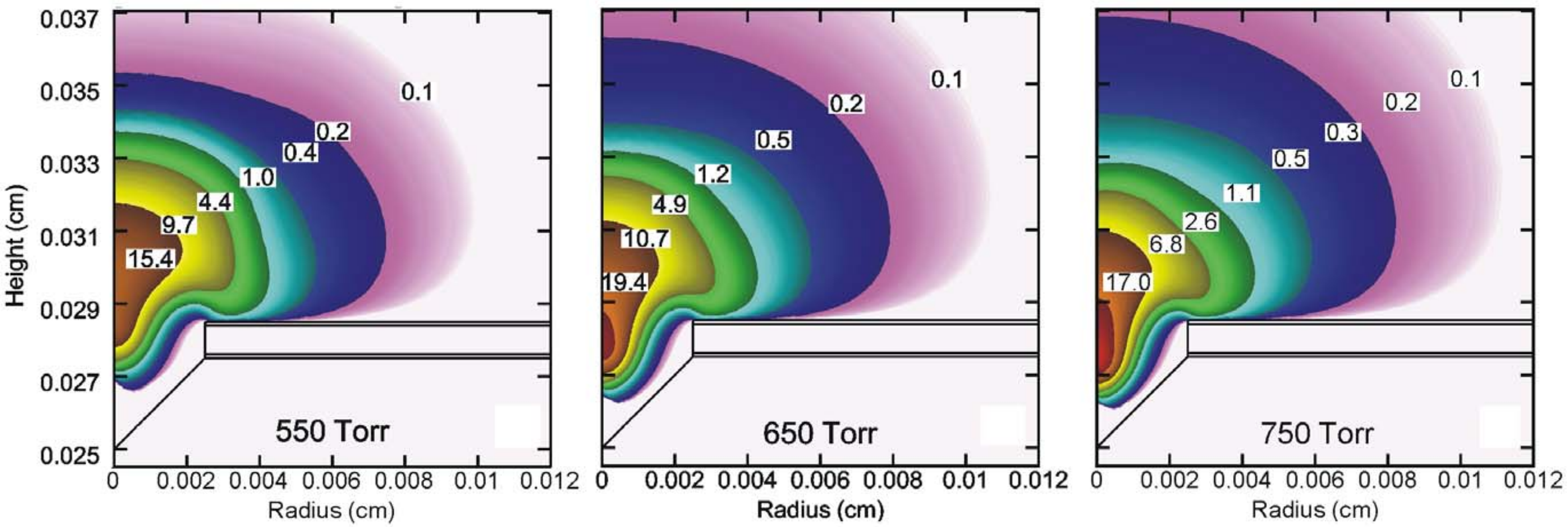
- **Although sensitive to ballasting and current density lower pressures requiring larger applied voltages also produce large plasma densities.**

- **Ne, 50 μm diameter, 1 MΩ**

SCALING WITH PRESSURE: PLASMA PROPERTIES

- Over a range of pressures that V(applied) and R(ballast) can be constant, confinement at higher pressures produces higher peak plasma densities.

- [e] x 10^{12} cm^{-3}

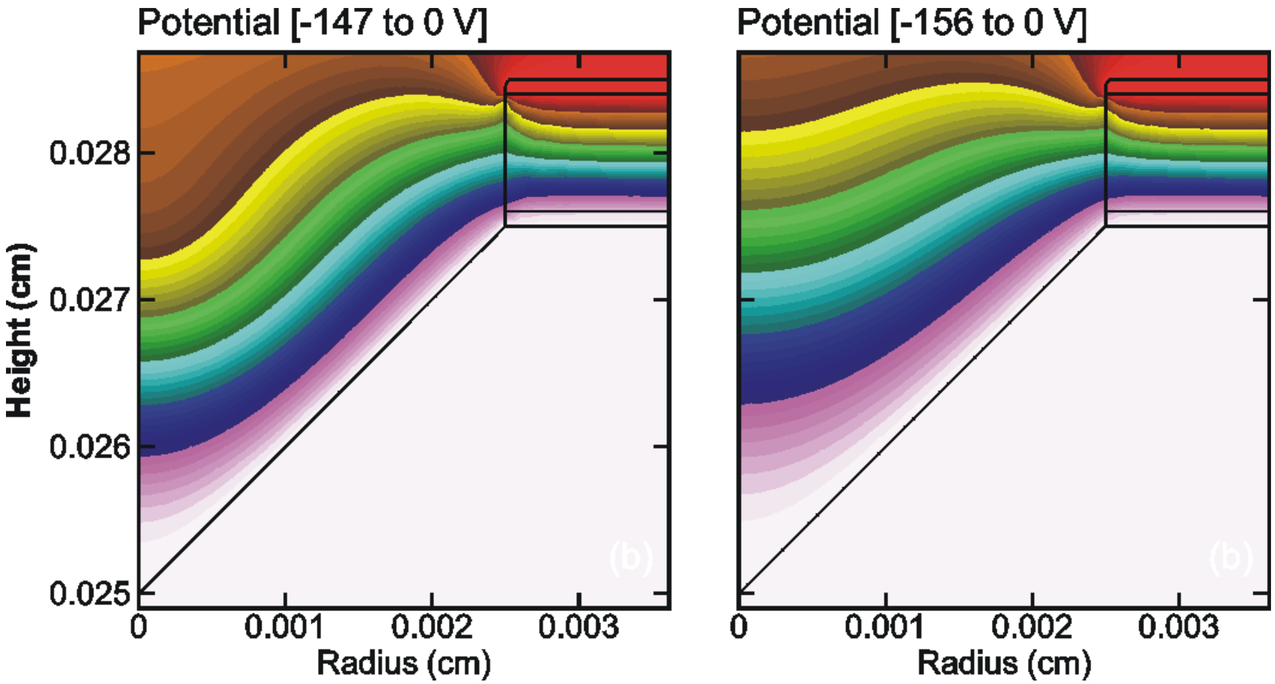


- 550 Torr [2.1 x 10^{13} cm^{-3}]
- 650 Torr [3.9 x 10^{13} cm^{-3}]
- 750 Torr [5.6 x 10^{13} cm^{-3}]

- Ne, 50 μm diameter, 200V, 1 MΩ

SCALING CONSIDERATIONS: CATHODE FALL THICKNESS

- **In MDs, the cathode fall thickness may be commensurate with cavity size. Current density is therefore critical to scaling.**



- **-210 V, 1 MΩ**
[e]= 4.9 x 10^{13} cm^{-3}

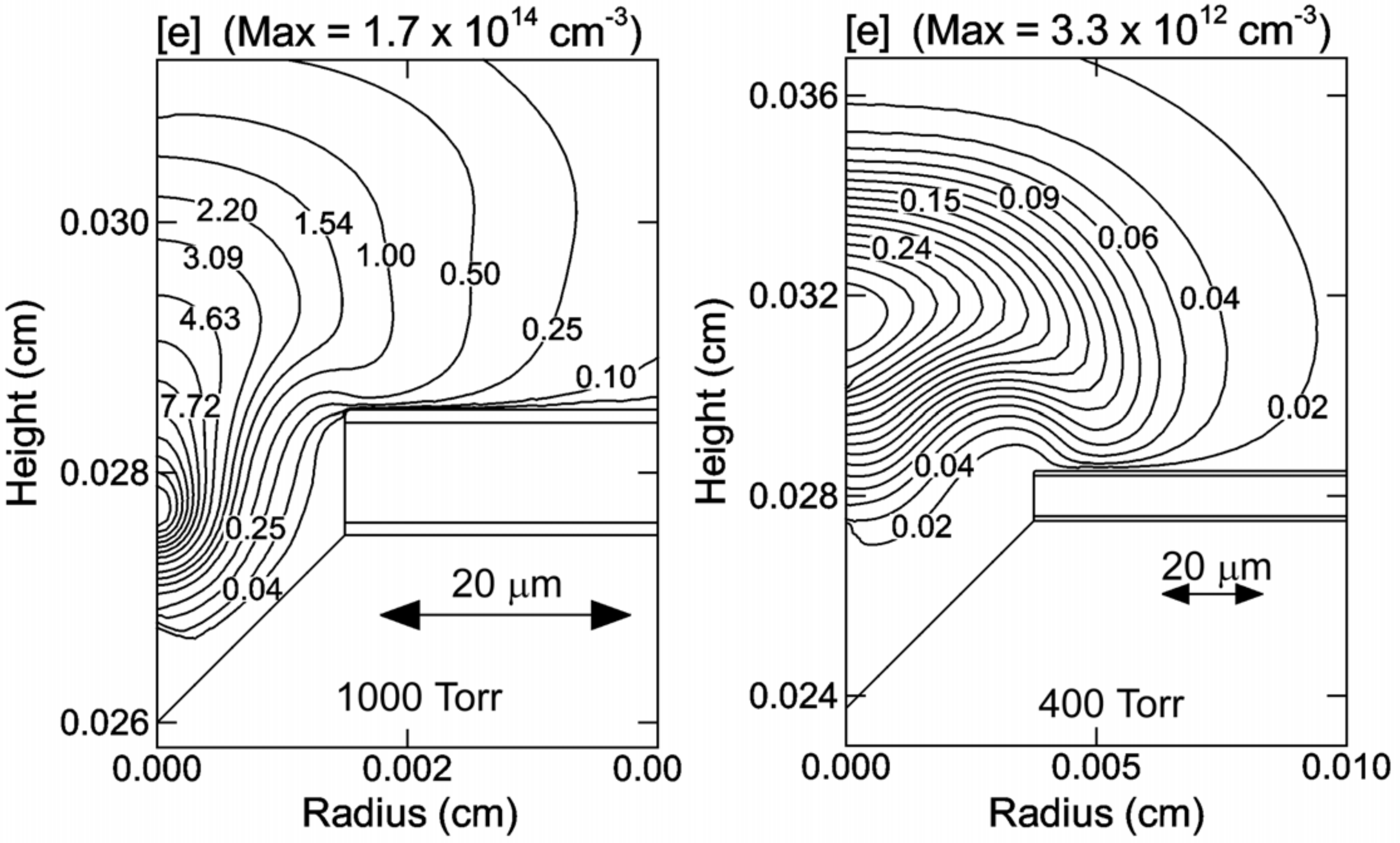
- **-200 V, 1.75 MΩ**
[e]= 5.3 x 10^{12} cm^{-3}

- **Low j (and [e]) may result in cathode fall not being conformal to cathode.**

- **Ne, 50 μm diameter, 600 Torr**

SCALING WITH SIZE: pd, BALLAST = CONSTANT

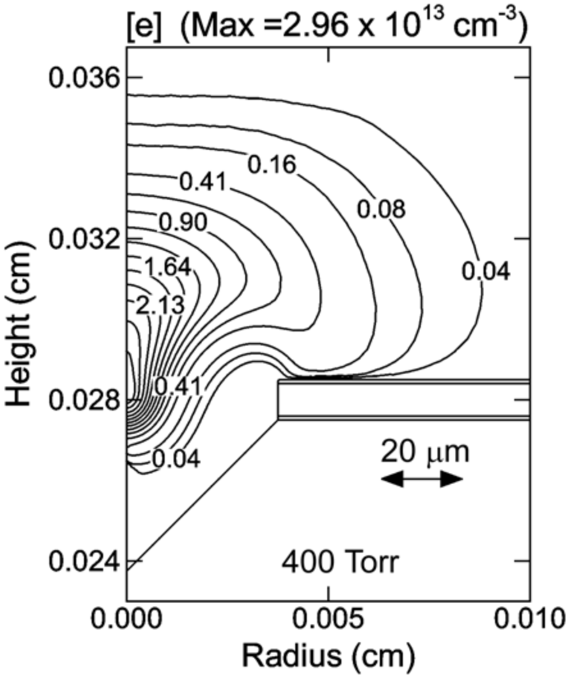
- **Scaling while maintaining pd, V(applied) and R(ballast) constant results in a reduced j and [e] in the larger device. The plasma is not conformal to the cathode.**



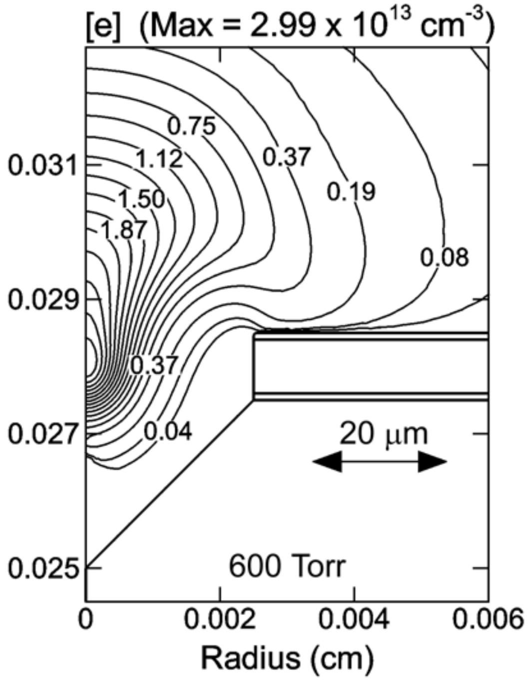
- **Ne, -200 V, 1 MΩ**

SCALING WITH SIZE: pd, j = CONSTANT

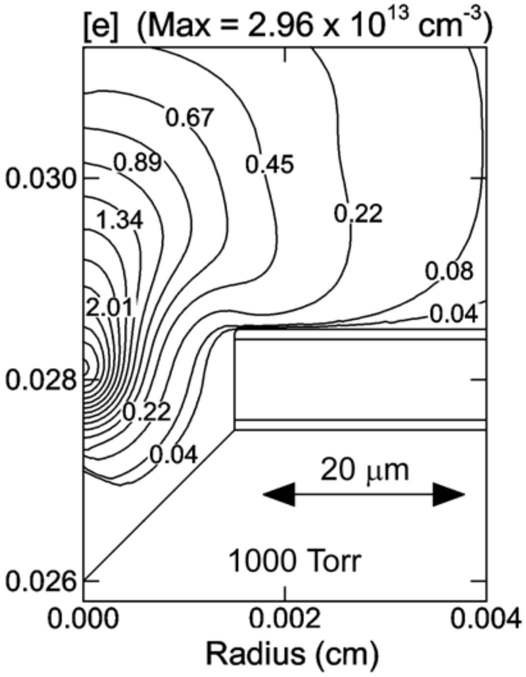
- Scaling while maintaining pd and j constant produces similar plasma densities and conformality to the cathode.



- 400 Torr



- 600 Torr



- 1000 Torr

- Ne, -200 V

CONCLUDING REMARKS

- MDs differ from macroscopic devices in that plasma scale lengths are commensurate with device dimensions.
- Scaling of MDs with pressure (traditionally “pd”) likely also required λ/L to remain constant or less than a critical value.
- Scaling with complex shapes must consider all dimensions.
- The transition from Townsend to negative glow is largely geometrically dependent, and can be controlled to some degree by shape.