Modeling Particle Transport in Low Pressure Under Plasma Conditions

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Sematech

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IEUVI Mask TWG

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TECH-X CORPORATION

Tech-X is a computational science company headquartered in Boulder, CO

- Founded in 1994
- 65 employees in 2009
- Offices in US (Boulder & Buffalo) and UK
- Main focus is computational plasma science
- Especially focused on multi-core computing

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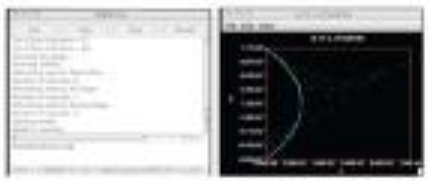
Tech-X produces four software tools for industrial simulation

VORPAL

VORPAL is a cross-platform software solution capable of large-scale, massively-parallel simulations of electromagnetic and electrostatic phenomena, modeling fields, particles, and fuids in one, two, or three dimensions.

OOPIC Pro

OOPIC Pro integrates simulation and visualization capabilities, allowing users to easily create PIC (Particle-in-Cell) simulations to solve problems in education, research, and engineering.

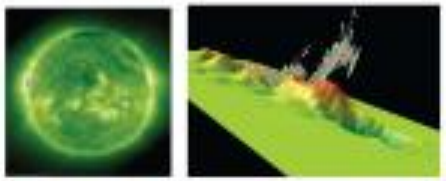


GPULib

GPULib unleashes the power of parallel, vectorized computations for GPUs with an easy-to-use, high-level API, allowing scientists and engineers to more easily leverage high-performance computing hardware in their desktop environment.

FastDL

FastDL bridges the gap between IDL and parallel computing. With FastDL, scientists and developers can run IDL visualization and analyses applications in parallel, significantly shortening the time required to get results.



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Goal:
Investigate defect transport in a plasma environment typical of ion beam processing tools

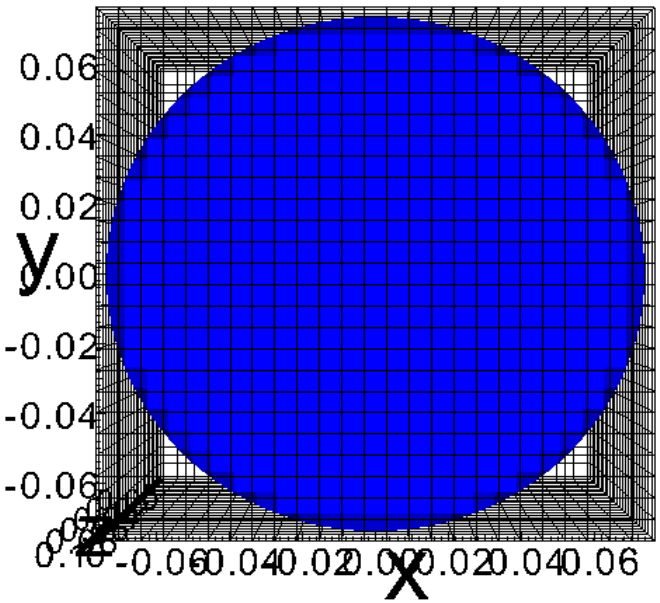
- Provide simulations of
  - the plasma conditions inside the chamber
  - the influence of the plasma on defect transport
  - optimizing surface voltages to minimize defects

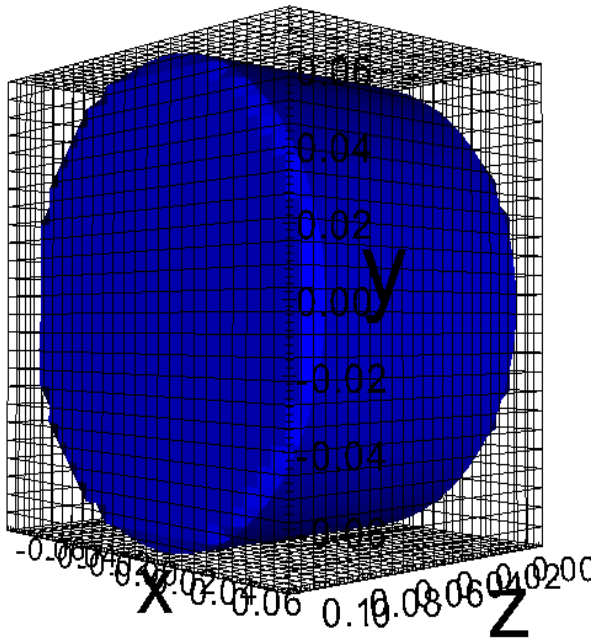
- Provide simulations of the ion beam divergence, including effects of charge exchange and grid voltages.

Approach: Apply a self-consistent plasma modeling tool to help understand these issues

- Algorithm overview
- FDTD, PIC, Monte Carlo
- Result from similar work in lunar charging

VORPAL is a 3D, FDTD PIC code with MCC to model plasmas





Self-consistent treatment of particles and fields
Includes Monte Carlo collisions for excitation, ionization, secondary emission

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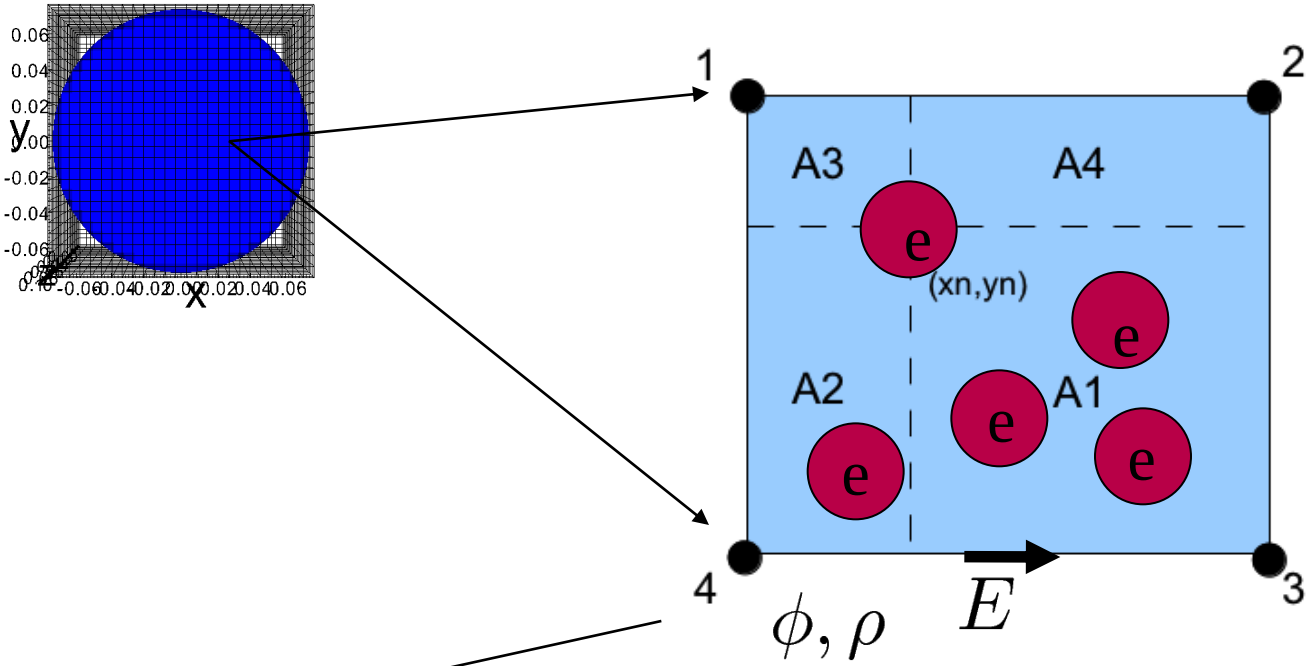

Area weighting preserves charge exactly

$$\nabla^2 \phi = -\rho/\epsilon_0$$

$$x_{n+1} = x_n + v_{n+1/2} * dt$$

$$v_{n+1/2} = v_{n-1/2} + q \cdot dt \left(E(x_n) + v_{n-1/2} \times B(x_n) \right)$$

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PIC is computationally expensive compared to other approaches

- Time step must resolve plasma frequency
- Cell size must resolve Debye length
- Often requires parallel computing for industrial plasmas
- Monte Carlo is only as good as the cross sections

Previous relevant effort: dust motion in plasma environment

	Moon	Processing Chamber
Species	Beam: -> Solar Ions, Electrons Surface-> Absorbed Ions, Electrons Bulk -> Photoelectrons	Incident Ion Beam Absorbed Ions, Electrons Ambient Plasma
Fields	Electrostatic simulations: Plasma in self-consistent electric field	Electrostatic simulations: Plasma in self-consistent electric field
Output	Track motion of dust grain in plasma environment	Track motion of defect in plasma environment

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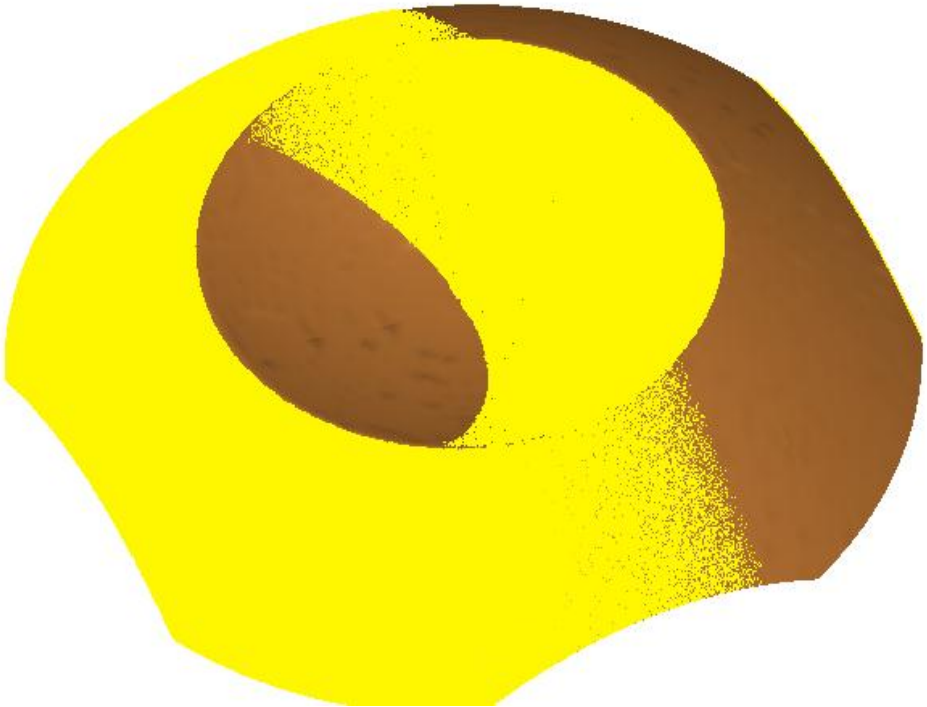
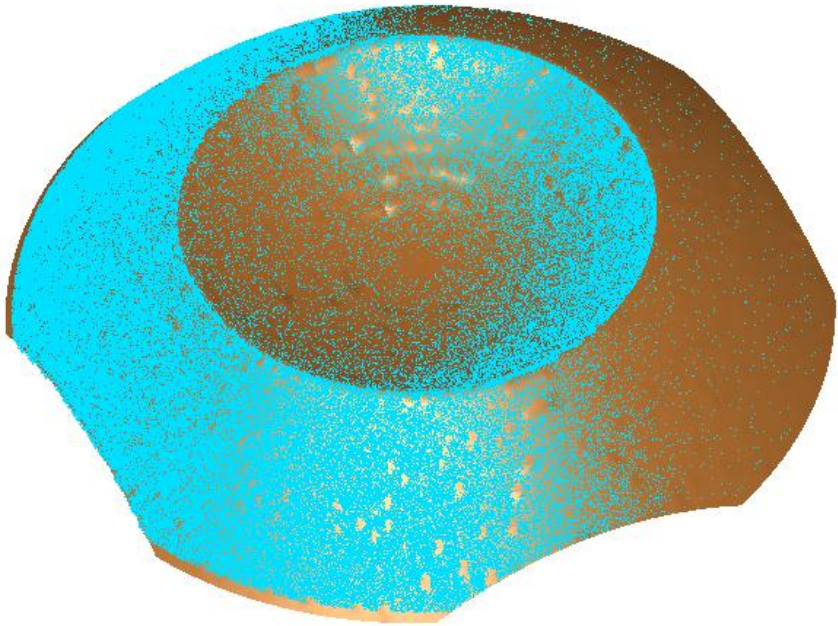
Previous relevant effort: dust motion in plasma environment





Positive charge

Negative charge

VORPAL computes charging in complex topology

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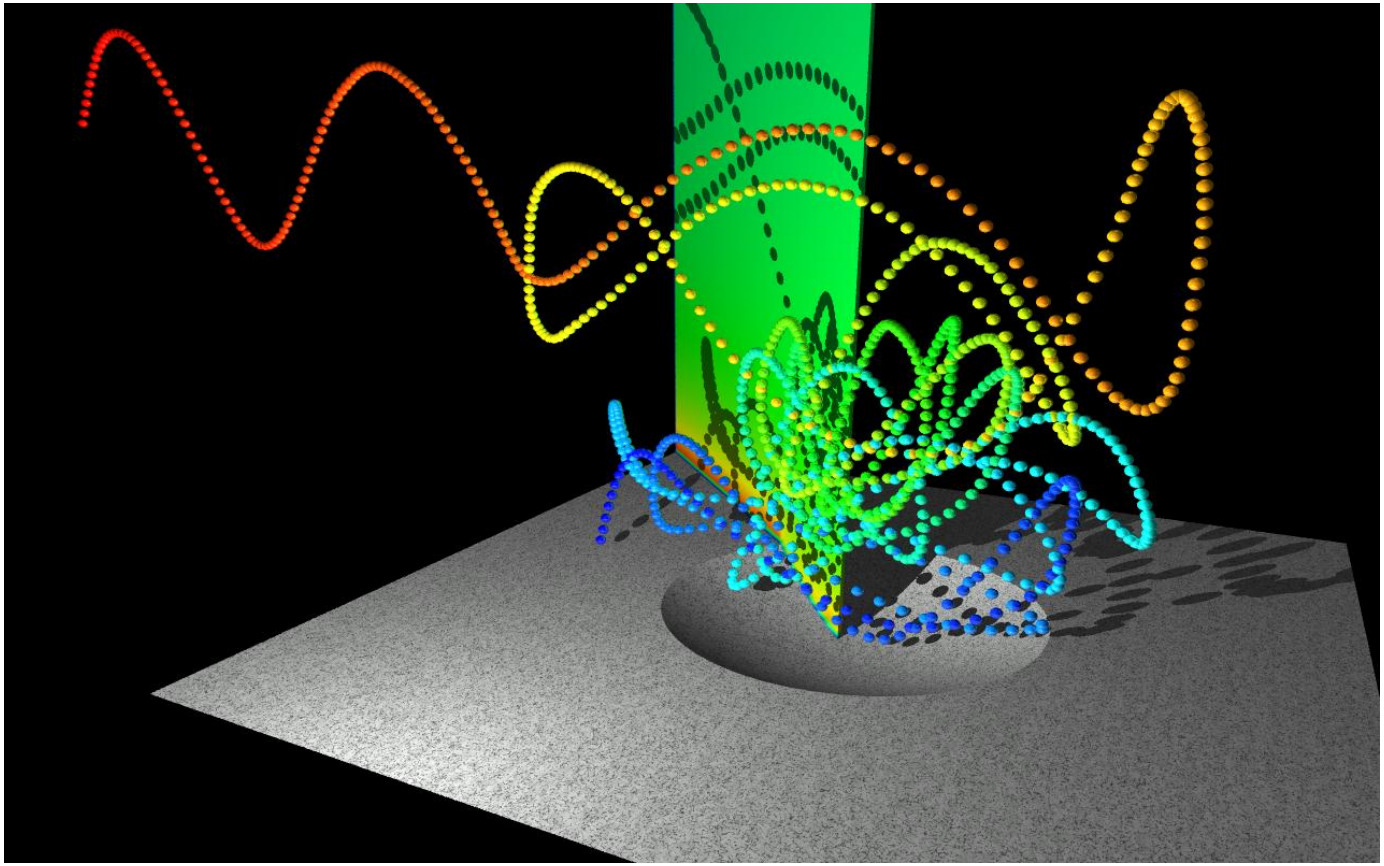
Previous relevant effort: dust motion in plasma environment



First time ever full scale calculation of dust levitation above lunar craters

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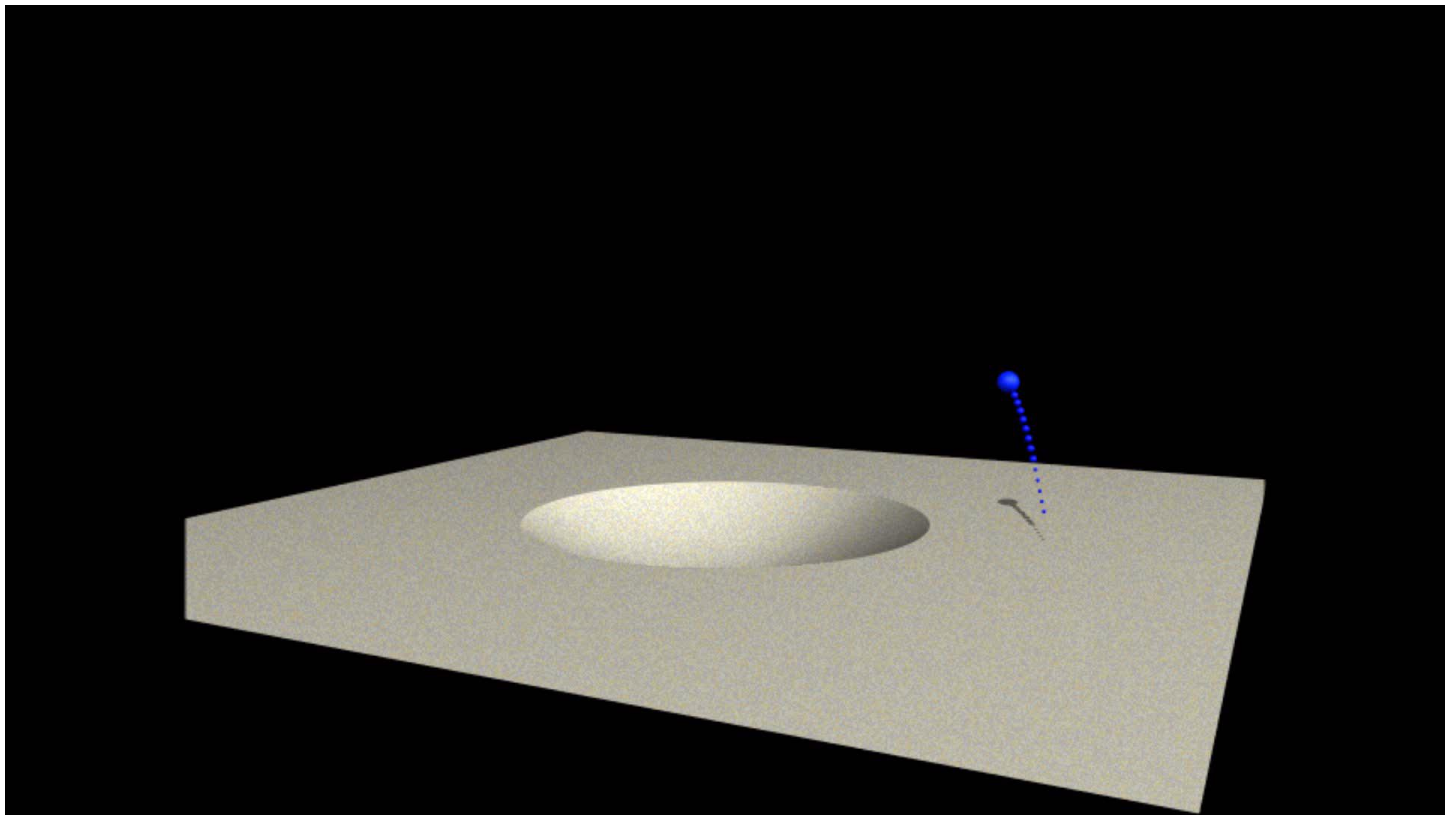
Previous relevant effort: dust motion in plasma environment



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Our Study of Defect Mitigation has Two Thrusts

- Thrust 1: Simulate defect transport in a typical IBD tool

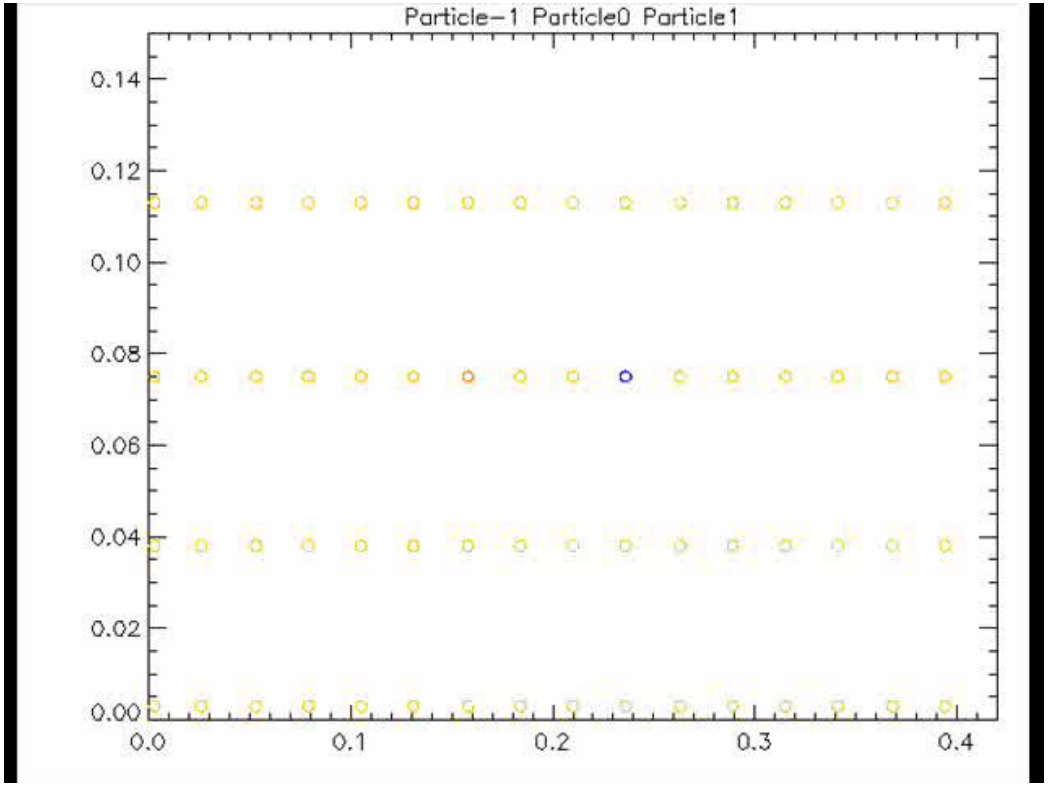
- Thrust 2: Simulate ion source behavior

- *Our work here focuses on Thrust 1*

Simplified Setup: Can VORPAL simulate defect charging and motion?

- 2D Simulation
- 100V between electrodes (mask and target)
- 42cmx15cm domain
- ~10^{15} $1/m^3$ plasma density
- Seeded defects (~100nm)

- Track defects charging
- Track defects motion



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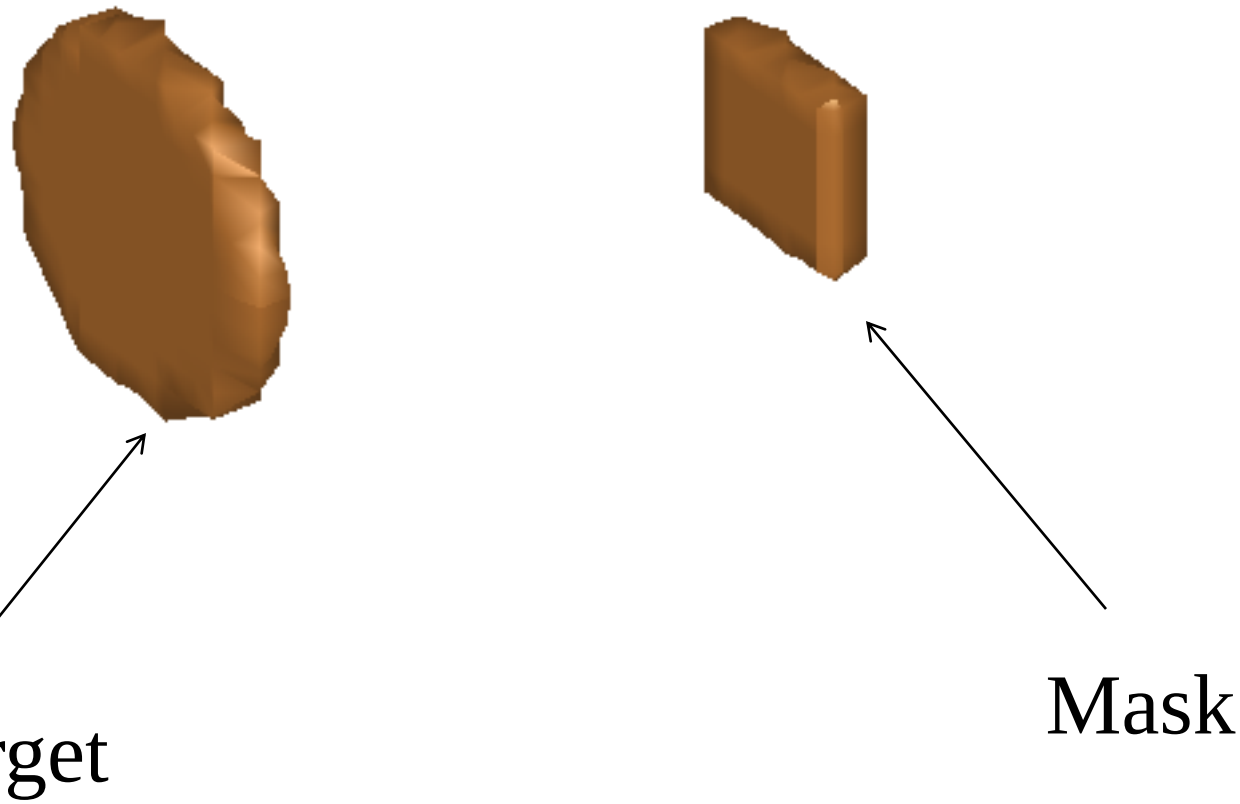
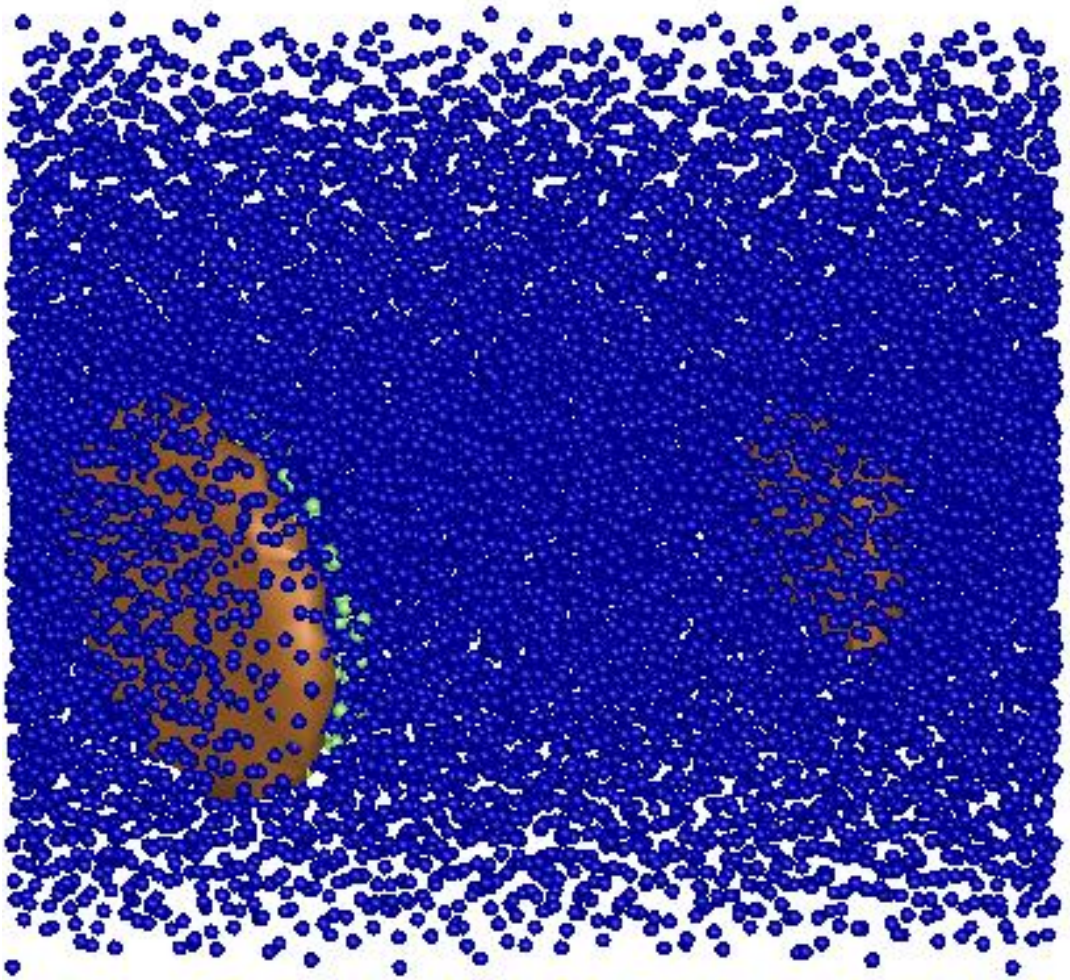
Realistic configuration



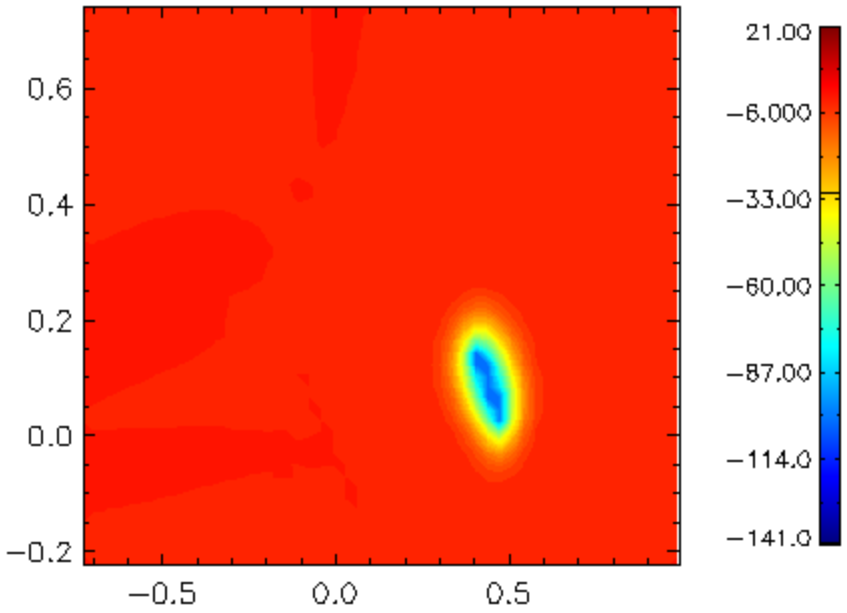
Realistic configuration

Chamber is filled with quasi-neutral plasma

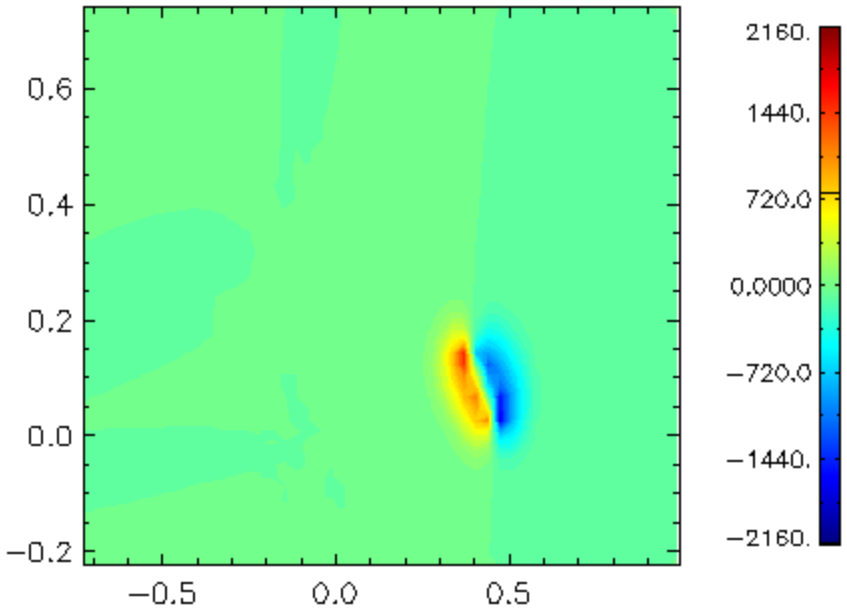


Realistic configuration

Mask is kept at -100V
Target and walls are grounded



Electric Potential



Electric Field

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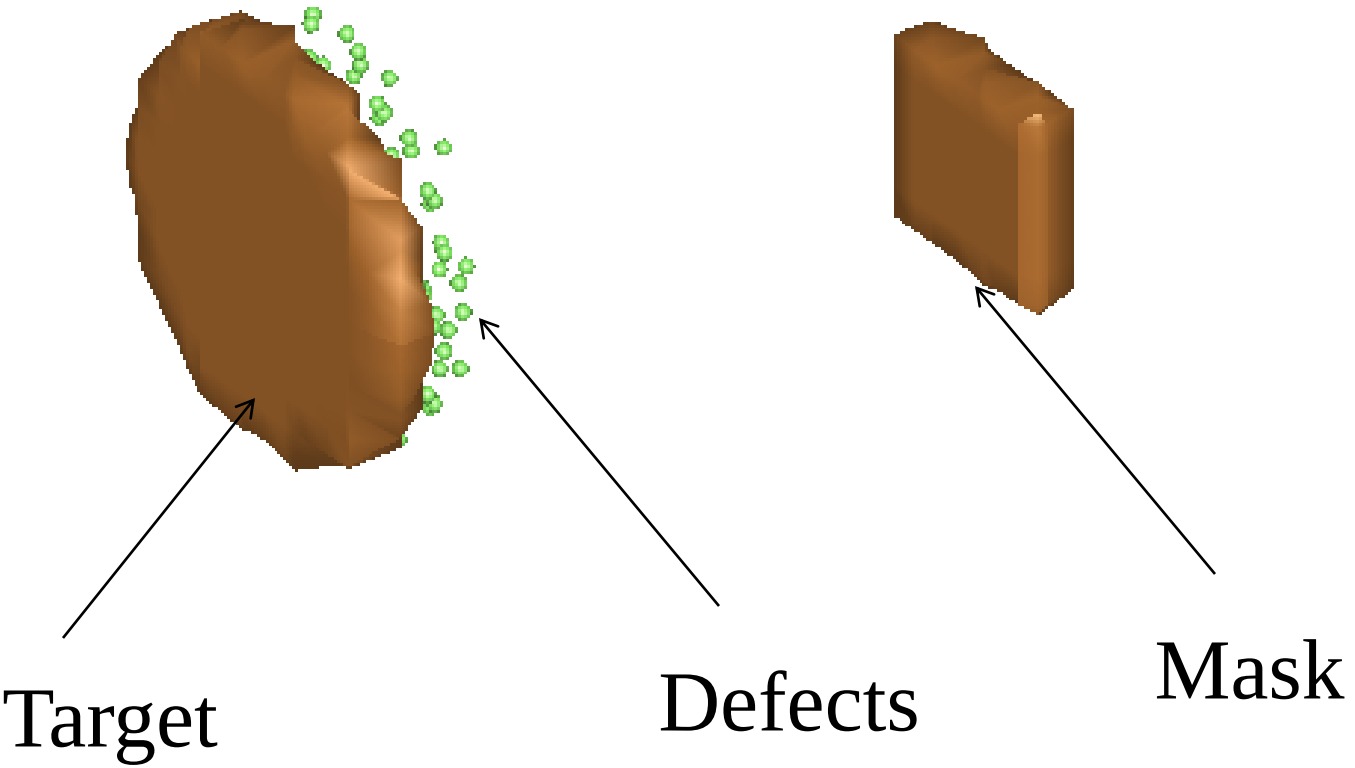
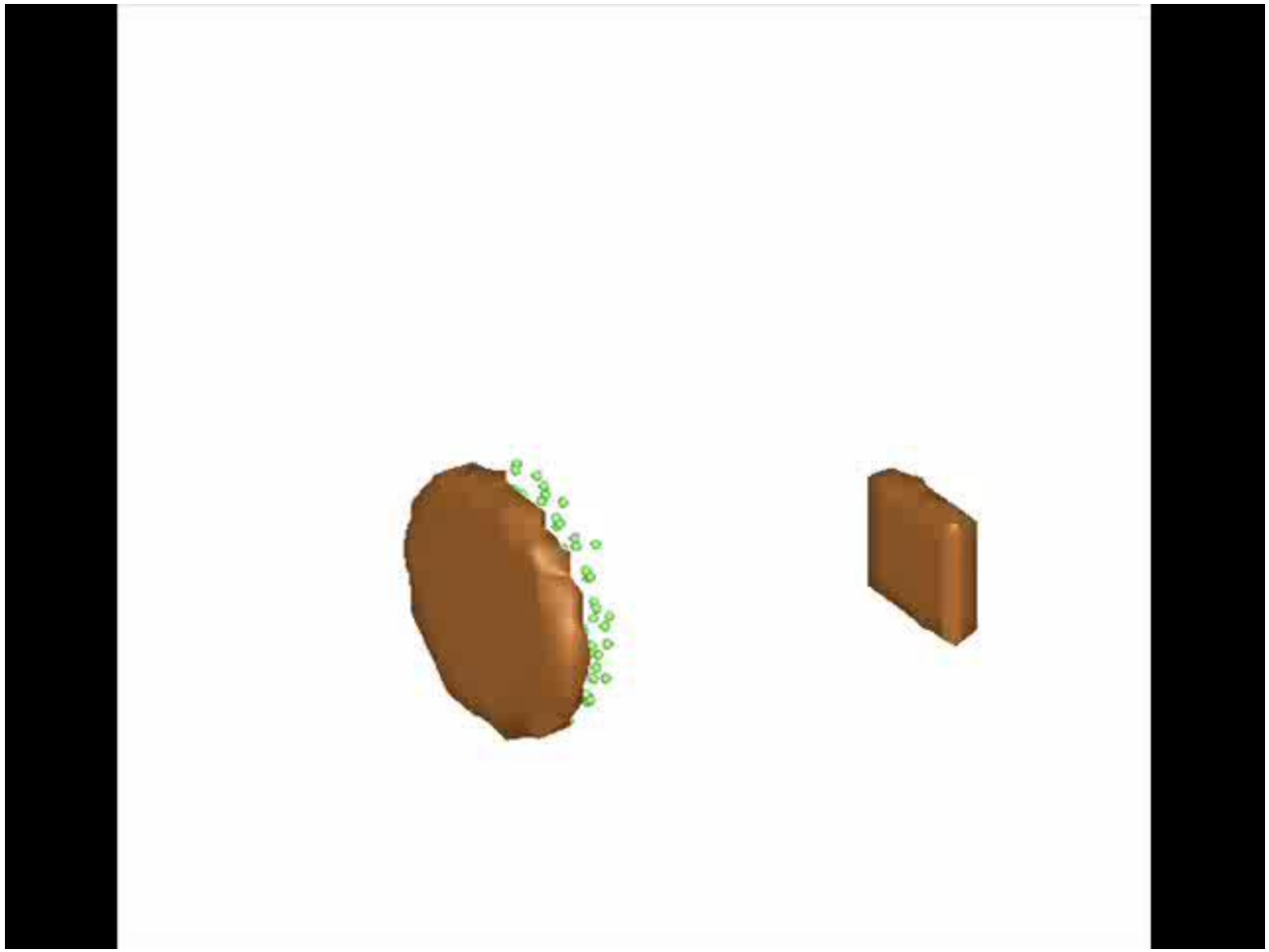
Realistic configuration

Let's launch sample defects
in the vicinity of the target



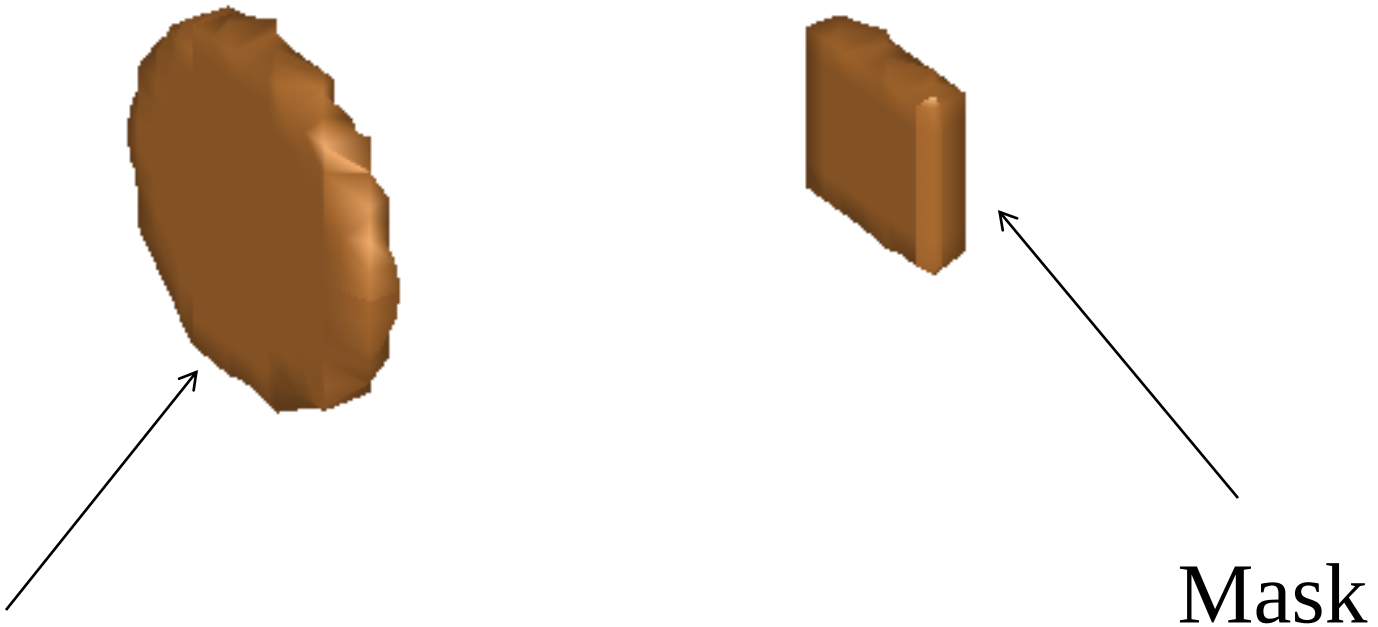
Realistic configuration



VORPAL tracks charging and motion of defects

Realistic configuration

How to affect defect motion?
Can we deflect them from the mask?



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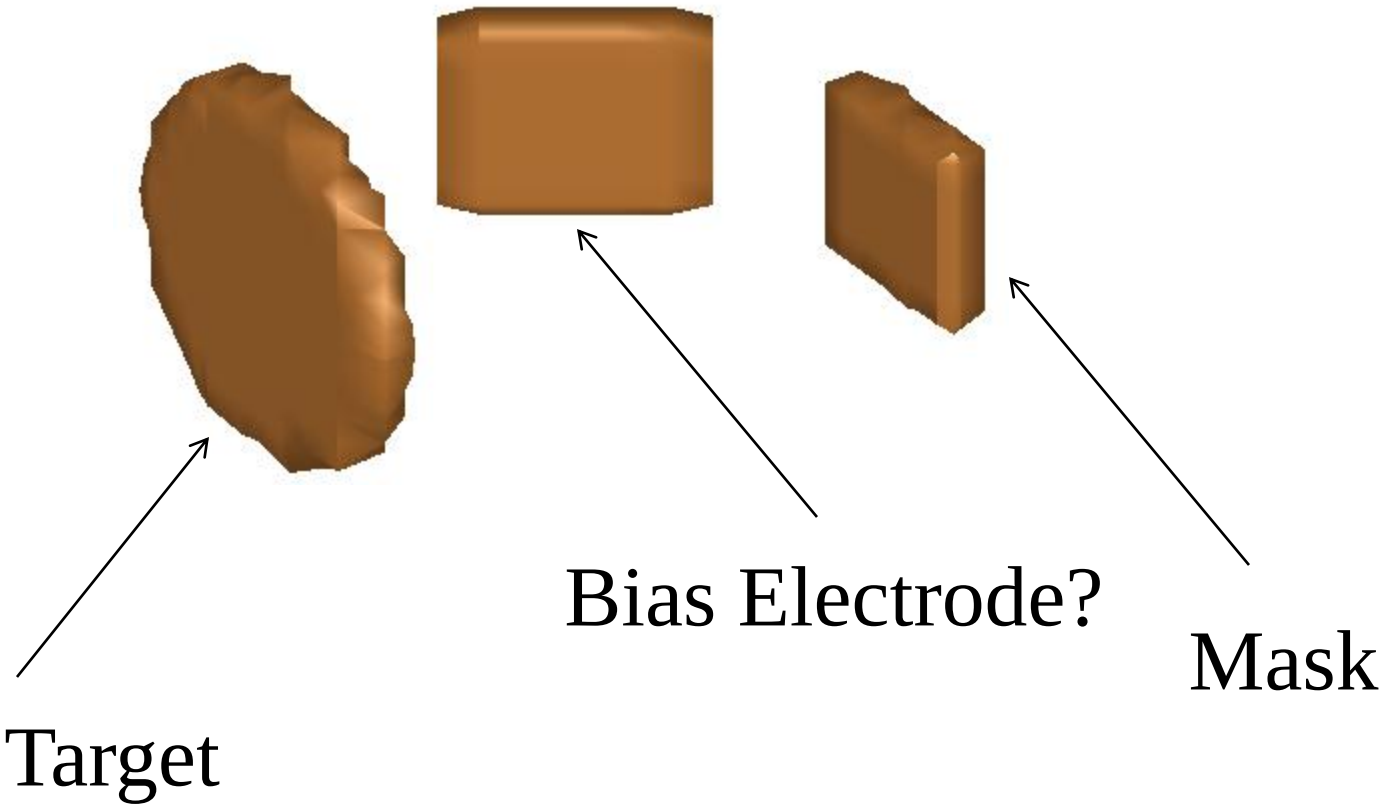
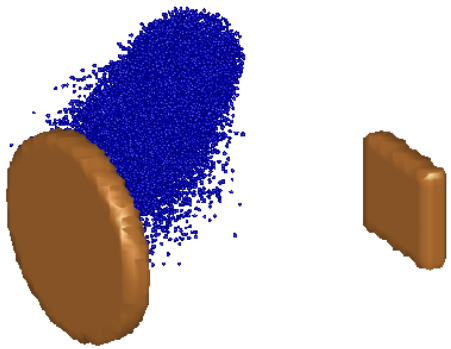


Beam on Target Modeling Gives Estimates of Plasma Conditions



- We have initial models of the ion beam on the target
- Future work will add secondary electrons, sputtering, and beam neutralization

Open Questions…

- What are the plasma conditions in the chamber?

- What is the time evolution of the defect charge state?

- What suppressor electrode configurations are most effective?