SOURCES OF ASYMMETRY IN IONIZED METAL PVD REACTOR+

Junqing Lu*, and Mark J. Kushner**

*Department of Mechanical and Industrial Engineering

**Department of Electrical and Computer Engineering

University of Illinois at Urbana-Champaign

November 1998

+Supported by SRC, TAZ, NSF

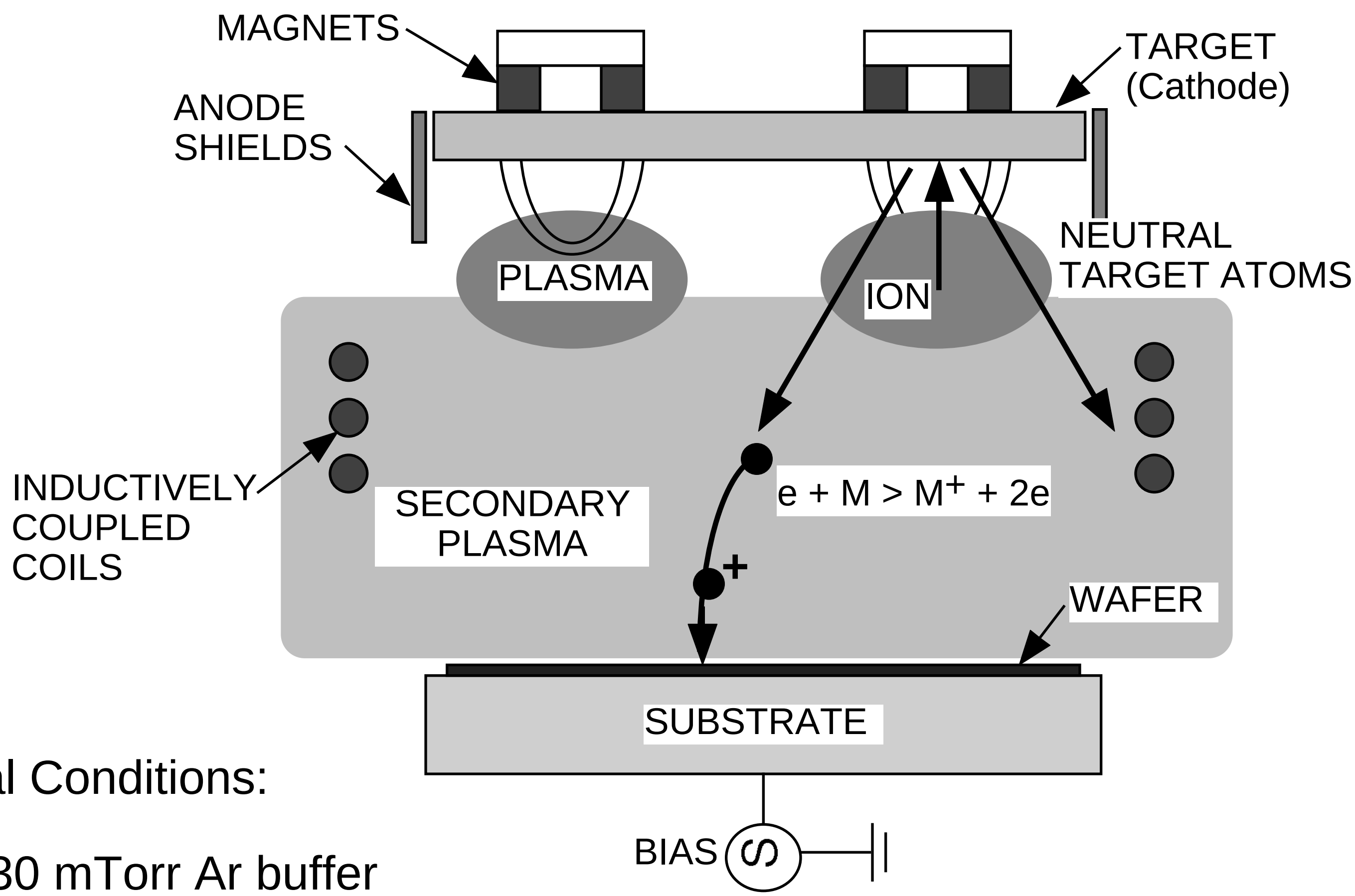
AGENDA

- Introduction to Ionized Metal Physical Vapor Deposition (IMPVD)
- Overview of Hybrid Plasma Equipment Model
- Symmetric excitation
- Asymmetric excitation for two aspect ratios
- Sputtering from two irregular targets
- Concluding remarks

UNIVERSITY OF ILLINOIS
OPTICAL AND DISCHARGE PHYSICS

IONIZED METAL PHYSICAL VAPOR DEPOSITION (IMPVD)

- In IMPVD, a second plasma source is used to ionize a large fraction of the the sputtered metal atoms prior to reaching the substrate.



- Typical Conditions:
  - 10-30 mTorr Ar buffer
  - 100s V bias on target
  - 100s W - a few kW ICP
  - 10s V bias on substrate

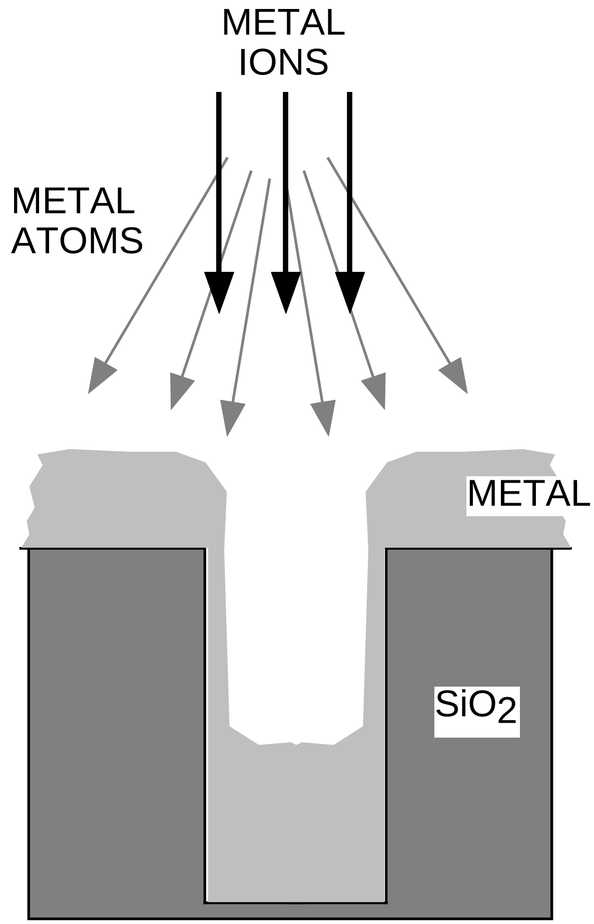
UNIVERSITY OF ILLINOIS
OPTICAL AND DISCHARGE PHYSICS

IMPVD DEPOSITION PROFILES

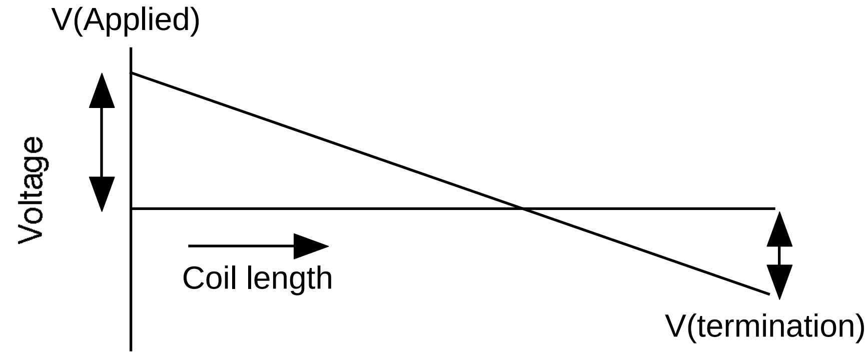
- In IMPVD, a large fraction of the atoms arriving at the substrate are ionized.

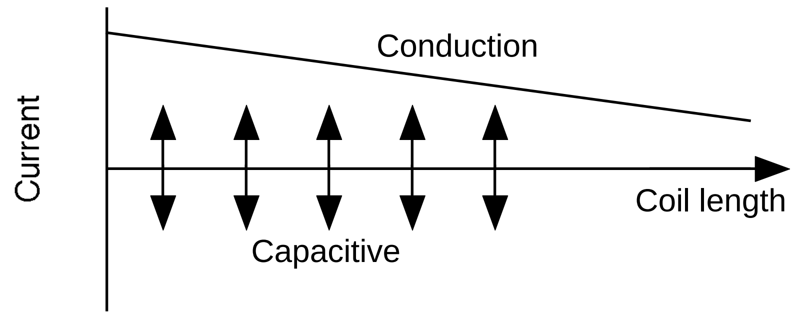
- Applying a bias to the substrate narrows the angular distribution of the metal ions.

- The anisotropic deposition flux enables deep vias and trenches to be uniformly filled.



ASYMMETRIC EXCITATION IN IONIZED METAL PVD





- IMPVD is an antenna excited system in which transmission-line effects can produce azimuthally asymmetric excitation rates.

- IMPVD differs, to some degree, from conventional etching and deposition systems because the two dominant species, a rare gas and a metal, have markedly different ionization potentials.

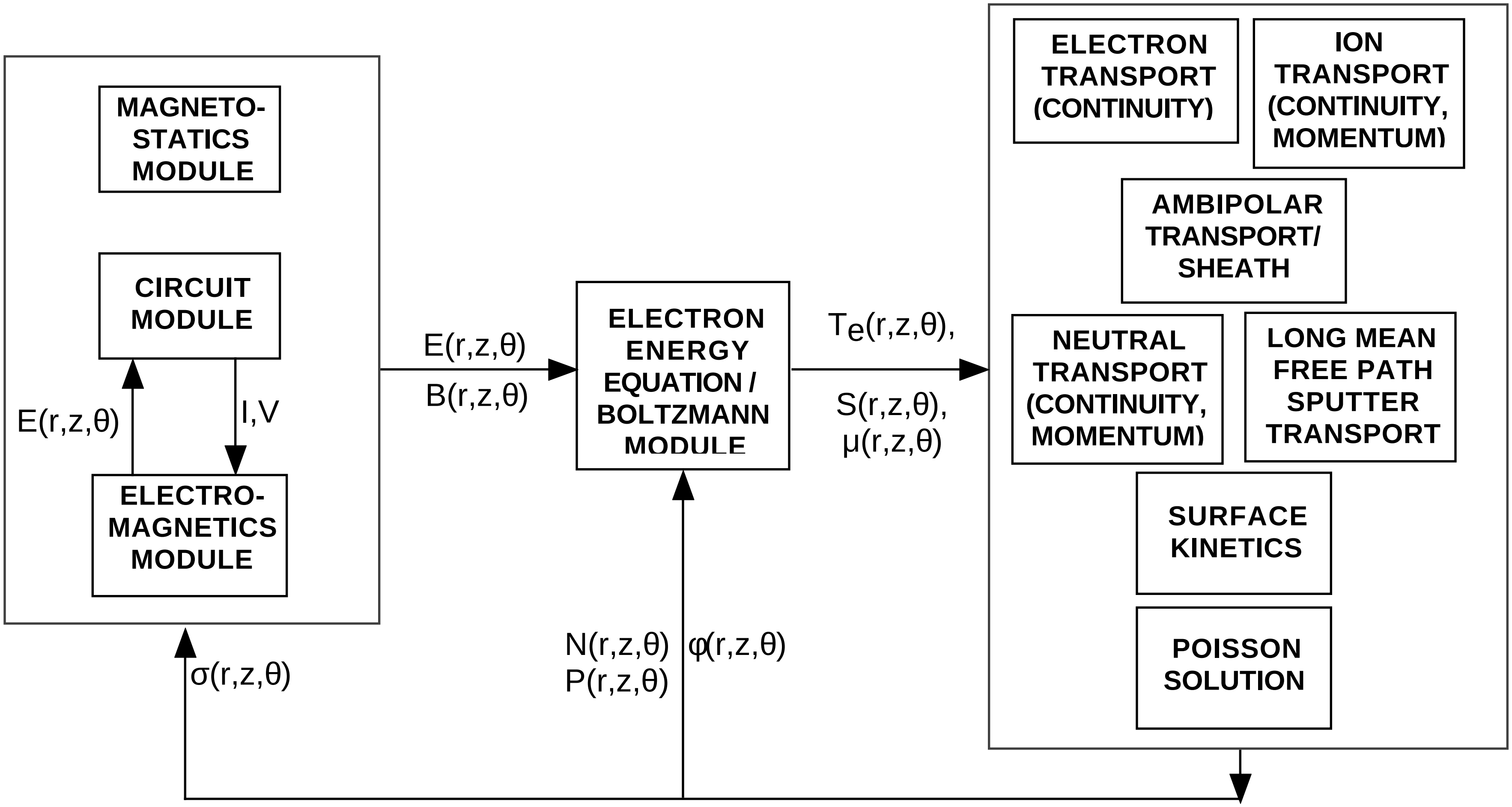
- IMPVD systems may also have a "positive feedback" character in that asymmetries in ionization produce asymmetries in metal sputtering rates, which can feed back by generating more low ionization potential atoms.

- In this paper, we will investigate the consequences of asymmetric excitation of IMPVD reactors on ion densities and fluxes in rare gas-metal vapor discharges.

UNIVERSITY OF ILLINOIS
OPTICAL AND DISCHARGE PHYSICS

SCHEMATIC OF 3-D HYBRID PLASMA EQUIPMENT MODEL

- HPEM-3D combines modules which address different physics or different timescales.



UNIVERSITY OF ILLINOIS
OPTICAL AND DISCHARGE PHYSICS

DESCRIPTION OF SPUTTERING MODEL

- The HPEM has been applied to analysis of IMPVD tools in which sputtered metal atoms are treated using a kinetic Monte Carlo approach.

- Energy of the emitted atoms (E) obeys the cascade distribution, an approximation to Thompson's law for $E_{inc} \approx 100$'s eV:

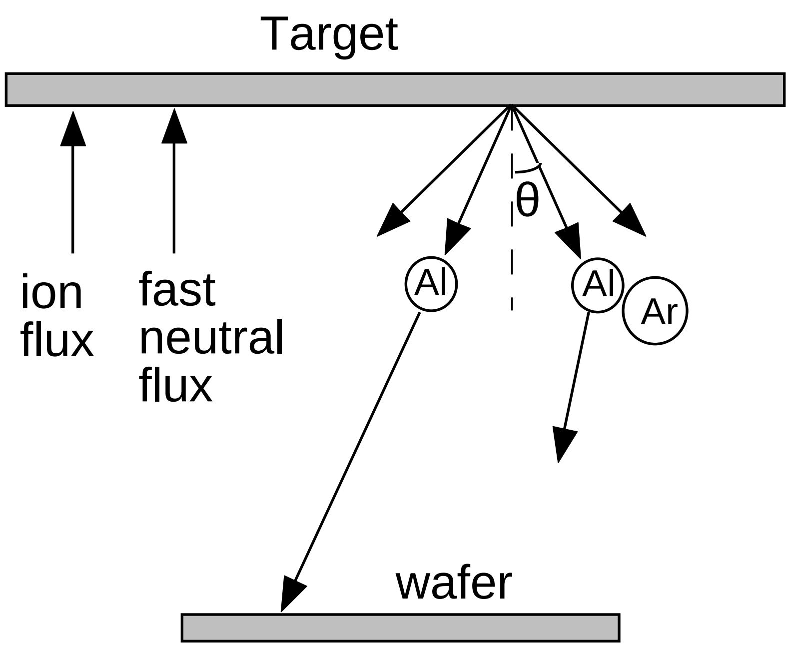
$$f(E) \sim E_b E/(E_b+E)^3$$

  where E_b is the surface binding energy.

- Collisions of the emitted atoms with the gas atoms are tracked, and locations where they slow to thermal speeds are recorded, formulating a Green's function.

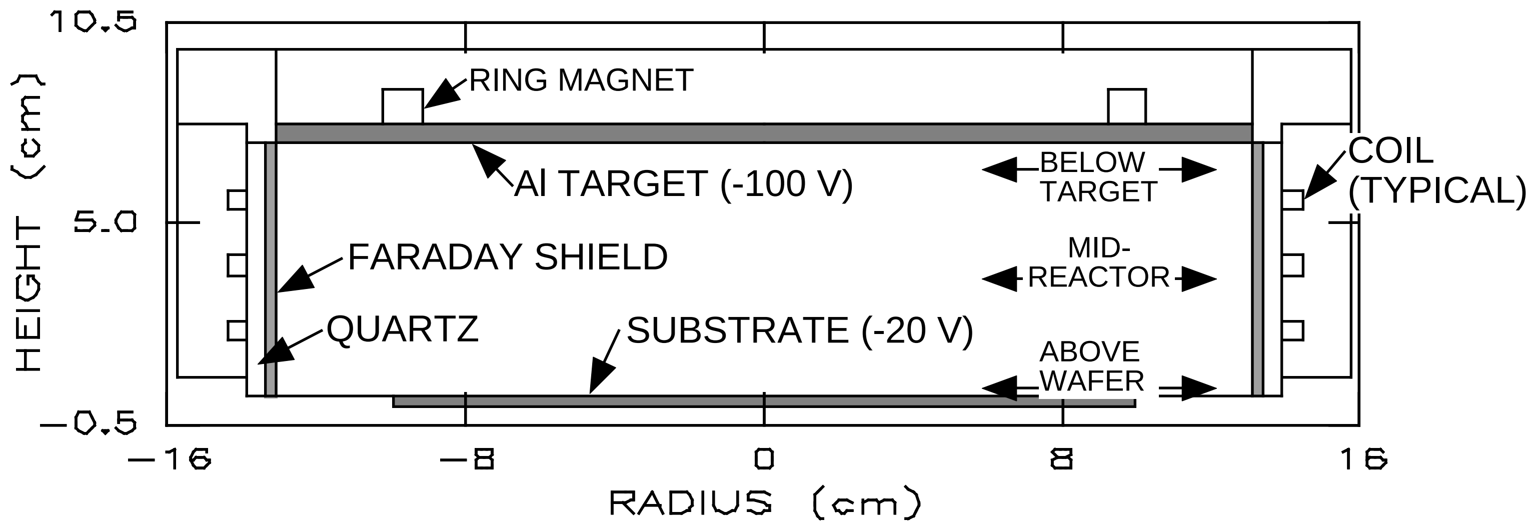
- The transport of thermalized atoms are modeled by fluid equations.

- The above approach generates metal atom sputtering sources in the plasma region, and the metal flux to the wafer.



IMPVD REACTOR

• An IMPVD reactor utilizing a Faraday shield and having external coils is examined.

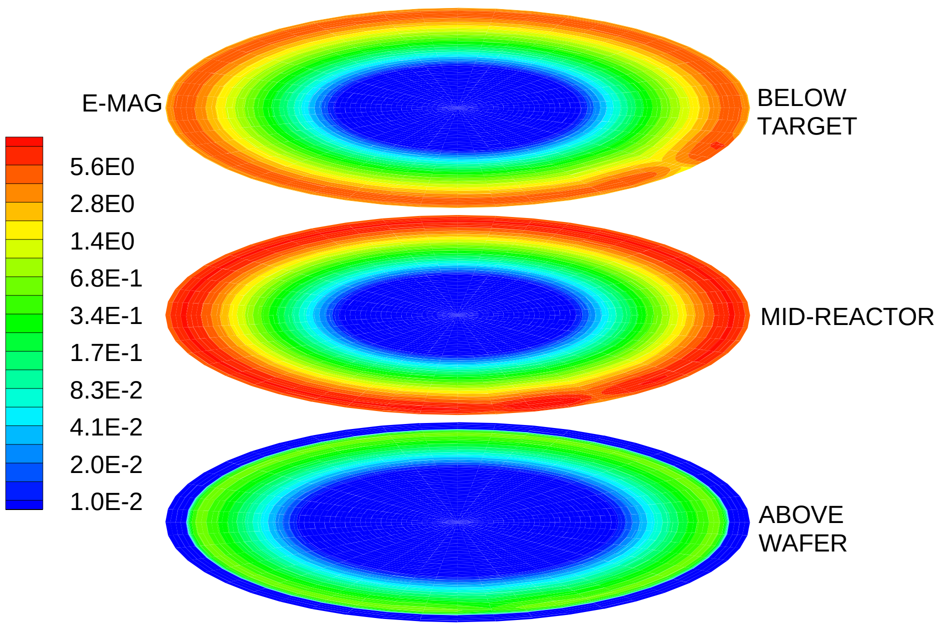


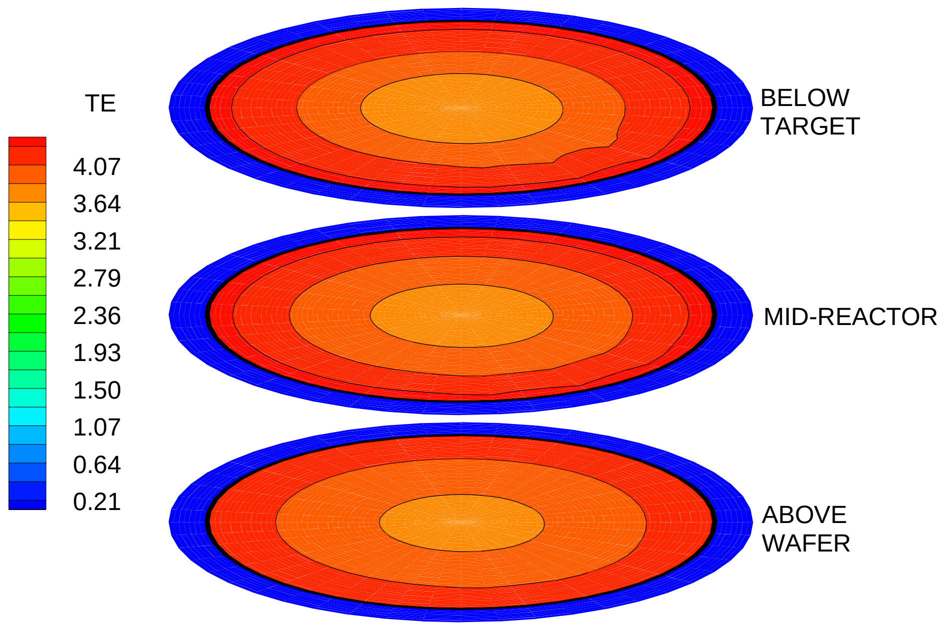
• Process conditions:

- • Ar, 10 mTorr, Al Target
- • 600 W (inductive),
- • -100 V target, -20 V substrate
- • 200 G (at target)

IMPVD REACTOR-UNIFORM AZIMUTHAL EXCITATION: ELECTRIC FIELD AND ELECTRON TEMPERATURE

- The “traverses” of the coil from one level to another produce small asymmetries in the electric field, electron temperature and electron source. These asymmetries quickly “diffuse” away with few consequences on ion densities.



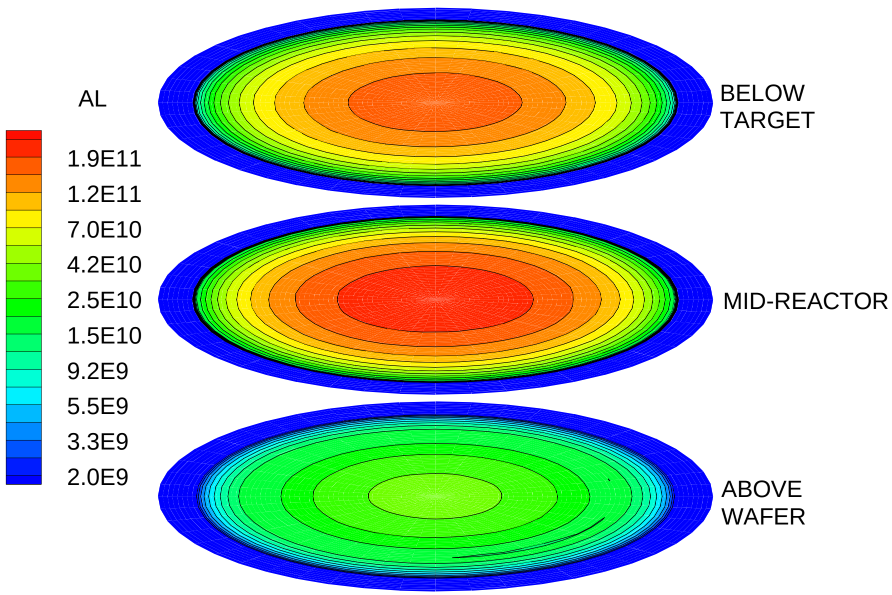


- Inductive Electric Field (V/cm)
- Electron Temperature (eV)
- Ar, 10 mTorr, Al target, 600 W, H/R = 0.5

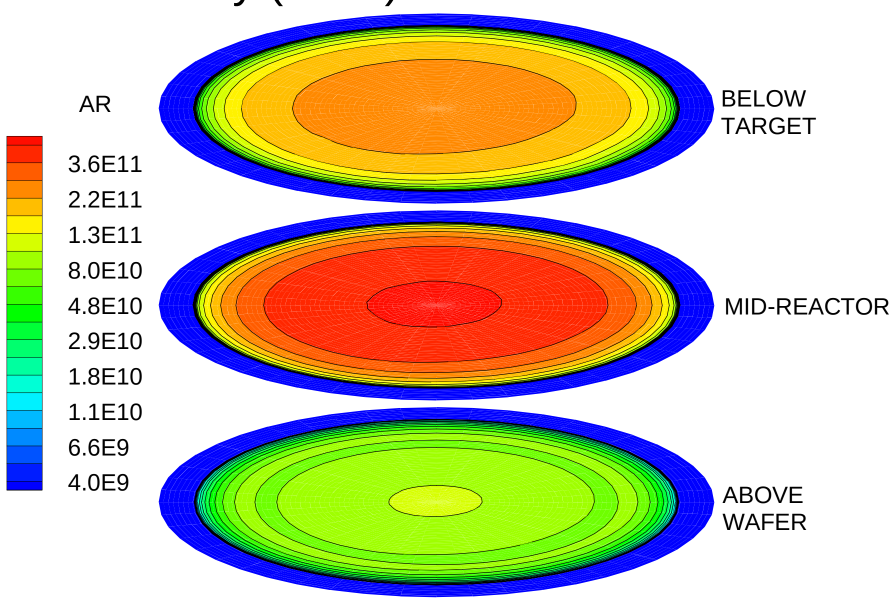
UNIVERSITY OF ILLINOIS
OPTICAL AND DISCHARGE PHYSICS

IMPVD REACTOR-UNIFORM AZIMUTHAL EXCITATION:

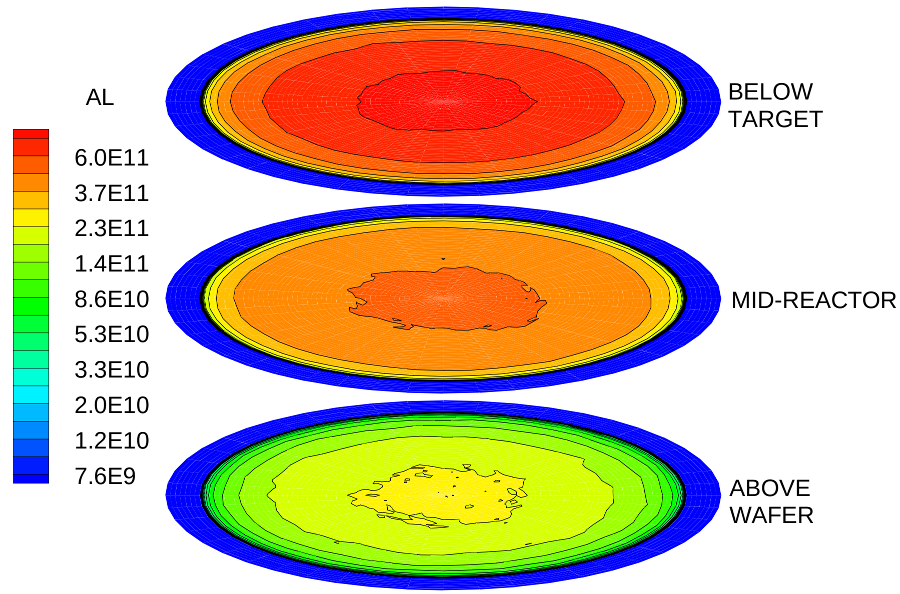
ION AND Al DENSITIES



• Al^+ Density (cm^{-3})



• Ar^+ Density (cm^{-3})



• Al Density (cm^{-3})

• Ar, 10 mTorr, Al target, 600 W, H/R = 0.5

UNIVERSITY OF ILLINOIS
OPTICAL AND DISCHARGE PHYSICS

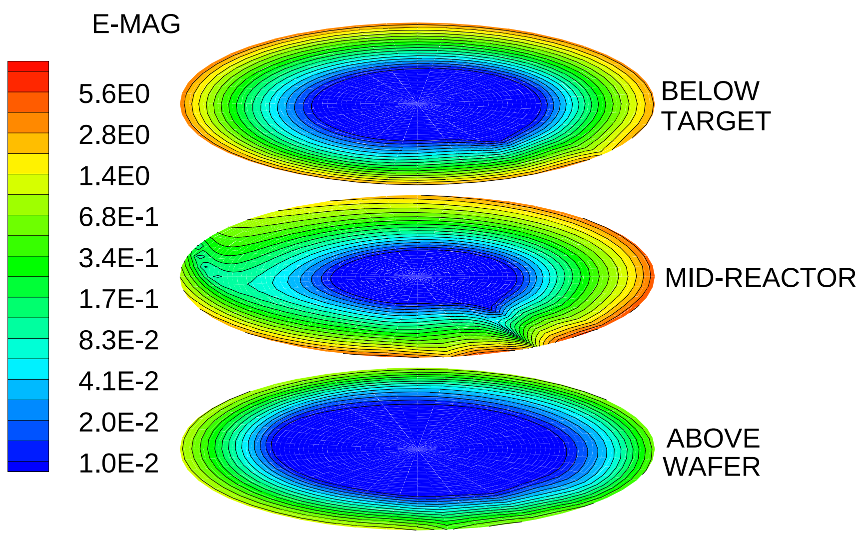
GRC98M04

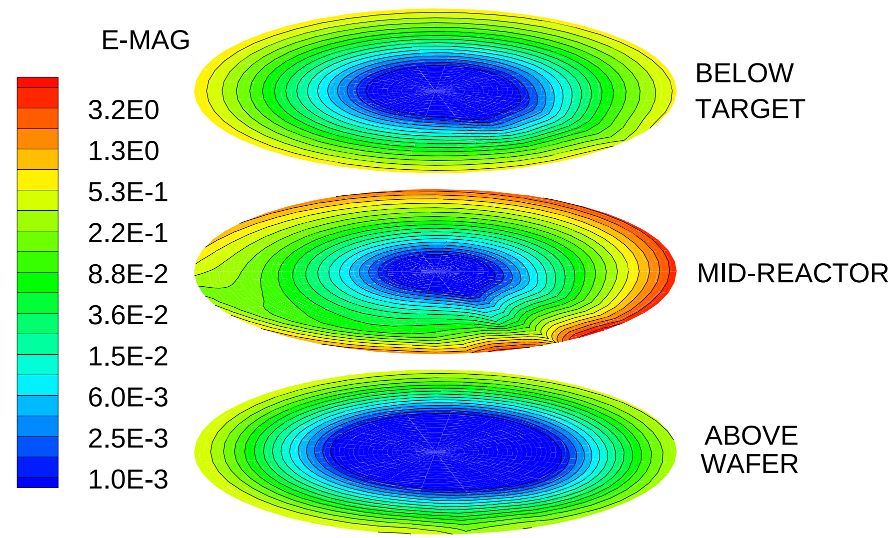
IMPVD REACTOR-ASYMMETRIC EXCITATION:

ELECTRIC FIELD AT TWO ASPECT RATIOS

- The electric field peaks at mid-reactor due to the coil location, and peaks on the right edge of the plasma due to the transmission line effects (C_{term} = 100 pF).

- The electric field for H/R = 0.75 below the target and above the wafer is smaller than that for H/R = 0.5 due to skin depth effects.





- Height/Radius = 0.5

E-field (V/cm)

- Height/Radius = 0.75

- Ar, 10 mTorr, Al target, 600 W

UNIVERSITY OF ILLINOIS
OPTICAL AND DISCHARGE PHYSICS