MICRODISCHARGES AS SOURCES OF PHOTONS, RADICALS AND THRUST*

Ramesh Arakoni[a] and Mark J. Kushner[b]

University of Illinois
[a] Dept. Aerospace Engineering
[b] Dept. Electrical and Computer Engineering
Urbana, IL 61801 USA
mjk@uiuc.edu arakoni@uiuc.edu
http://uigelz.ece.uiuc.edu

September 2004

*** Work supported by the National Science Foundation and Air Force Research Labs.**

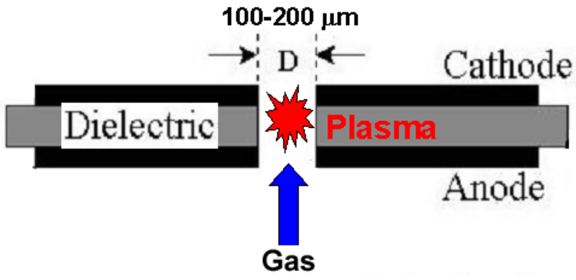
AGENDA

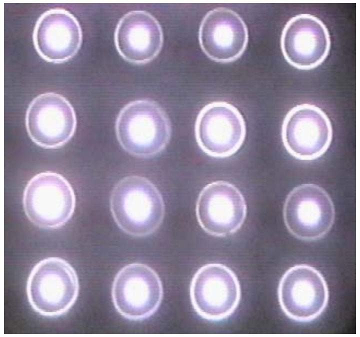
- Introduction to microdischarge (MD) devices.
- Description of model.
- Scaling of the annular sandwich MD
    - Visible and Excimer Emission
    - Thrust
    - Radicals
- Concluding remarks.

University of Illinois
Optical and Discharge Physics

MICRODISCHARGE PLASMA SOURCES

- Microdischarges are plasma devices which leverage pd scaling to operate dc atmospheric glows 10s –100s μm in size.
- 150-300 V, a few mA
- Although similar to PDP cells, MDs are usually 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.

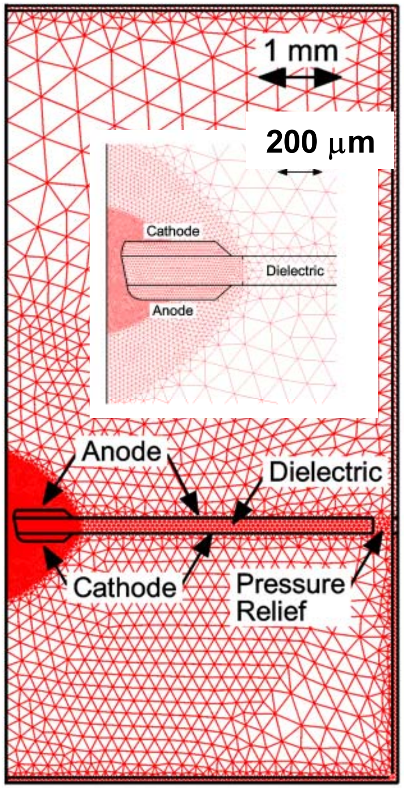


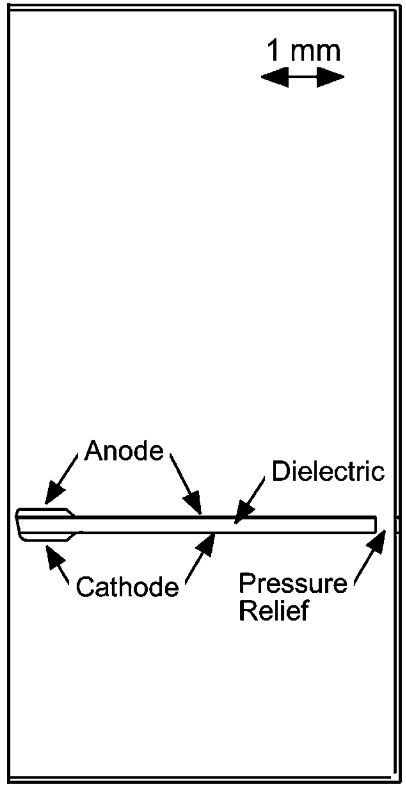


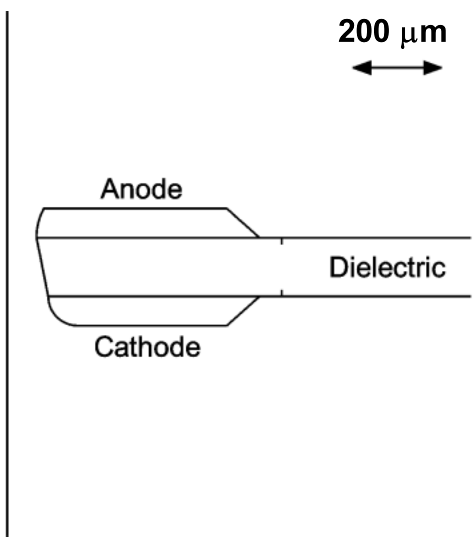
- Ref: Kurt Becker, GEC 2003

DESCRIPTION OF MODEL

- To investigate scaling processes in microdischarge sources, nonPDPSIM has been developed, a 2-dimensional model.
  - Rectilinear or cylindrical unstructured mesh
  - Implicit drift-diffusion-advection for charged species
  - Navier-Stokes for neutral species
  - Poisson’s equation (volume, surface charge, material conduction)
  - Circuit model
  - Electron energy equation coupled with Boltzmann solution
  - Monte Carlo beam electrons
  - Optically thick radiation transport with photoionization
  - Secondary electrons by impact, thermionics, photo-emission
  - Surface chemistry







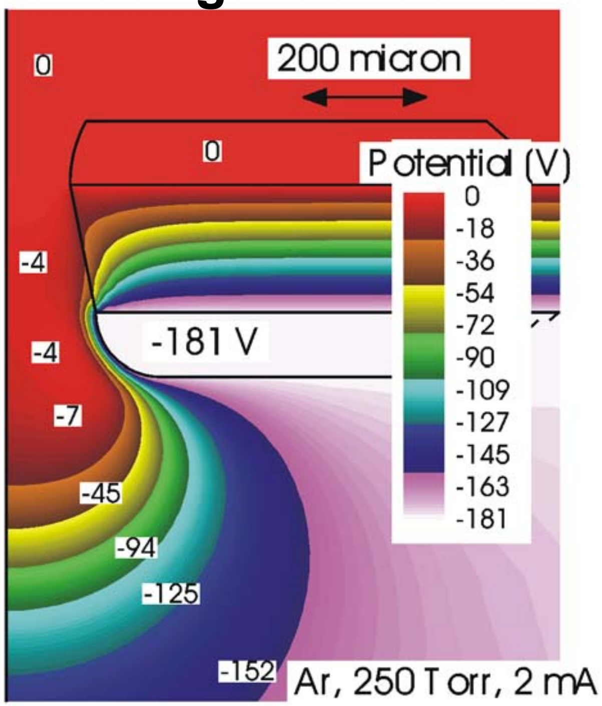
GEC04_05

BASE CASE PARAMETERS

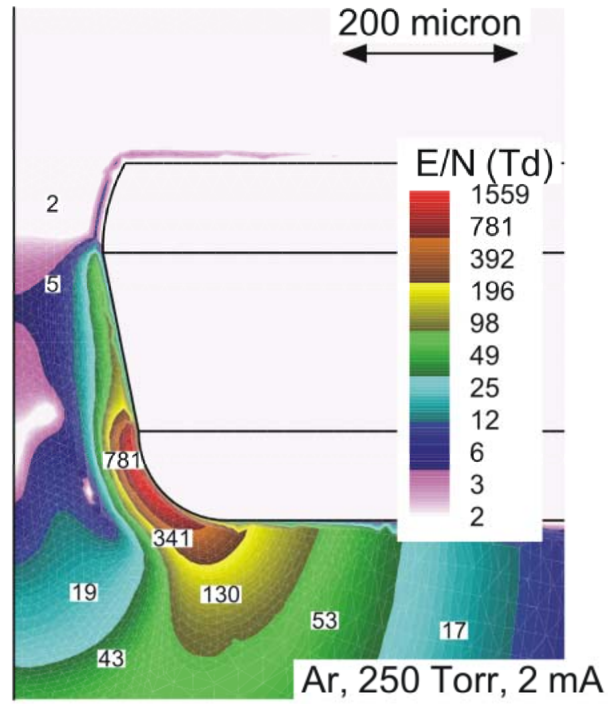
- Sloped dielectric (flow issues)
- Hole: 200 μm diameter at anode to 300 μm at cathode.
- Dielectric: 200 μm thick
- Anode/Cathode 100 μm thick
- Cylindrically symmetric
- Argon, 250 Torr, 2 mA (set by adjusting ballast resistor)
- Meshing is critical (100-1000 dynamic range)
- Total nodes: 5424
  Plasma nodes: 3693

ELECTRIC POTENTIAL AND FIELDS

- **Anode potential penetrates into lower plenum, producing hollow-cathode-like structure.**
- **Geometrical enhancement and space charge produce fields approaching 100 kV/cm.**



- **Electric Potential**

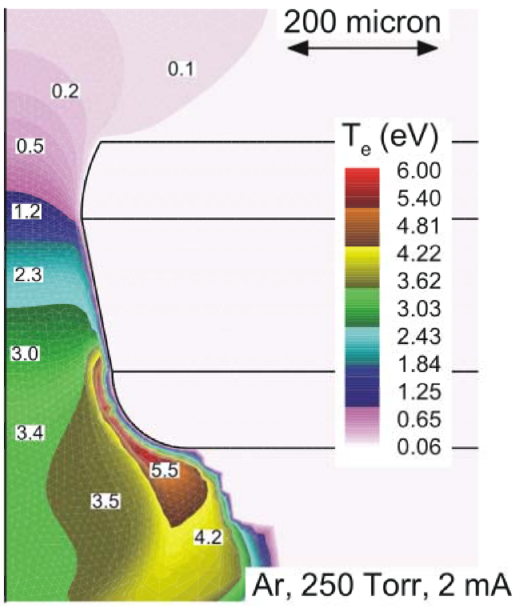


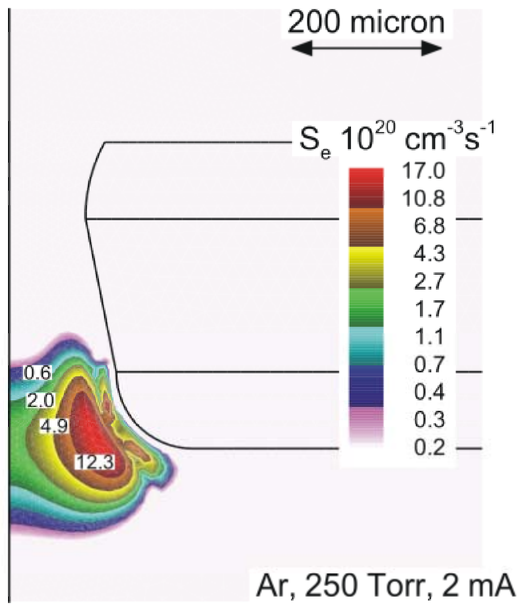
- **E/N (Electric Field/Gas Density) Max = 80 kV/cm**

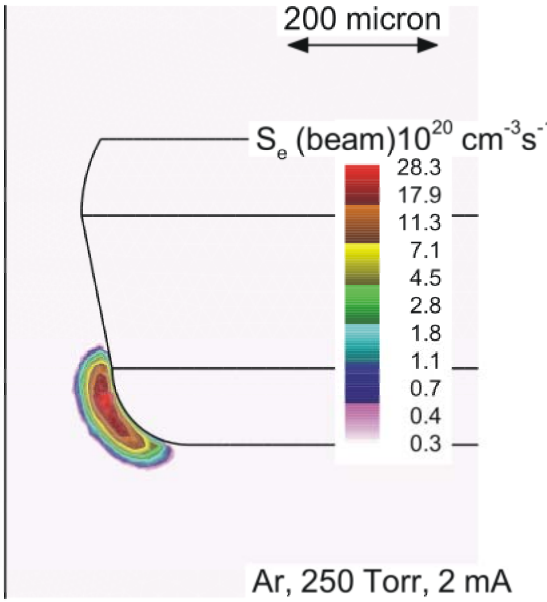
University of Illinois
Optical and Discharge Physics

ELECTRON TEMPERATURE AND IONIZATION SOURCES

- In the bulk plasma, T_e of 3.5 eV suggests positive column conditions.
- Large contributions to ionization occur from both bulk and beam electrons





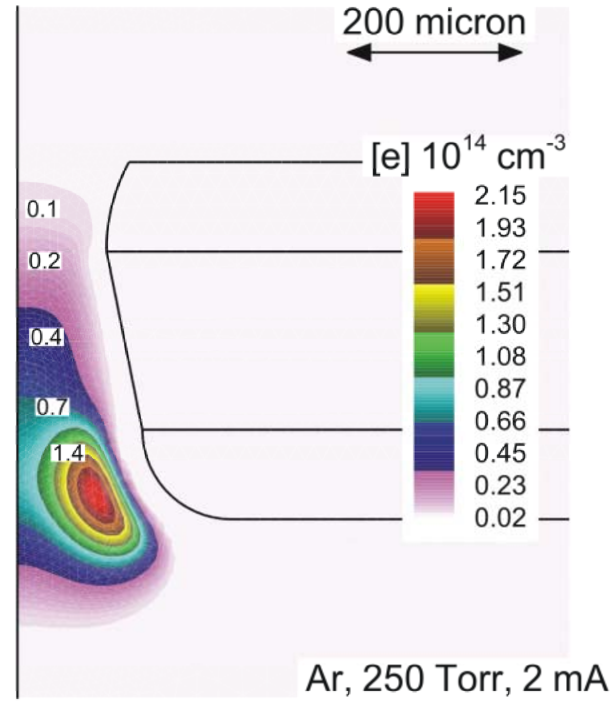


- Electron Temperature
- Bulk Ionization
- Beam ionization

University of Illinois
Optical and Discharge Physics

ELECTRON DENSITY

- Peak electron densities of $>10^{14}$ cm^{-3} are produced in the steady state.
- These high cw densities enable large rates of excitation of high lying electronic states.

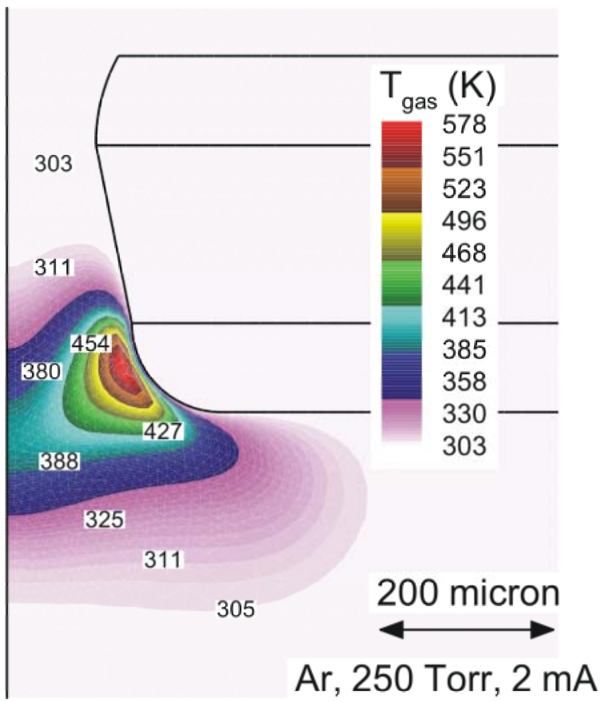


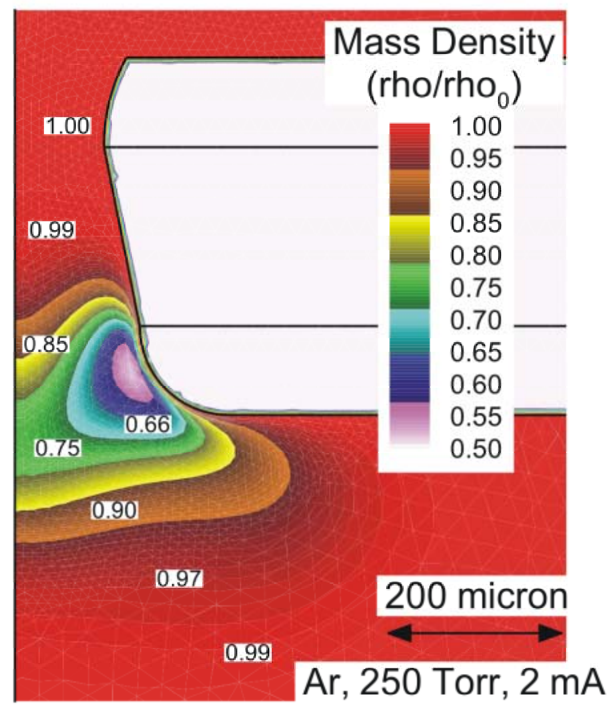
- Electron density

University of Illinois
Optical and Discharge Physics

THERMODYNAMIC PROPERTIES

- **Current densities of 5-10 A/cm^2 and power of 10s-100 kW/cm^3 produce significant gas heating and rarefaction.**
- **Rarefaction increases range of secondary electrons.**

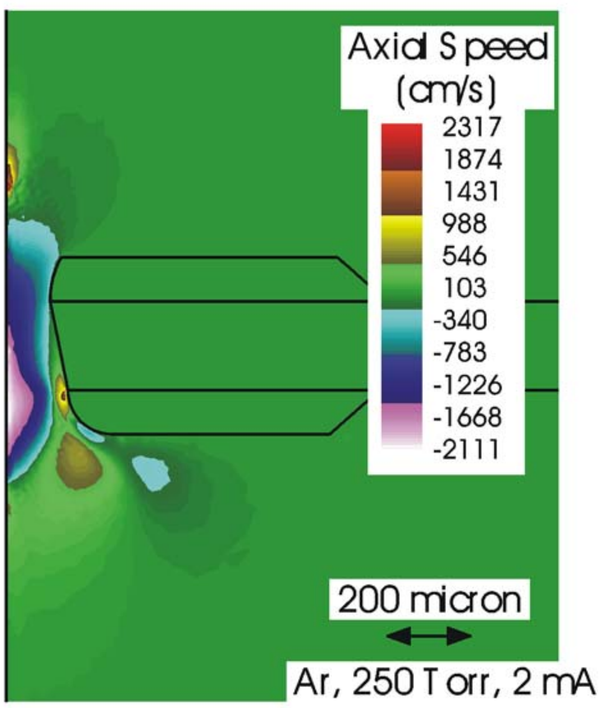


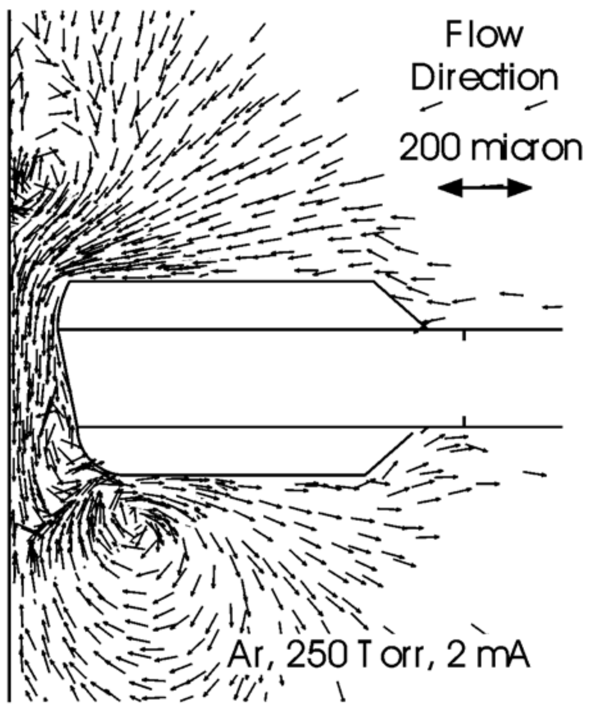


- **Gas Temperature**
- **Relative Mass Density**

ADVECTIVE FLOWFIELD

- Cataphoresis entrains gas, producing pumping action from above the plenum, through the hole to below the plenum.
- The jet experiences resistance in the stagnation zone below the plenum and recirculation results.



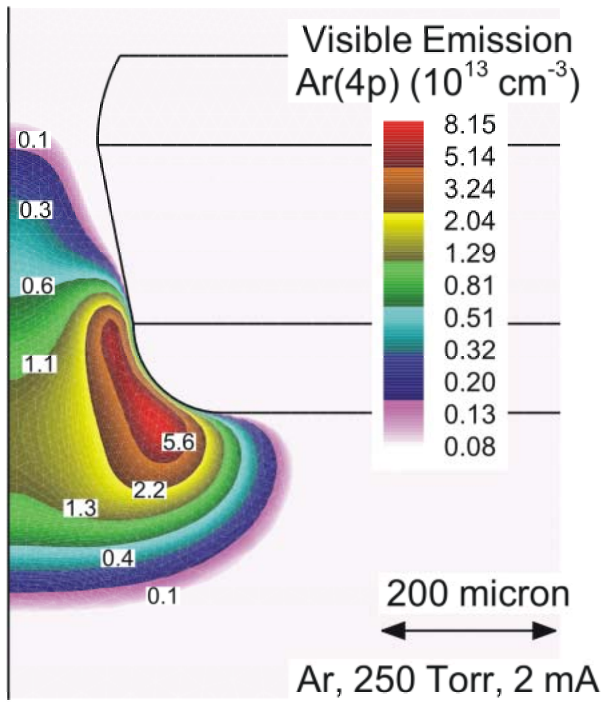


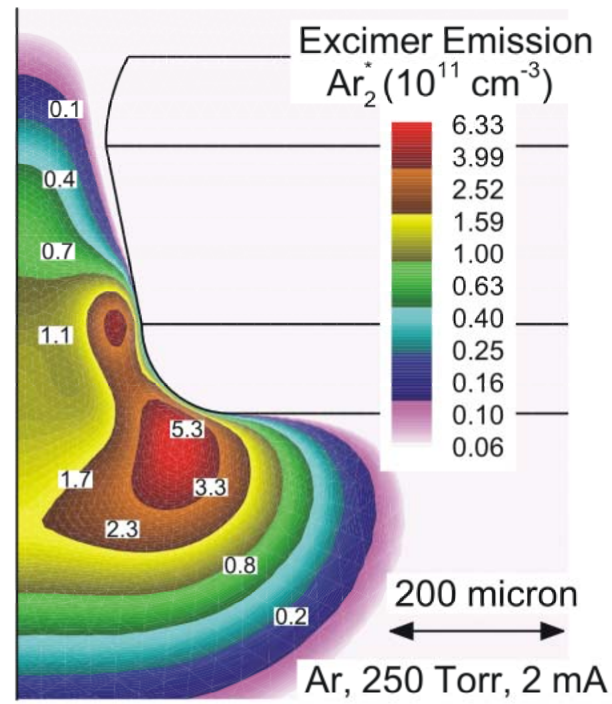
- Axial Gas Speed
- Flow Direction

University of Illinois
Optical and Discharge Physics

VISIBLE AND UV EMISSION

- **Visible emission is constrained to an annulus due to short lifetimes of states. UV emission from excimer is more distributed due to the large range of Ar(4s) metastable precursor.**



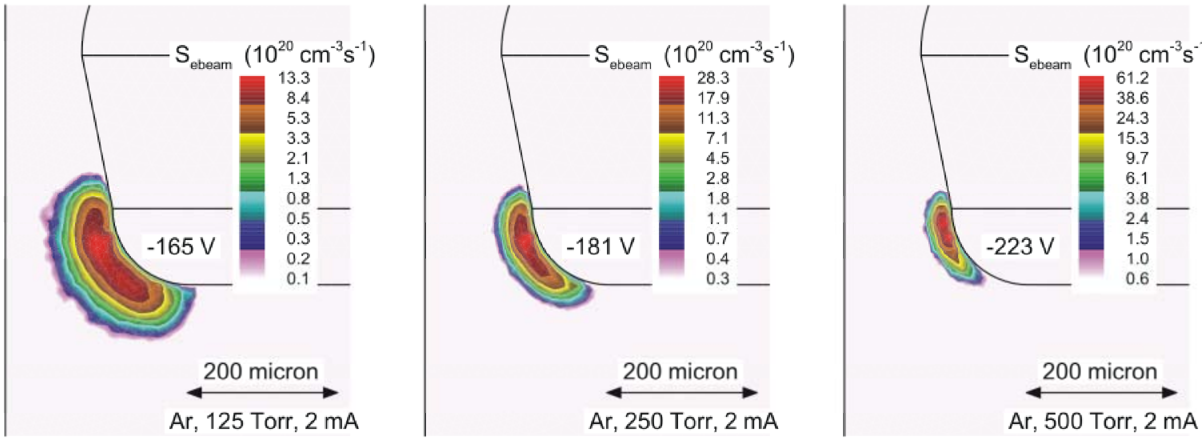


- **Ar(4p) Density (Visible Emission)**
- **Ar_2* Density (UV Emission)**

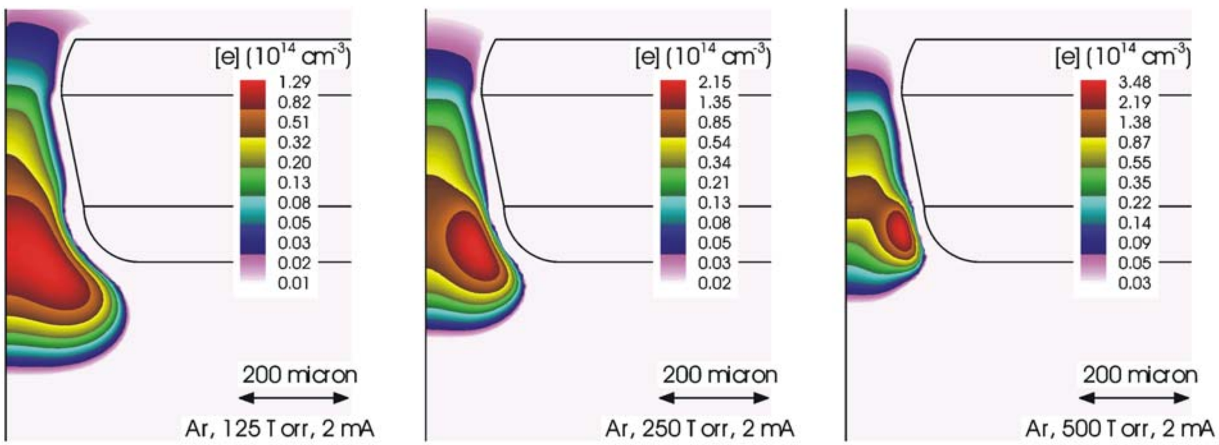
University of Illinois
Optical and Discharge Physics

MD PROPERTIES vs PRESSURE

- Beam Ionization



- Electron Density



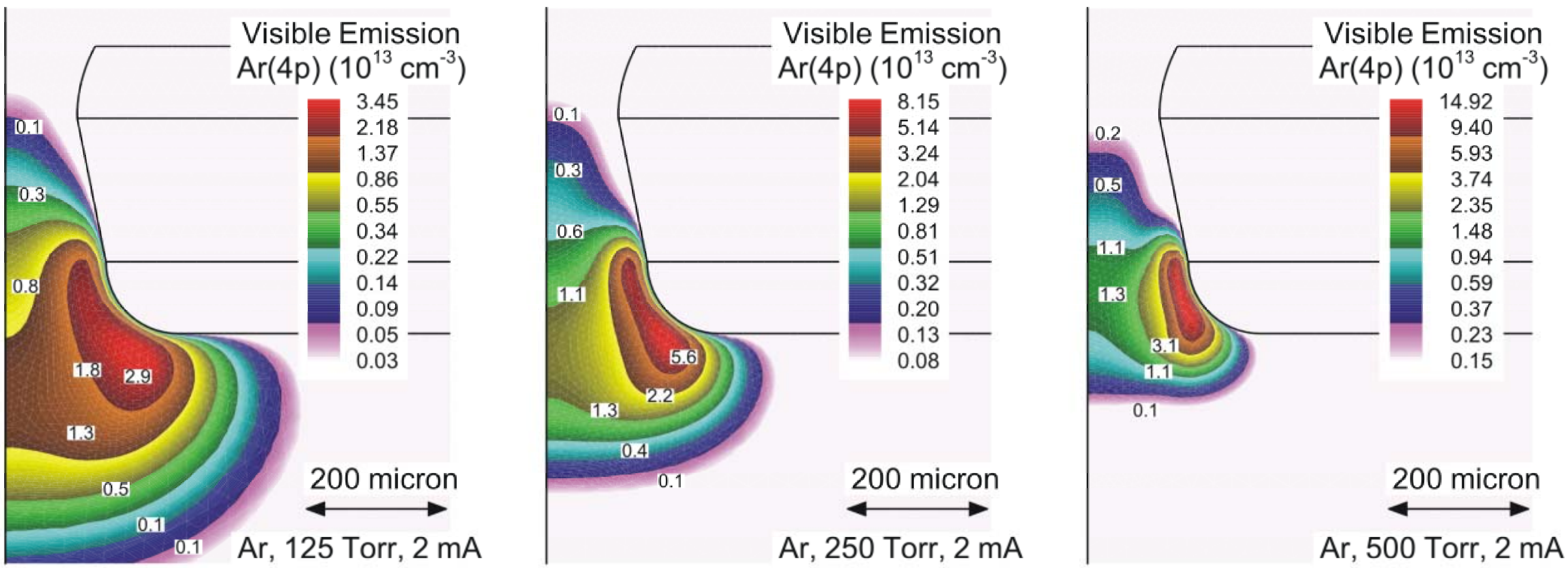
- 125 Torr
- 250 Torr
- 500 Torr

- Decreasing pressure enables deeper penetration of beam electrons in spite of the lower cathode voltage.
- The result is more confinement at higher pressure and higher peak electron density.
- Ar, 2 mA

University of Illinois
Optical and Discharge Physics

MD PROPERTIES vs PRESSURE: VISIBLE EMISSION

- Visible emission is significantly more extended at low pressure, penetrating far out the hole. Peak emission is greater at higher pressure due to confinement of beam component.

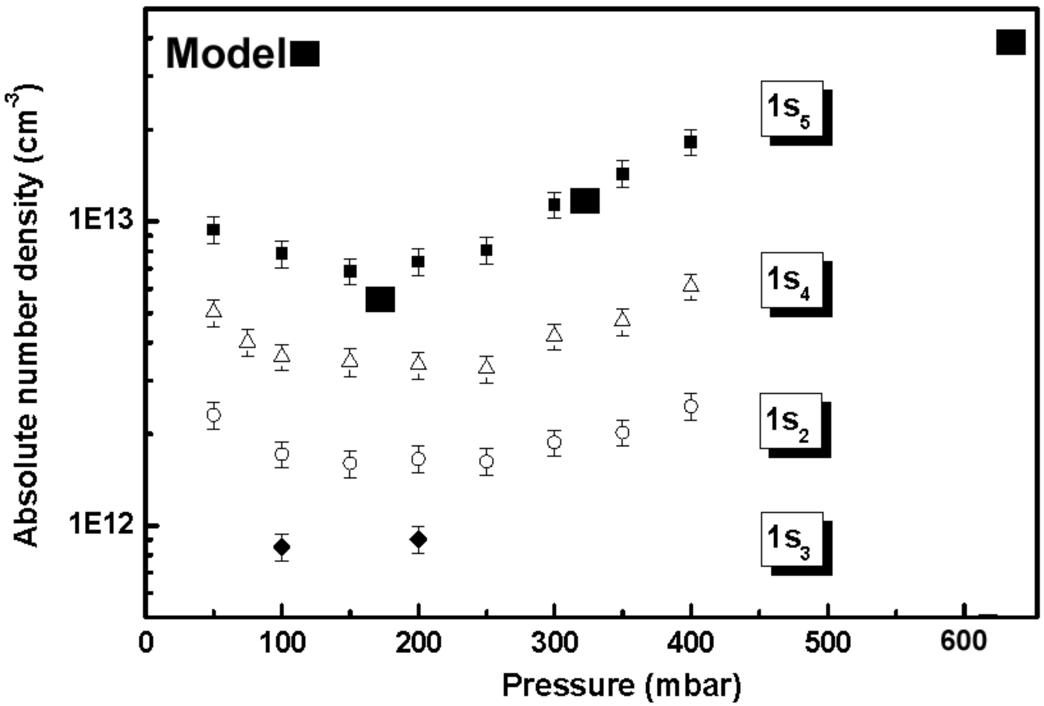


- 125 Torr
- 250 Torr
- 500 Torr

University of Illinois
Optical and Discharge Physics

MD PROPERTIES vs PRESSURE: Ar(4s) DENSITY

- Excited state densities increase with increasing pressure due to higher stopping power of gas.

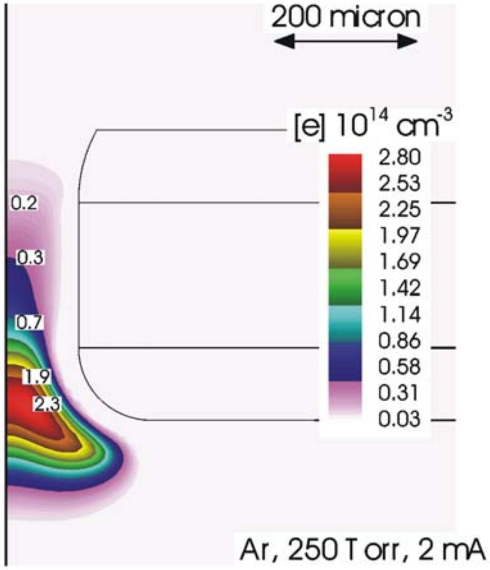


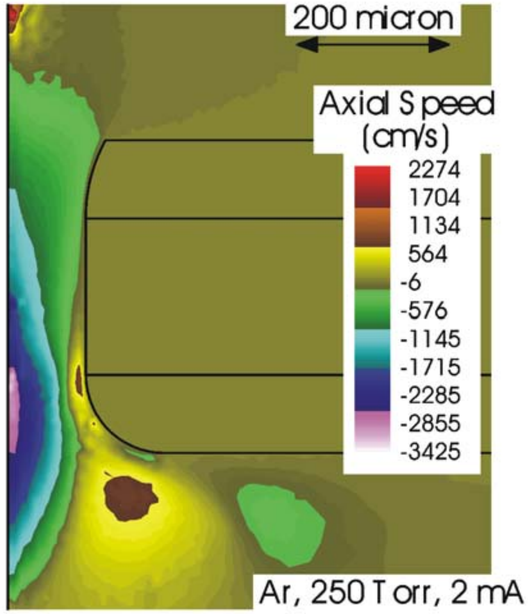
- Ref: Maria Cristina Penache, Thesis, 2002

- Ar, 2 mA

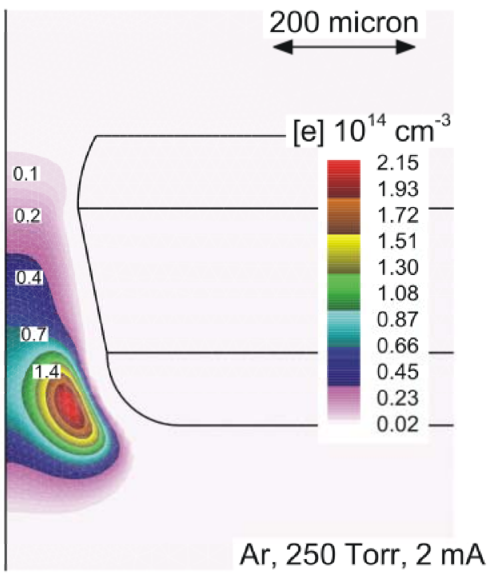
University of Illinois
Optical and Discharge Physics

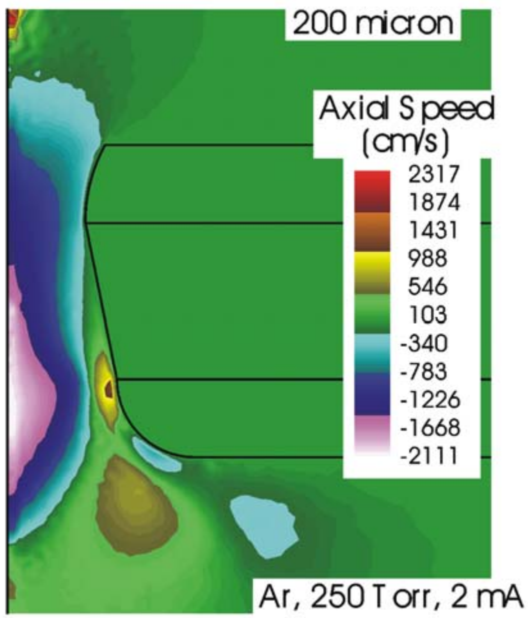
SENSITIVITY TO SHAPE: [e], AXIAL FLOW





- **Straight**



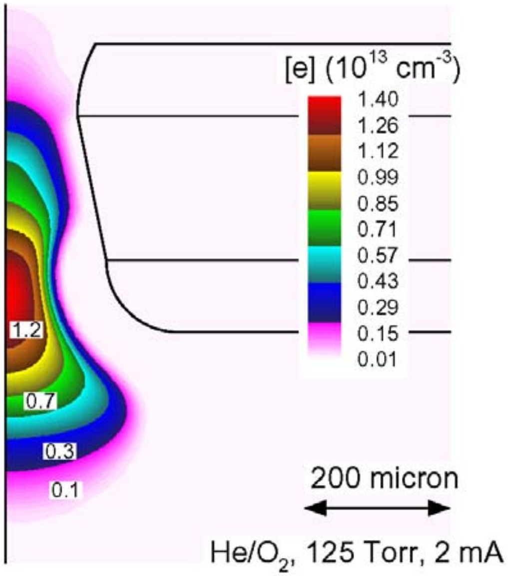


- **Tapered**

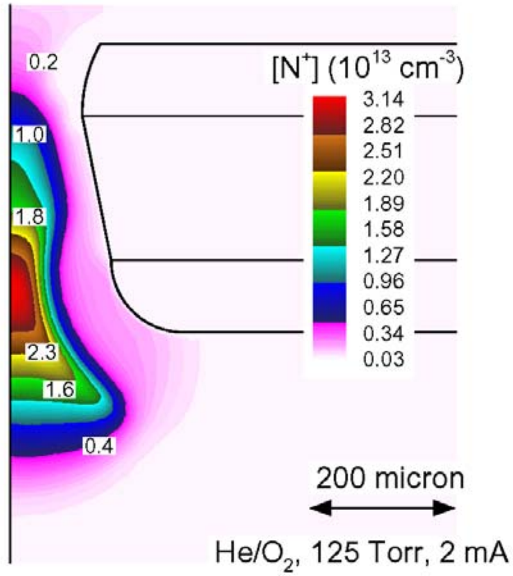
- **Speed of (downward) axial flow produced by cataphoresis is > 50% higher in the less tapered MD.**
- **Higher current density, larger E/N, larger on-axis plasma density all contribute.**
- **Ar, 250 Torr, 2 mA**

University of Illinois
Optical and Discharge Physics

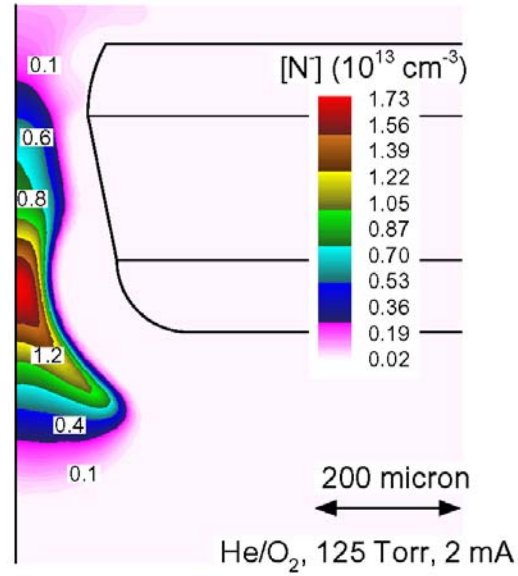
MD SUSTAINED IN He/O_2: ELECTRON, ION DENSITIES



- [e]



- [+ ions]



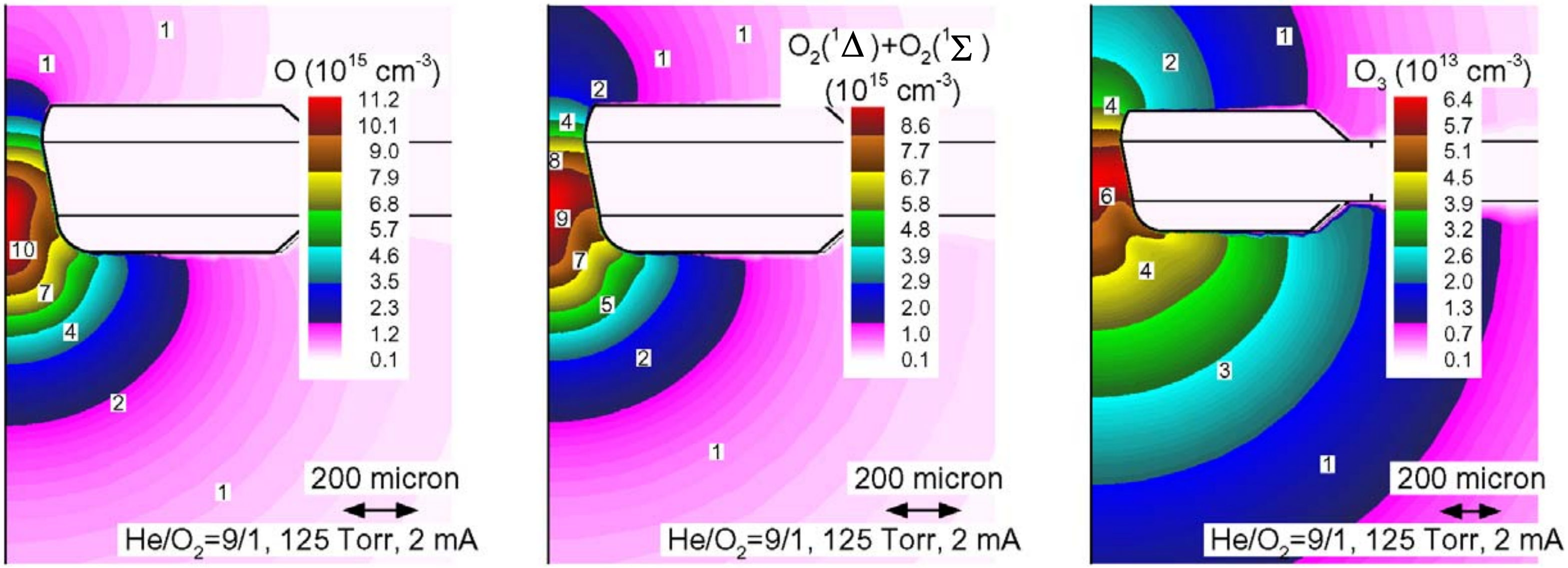
- [- ions]

- **Large current densities and intrinsically high gas flow makes MDs ideal for reactant generators.**
- **Negative ions are dominated by O_2- at pressures of 100s Torr.**

- **He/O_2=90/10, 125 Torr, 2 mA**

University of Illinois
Optical and Discharge Physics

MD SUSTAINED IN He/O_2: RADICAL, EXCITED STATE DENSITIES



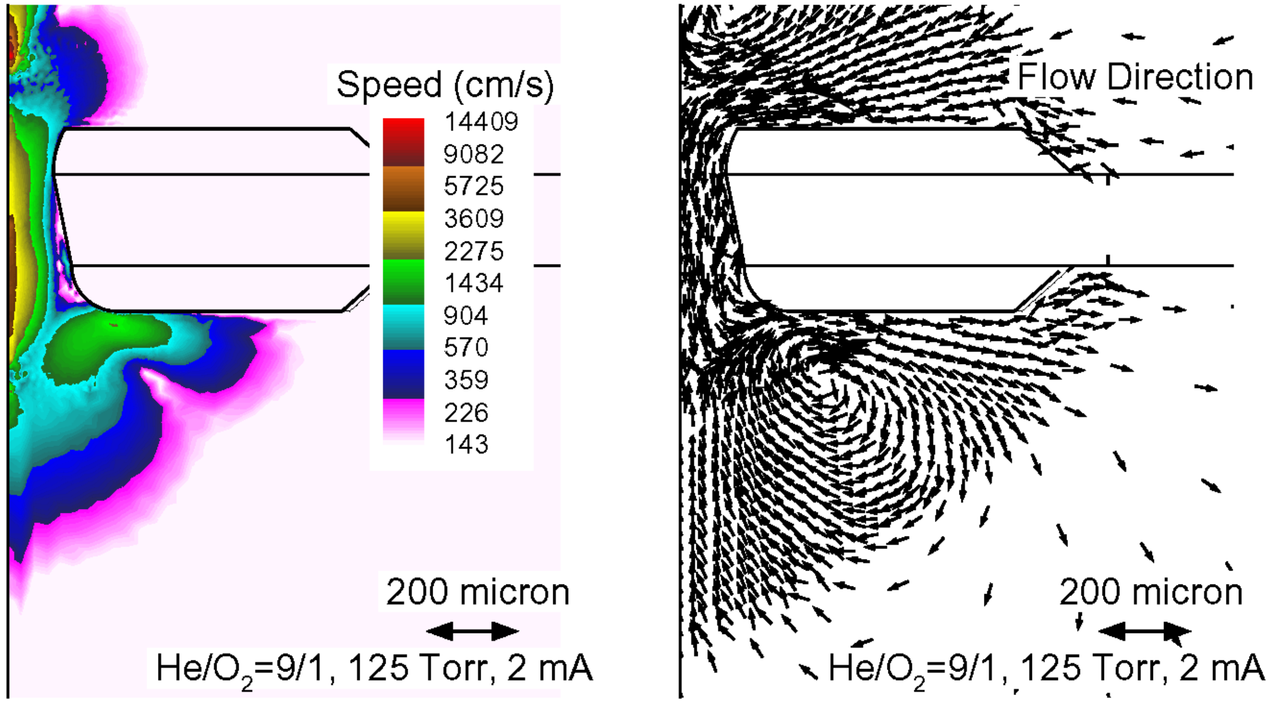
- [O]
- [$O_2(^1\Delta)$]
- [O_3]

- **The range of O atoms is limited by recombination and ozone formation. $O_2(^1\Delta)$ and O_3 are final products, having longer ranges.**
- **Cataphoresis induced flow preferentially ejects reactants downward.**

- **He/O_2=90/10, 125 Torr, 2 mA**

University of Illinois
Optical and Discharge Physics

MD SUSTAINED IN He/O_2: FLOW PROPERTIES



- **Optimization of MDs as radical sources will require careful attention to flow properties to maximize delivery of reactants.**

- **He/O_2=90/10, 125 Torr, 2 mA**

University of Illinois
Optical and Discharge Physics

CONCLUDING REMARKS

- Annular sandwich microdischarges have been computationally investigated.
- Ionization is largely dominated by beam components though bulk ionization in positive-column like regions also heavily contribute.
- Diffusive transport by long-lived metastables enable both visible (by multistep processes) and excimer emission far beyond electrodes.
- Cataphoresis produces ion pumping which can produce jets of gas through MD device.
- Use of MDs as radical generators will require careful optimization for dissociation and delivery (through gas dynamics).

University of Illinois
Optical and Discharge Physics