Simulations and Experimental Measurements of a Hollow Cathode Magnetron Ionized Metal Plasma Deposition System

Gabriel I. Font, Kwok Lai, and Jean Q. Lu
Novellus Systems, Inc

and

Mark J. Kushner
University of Illinois at Urbana-Champaign

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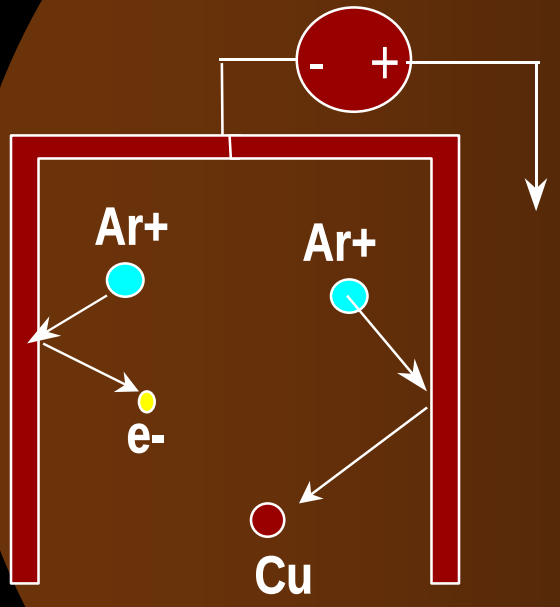
OUTLINE

- Details of Hybrid Plasma Equipment Model (HPEM)
- Theory of Hollow Cathode Magnetron operation
- Comparison with experiments
- Simulation results
- Summary

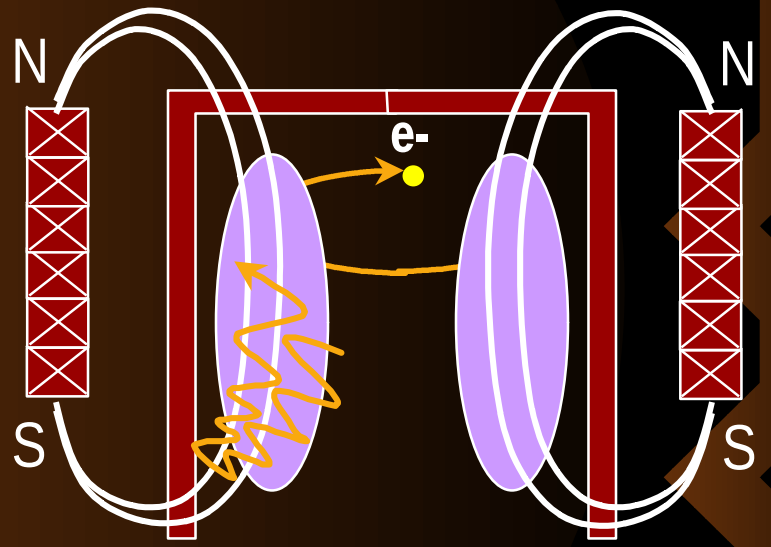
HCM - Utilizes Well Known PVD Effects

Hollow Cathode



-Sputtering
-Secondary Electron Emission
-Electrostatic Confinement
-Geometric Confinement

Magnetron



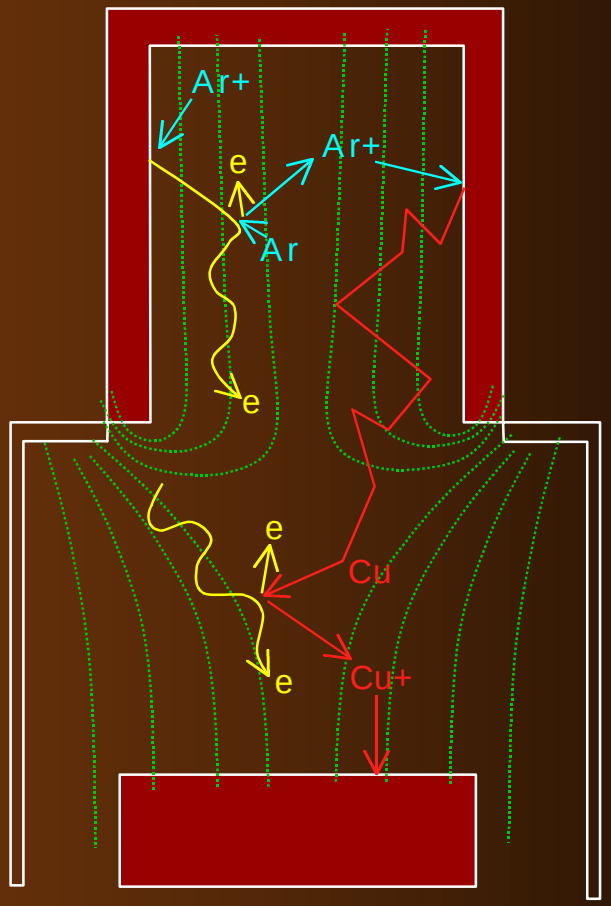
-Magnetic Confinement
  -ExB
  -Grad B

Hybrid Plasma Equipment Model (HPEM)

- Modular Plasma Simulation

Separation of Time Scales:

- **electron**
- **ion**
- **neutral**



Code Particle Modules:

- **sec. electron emission**
- **electron magnetization**
- **energetic copper sputter**
- **copper thermalization**

Code Fluid Modules:

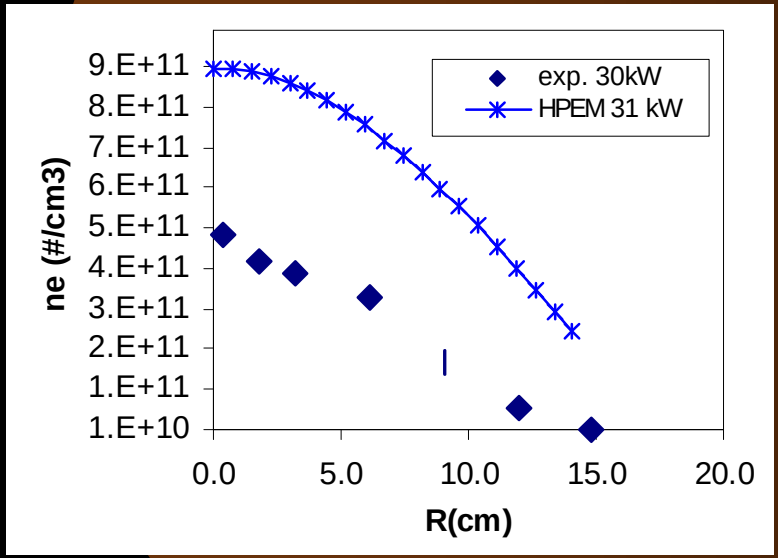
- **neutral transport (r,ru)**
- **ion transport (r,ru)**

Additional Modules:

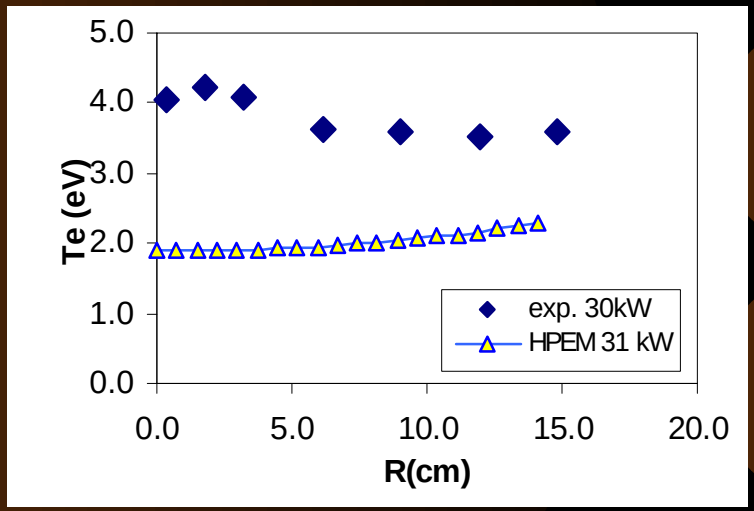
- **sheath transport**
- **Poisson solution (V_p)**
- **Boltzmann Solver (e_e)**

Hollow Cathode Magnetron Simulation
- Comparison with Experiments

Plasma Density

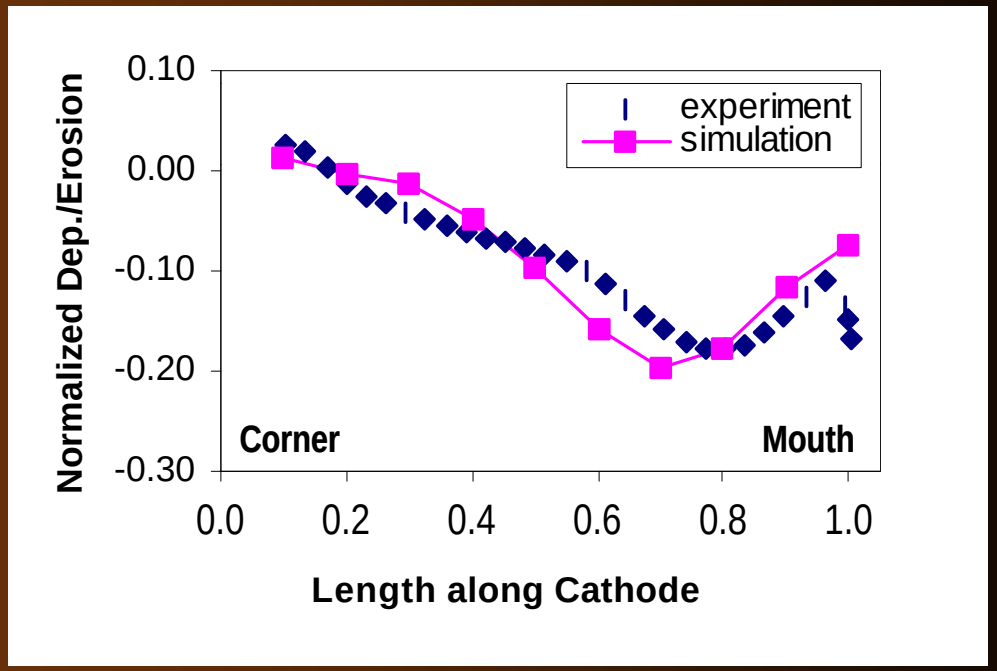


Electron Temperature



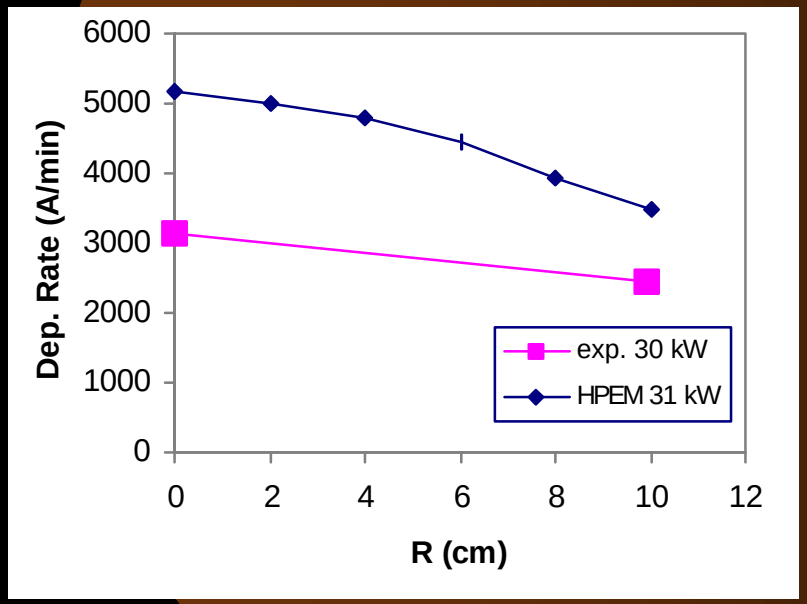
Hollow Cathode Magnetron Simulation
- Comparison with Experiments

HCM Target Erosion Profile

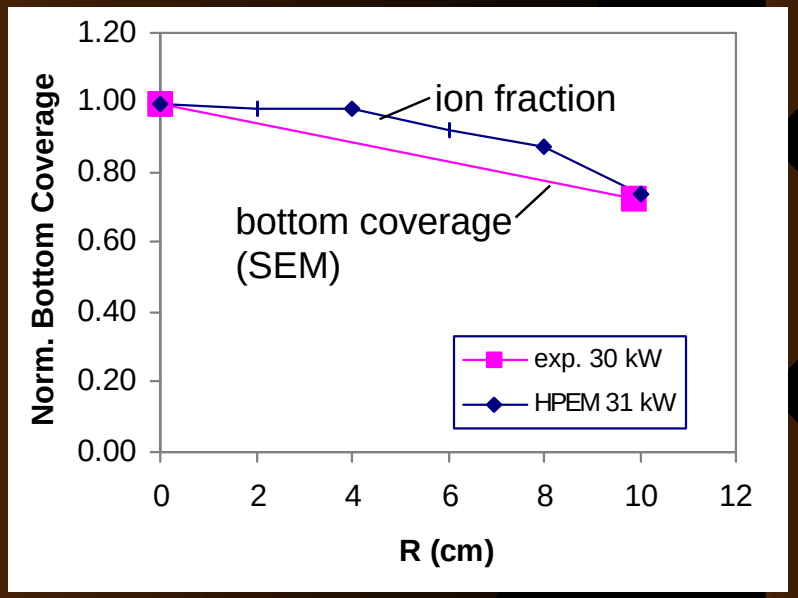


Hollow Cathode Magnetron Simulation
- Comparison with Experiments

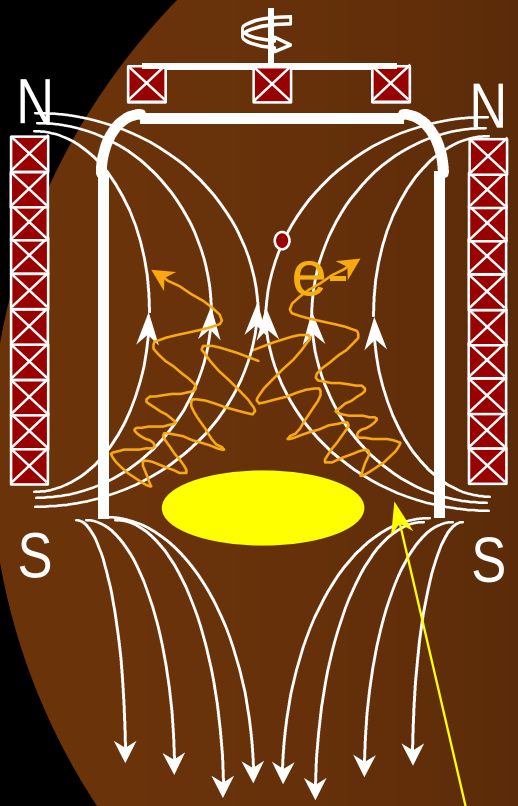
Wafer Deposition

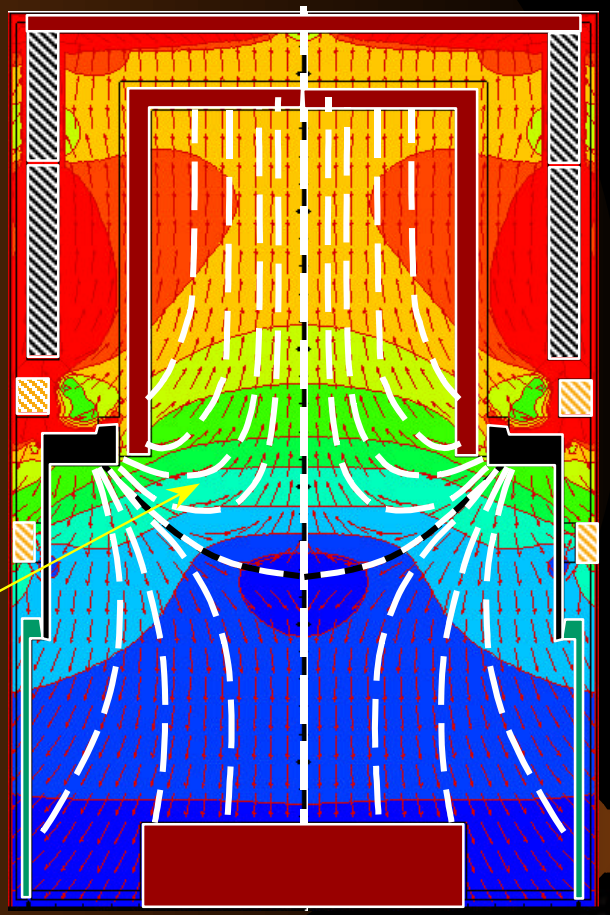


Bottom Coverage



Hollow Cathode Magnetron Simulation
- Magnetic Mirror





Magnetic Field Strength
High
Low

Magnetic Mirror will result in electron confinement

Cu 29 novellus

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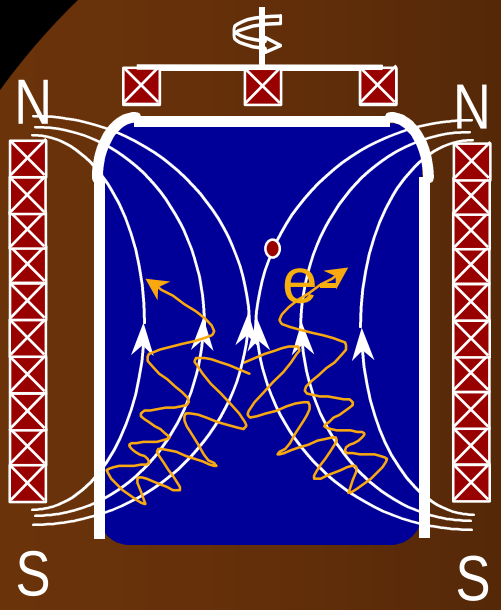
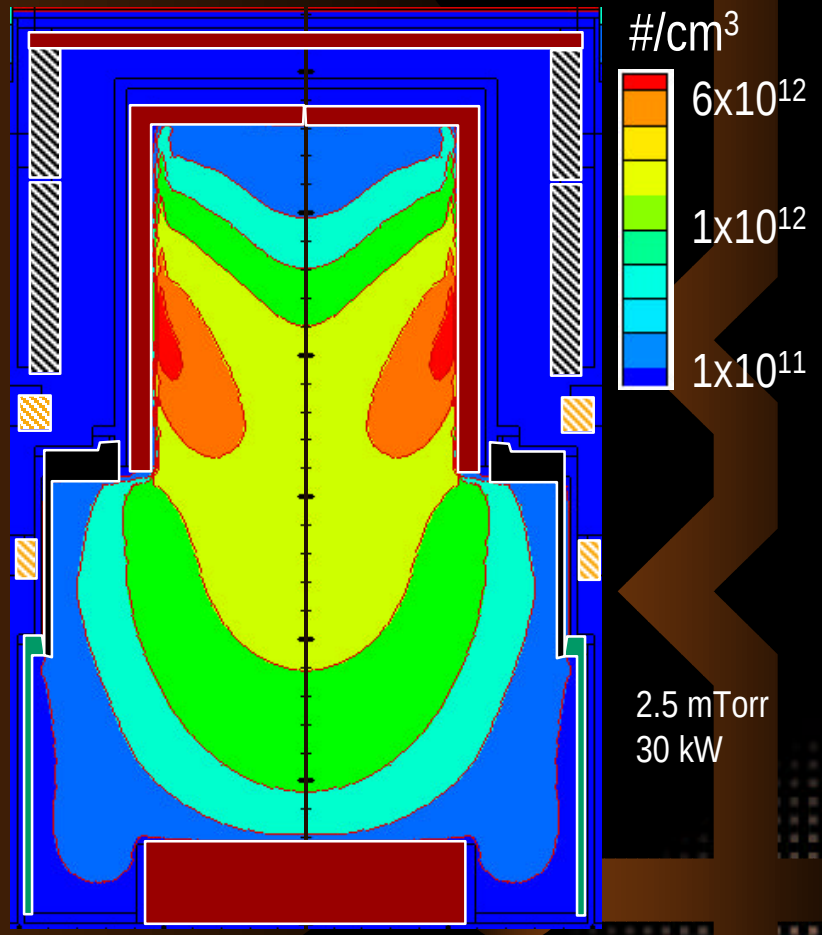
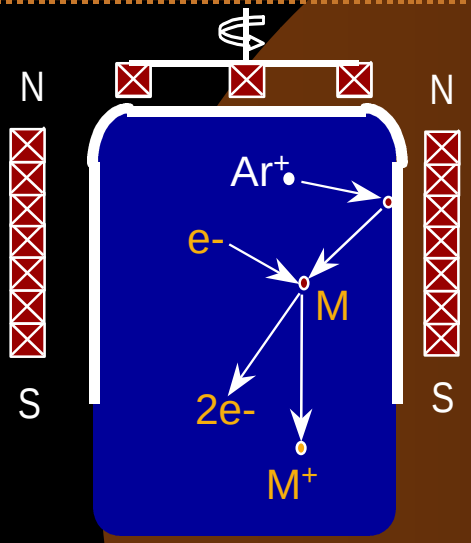
Hollow Cathode Magnetron Simulation
- Plasma Density





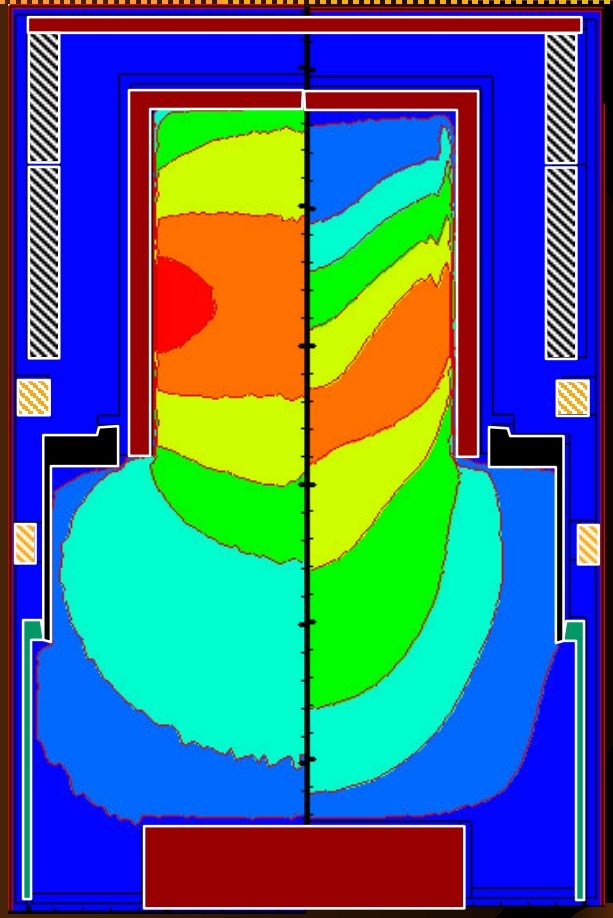
Confinement of Electrons in the Three Dimensional source Results in High Density Plasma

Hollow Cathode Magnetron Simulation
- Copper Neutrals and Ions



Cu Neutral Density (10^{12} #/cm^3)

30
20
10
5.0
1.0
0.5



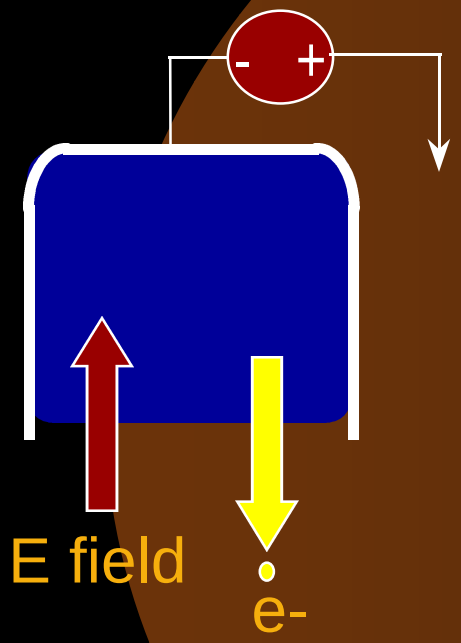
Cu Ion Density (10^{12} #/cm^3)

4.0
3.0
2.0
1.0
0.5
0.1

2.5 mTorr
30 kW

High density of electrons efficiently ionize the sputtered copper

Hollow Cathode Magnetron Simulation
- Electron Flux

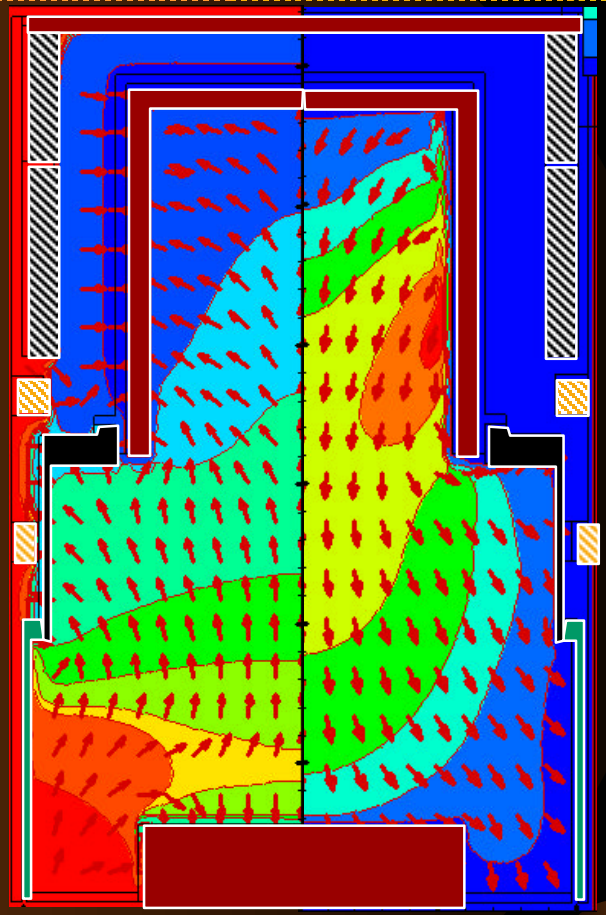


Electric Field Vectors and Potential (V)

-5

-12

-20



Electron Flux Vectors and Density (#/cm^{3})

$6x10^{12}$

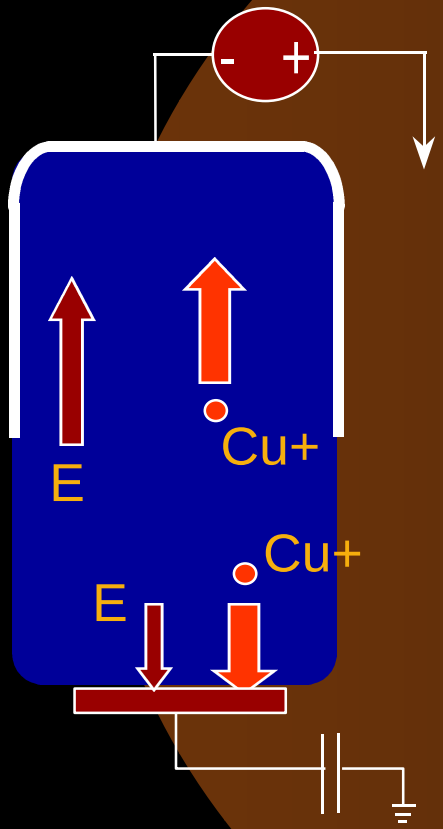
$1x10^{12}$

$1x10^{11}$

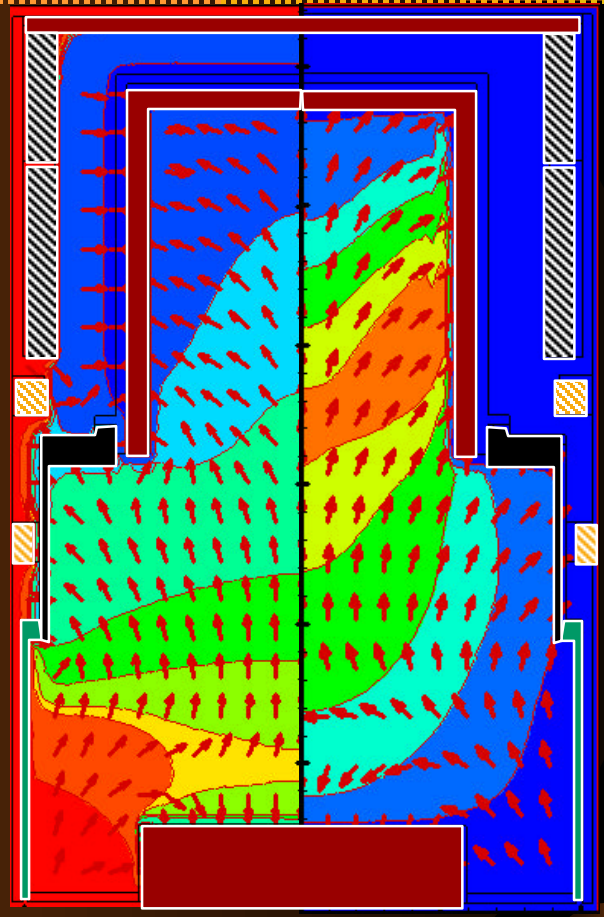
2.5 mTorr
30 kW

Electrons are pushed out of the cathode by the electric field

Hollow Cathode Magnetron Simulation
- Copper Ion Flux



Electric Field Vectors and Potential (V)



Cu+ Flux Vectors and Density (10^{12} #/cm^3)

2.5 mTorr
30 kW

Ions are attracted to the cathode and the wafer by the electric field

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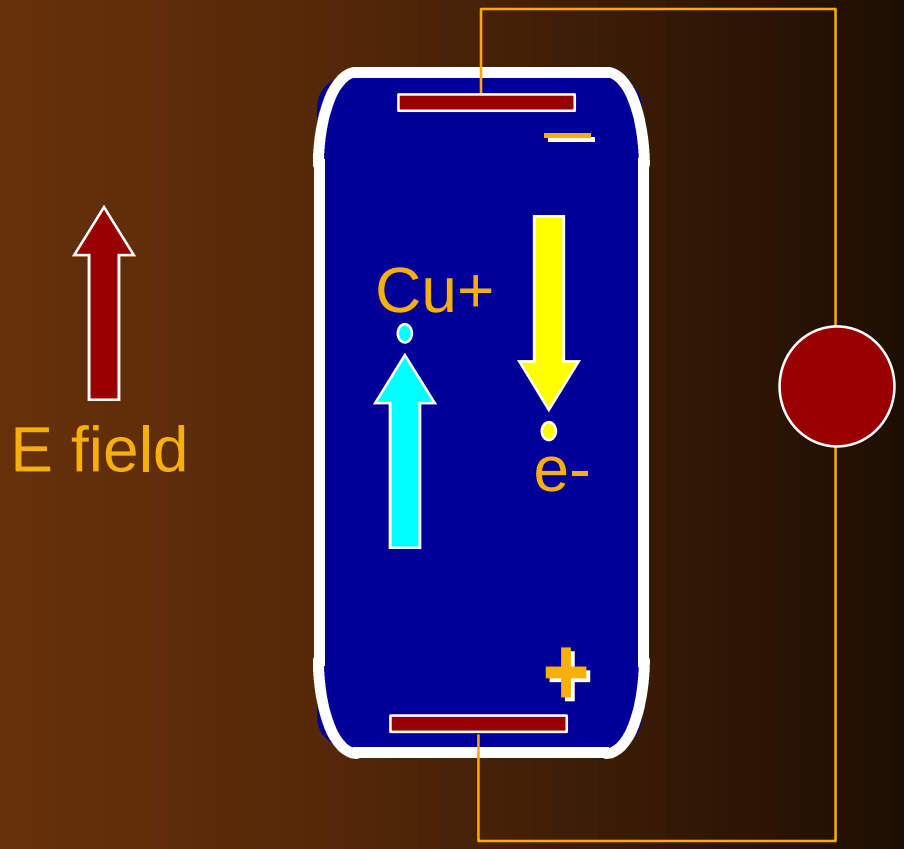
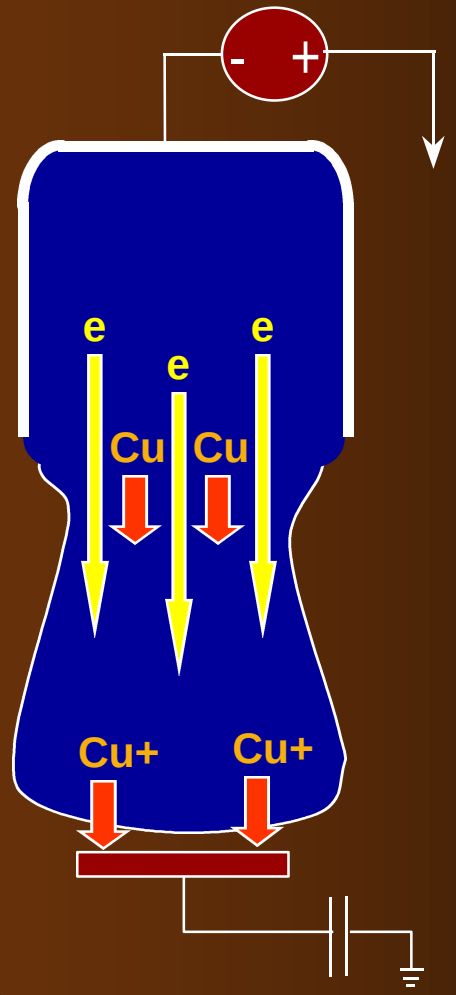
Hollow Cathode Magnetron Simulation
- Plasma Analogy



The ion and electron flux are similar to a column discharge

Hollow Cathode Magnetron Simulation
- Principal Features

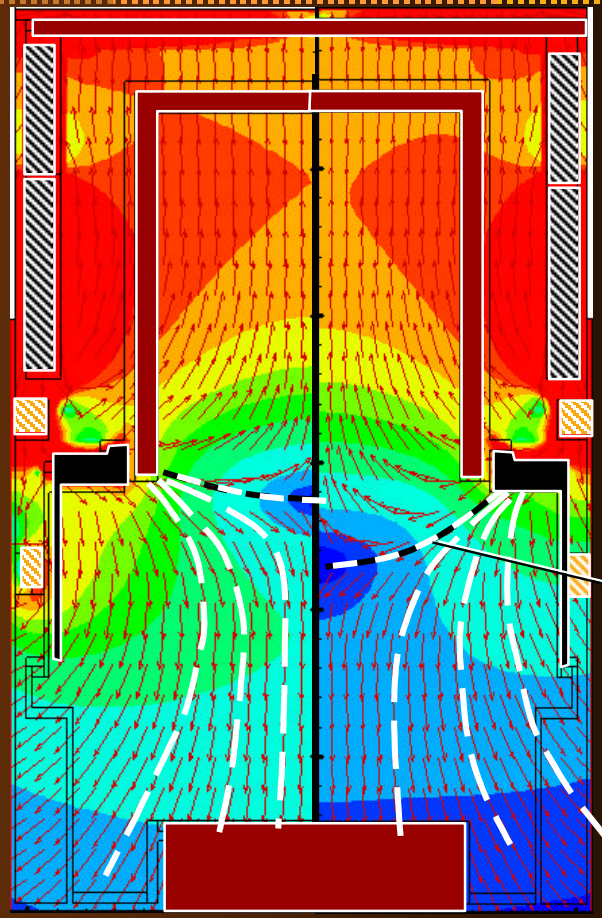


The Hollow Cathode Magnetron is:

1) Electron Source
2) Neutral Copper Source

The electron beam ionizes the copper which deposits on the wafer

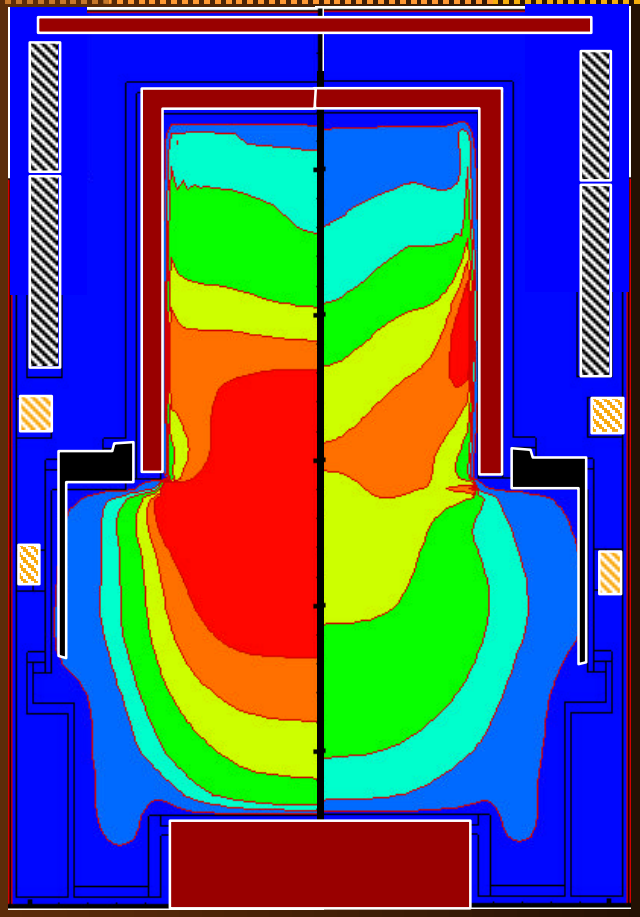
Hollow Cathode Magnetron Simulation
- Electro-magnetic Coil



EM Coil shapes the magnetic field at the edge of and outside the source

Hollow Cathode Magnetron Simulation
- EM Coil effects on plasma density

EM Coil: 0 Amp



EM Coil: 3 Amp

Electron Density (#/cm^{3})

$4x10^{12}$

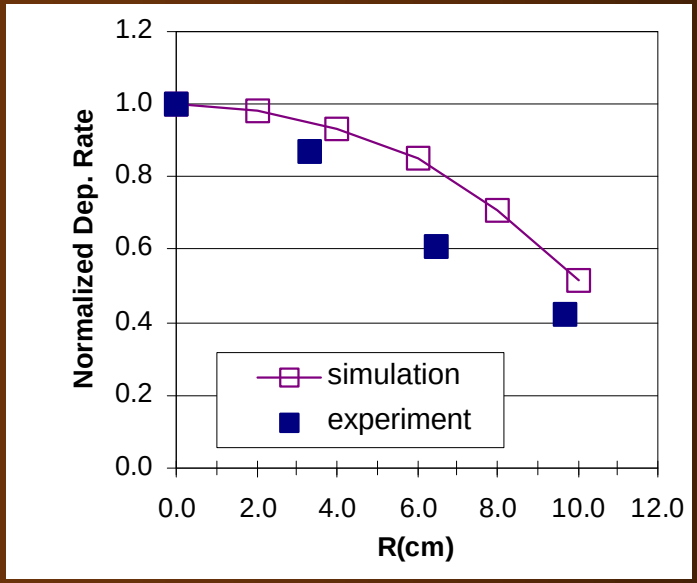
$1x10^{12}$

$1x10^{11}$

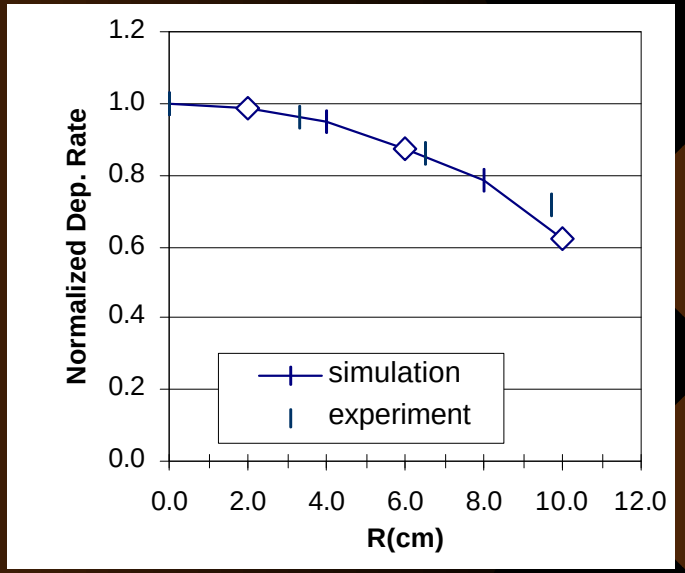
EM coil changes to the magnetic field shape result in changes to the plasma maximum density and distribution near the wafer

Hollow Cathode Magnetron Simulation
- EM Coil effects on Deposition Profile

EM: 0 Amp



EM: 3 Amp



The EM coil can be used to tailor the deposition profile on the wafer

Hollow Cathode Magnetron Simulation
- Summary

- HPEM has provided a window into the physical processes occurring inside the Hollow Cathode Magnetron
- The HCM generates a dense plasma through magnetic, electrostatic, and geometric confinement
- Electrons are pushed out of the source by the electric field in a manner similar to a column discharge
- High electron density ensures efficient ionization of the sputtered copper throughout the reactor
- Magnetic fields outside the HCM source can be modulated to control the deposition profile on the wafer
- The knowledge gained has been used to improve the design of the Hollow Cathode Magnetron