Designing a Clean Multilayer Deposition Process: A Computational Model of Particle Transport

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Overview

Objective

- Simulate transport of particle defects in ion-beam sputter chambers
- With understanding of transport we can design a cleaner process

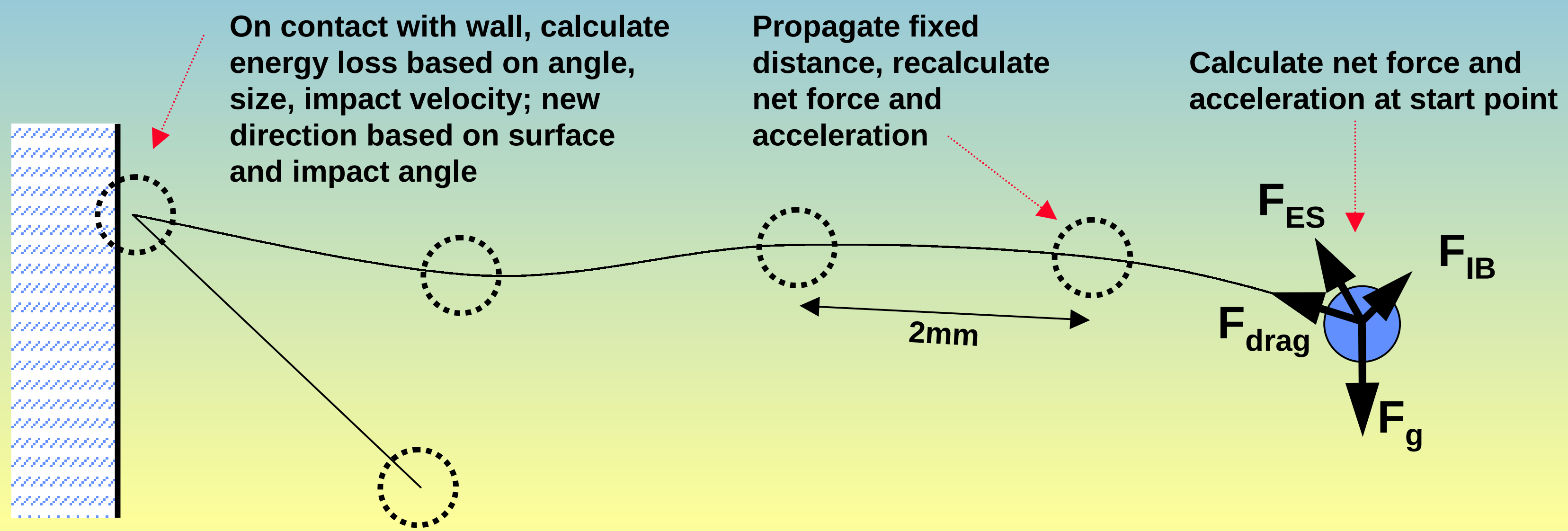
Method

- Assume initial particle locations. Use LLNL's defect-reduction knowledge from mask development under CRADA.
- Simulate particle motion; track until particles land on a surface. Repeat Monte Carlo calculation for statistics.
- Vary initial conditions; compare with experiment
- Identify principal transport paths to mask substrate; modify chamber design to minimize exposure.

Recent Improvements

- Adding treatment of electrostatic forces, in ion beam and in background plasma

Monte Carlo Particle Trajectories



Forces considered:

- Momentum transfer from ion beam, if particle enters beam
- Electrostatic force (when near plasma sheath or in ion beam)
- Particle bounce, if particle impacts wall with high velocity
- Drag from background gas
- Gravity

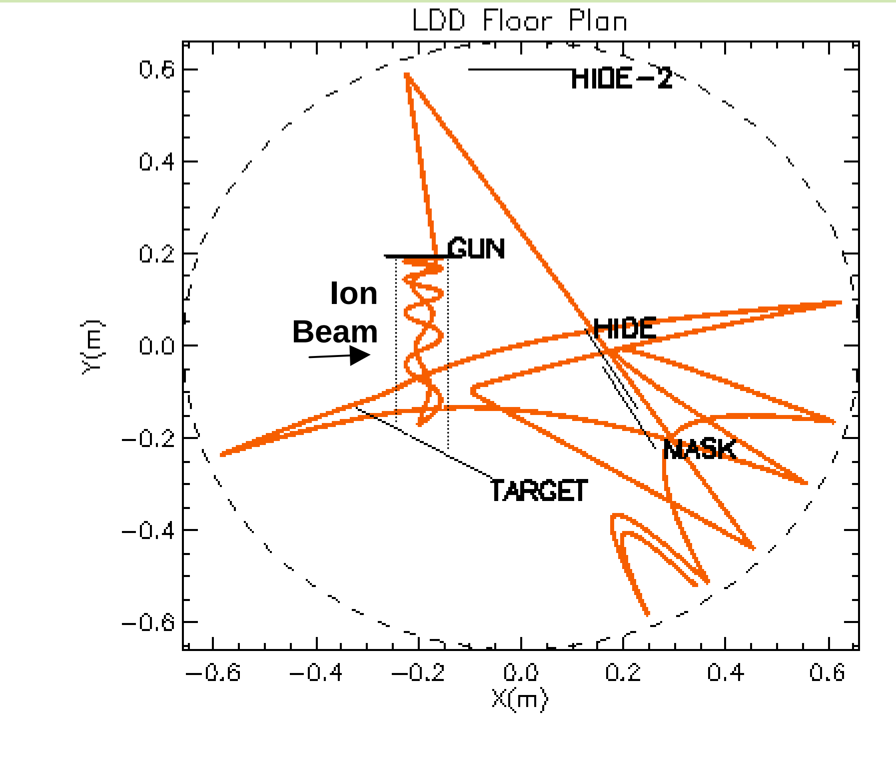
Typical particle trajectory calculated by model

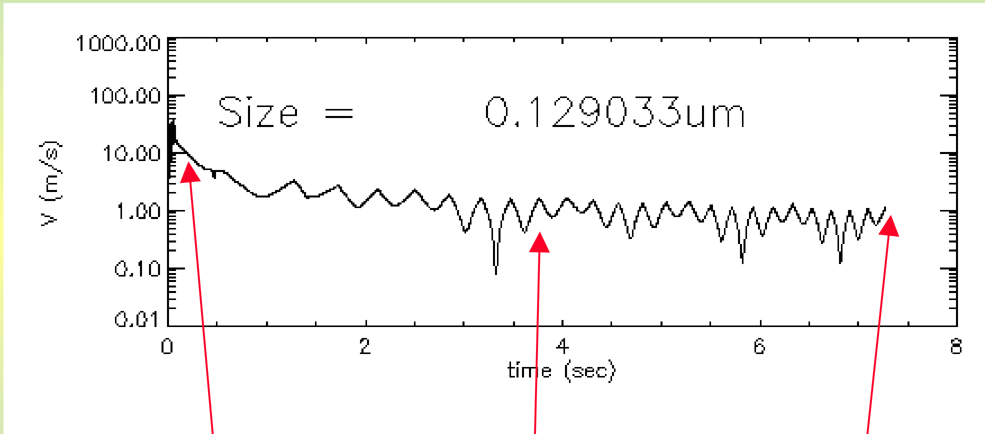
Sample particle trajectory:

0.13µm particle originating at ion gun grids, at V_0 = 1m/s

Particle velocity vs. time:

Top view of ion-beam deposition tool:





Particle accelerated by electrostatic trapping in ion beam

Final impact

Bounce from plasma sheath at walls

Treatment of particle bounce

1. There is a critical velocity for particle bounce. It depends on velocity, particle size, and angle. Calculation based on fits to numerous literature values.
2. Random direction chosen for bounce from rough surfaces; near-specular for bounce from smooth surface.

Typical energy loss on bounce:

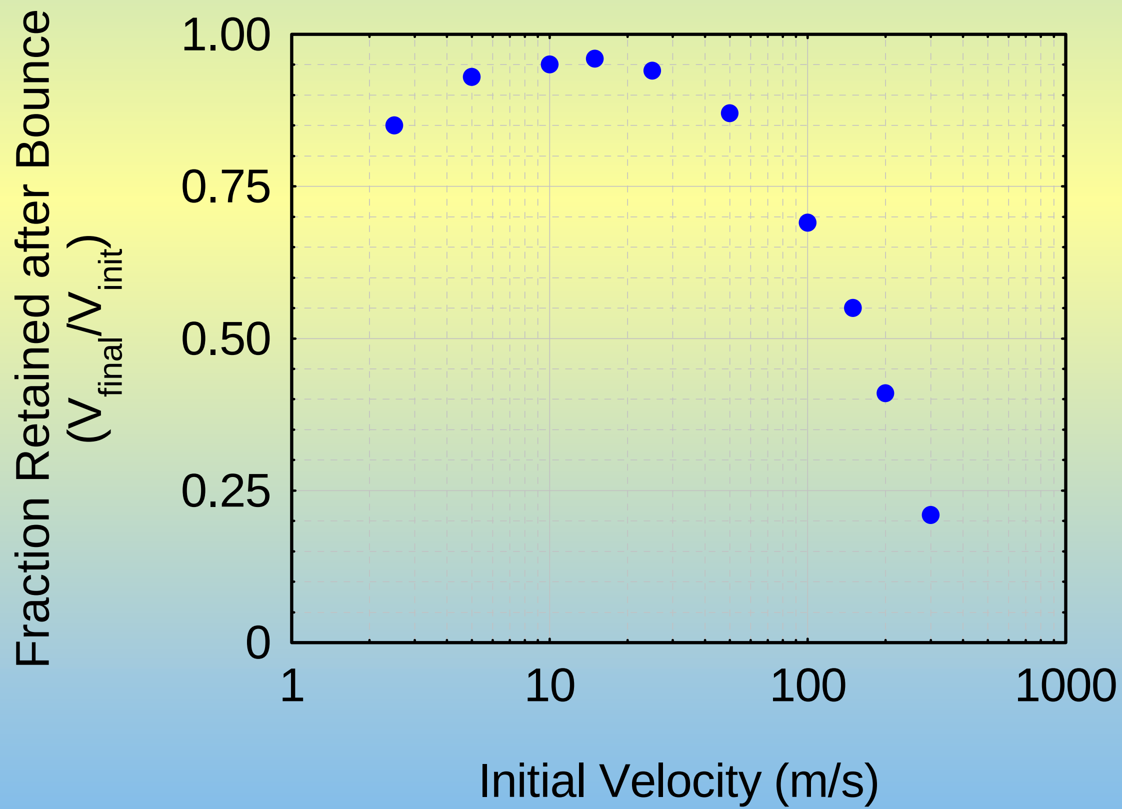
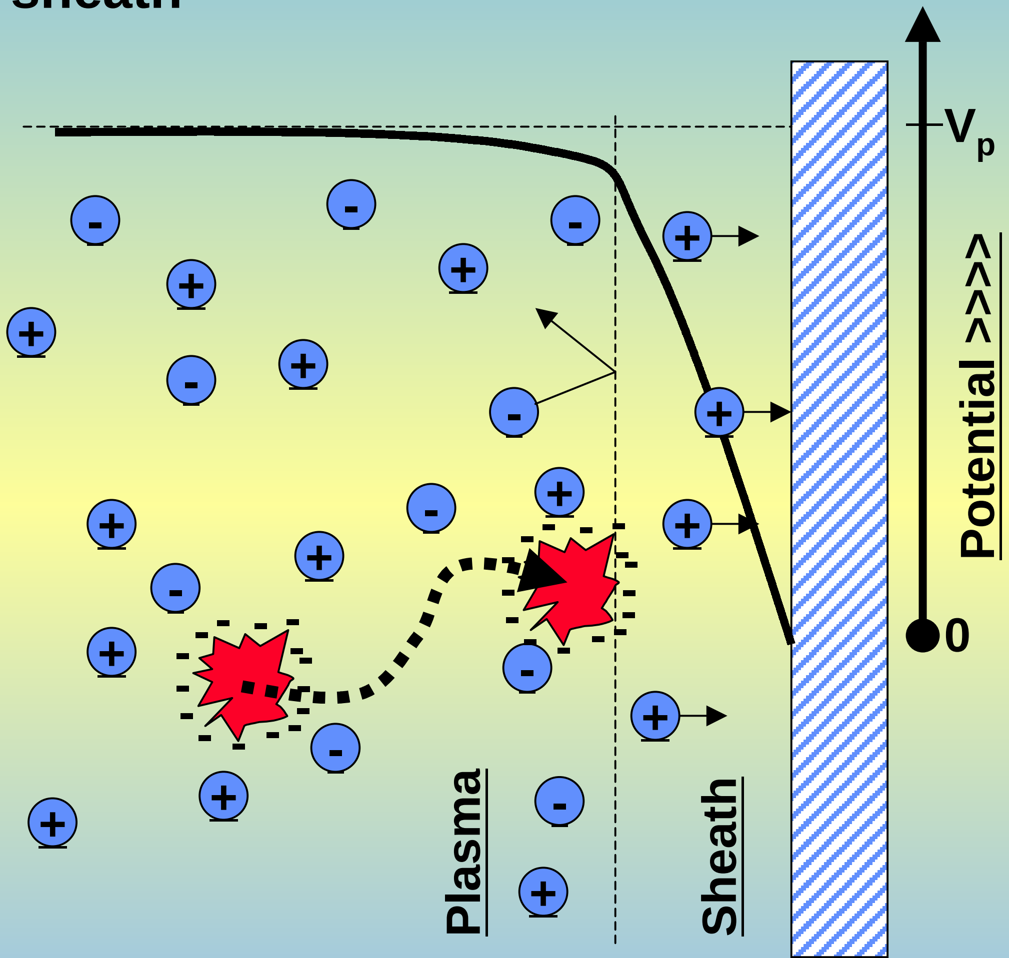


Figure is from: B. Dahneke, J. Colloid Interf. Sci. 51(1): 58-65 (1975).

Treatment of electrostatics (outside ion beam)

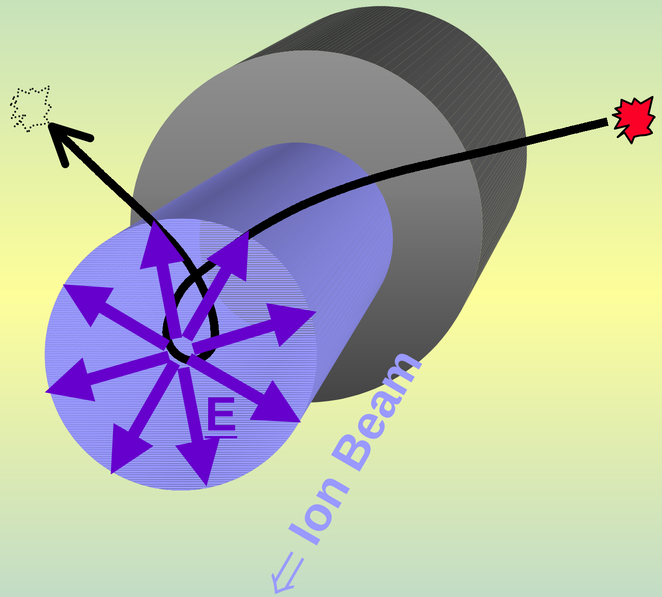
Particle charges negatively in plasma; is repelled by potential drop at sheath



- A particle in the plasma will become negatively charged. Charging time is short compared to transport processes.
- When pushed to the plasma sheath boundary by other forces, the particle is repelled by the potential drop. This may provide an additional bounce mechanism from walls
- Initial calculations indicate velocity to penetrate sheath is ~7m/s for a 1μm particle

Treatment of electrostatics (inside ion beam)

Particle charges negatively in plasma, is repelled by potential drop at sheath



•A particle in the ion beam will become negatively charged by the surrounding plasma. Charging time is short compared to transport processes.

•There is an electric field inside the ion beam, mostly radial in direction. Particle experiences force

$$\underline{F} = q\underline{E}$$
$$q = q(\underline{r})$$
$$\underline{E} = \underline{E}(\underline{r})$$

•This area is still under development, based on literature work by Brown and Holmes

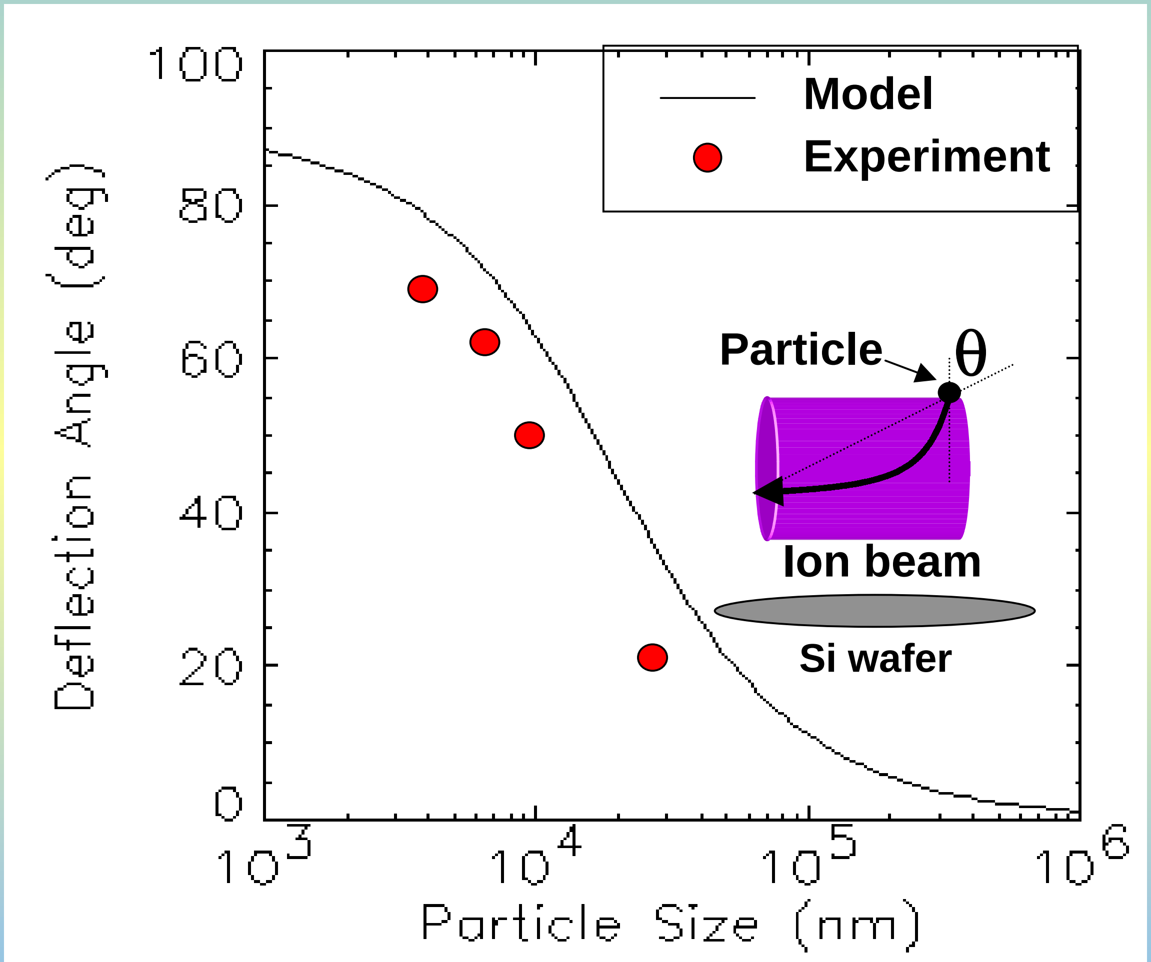
References:

D. A. Brown, P. Sferlazzo, S. E. Beck, *et al.*, Journal of Applied Physics 71, 2937 (1992).

J. A. Holmes, Phys. Rev. A19 367 (1979)

Treatment of momentum transfer to particle from ion beam

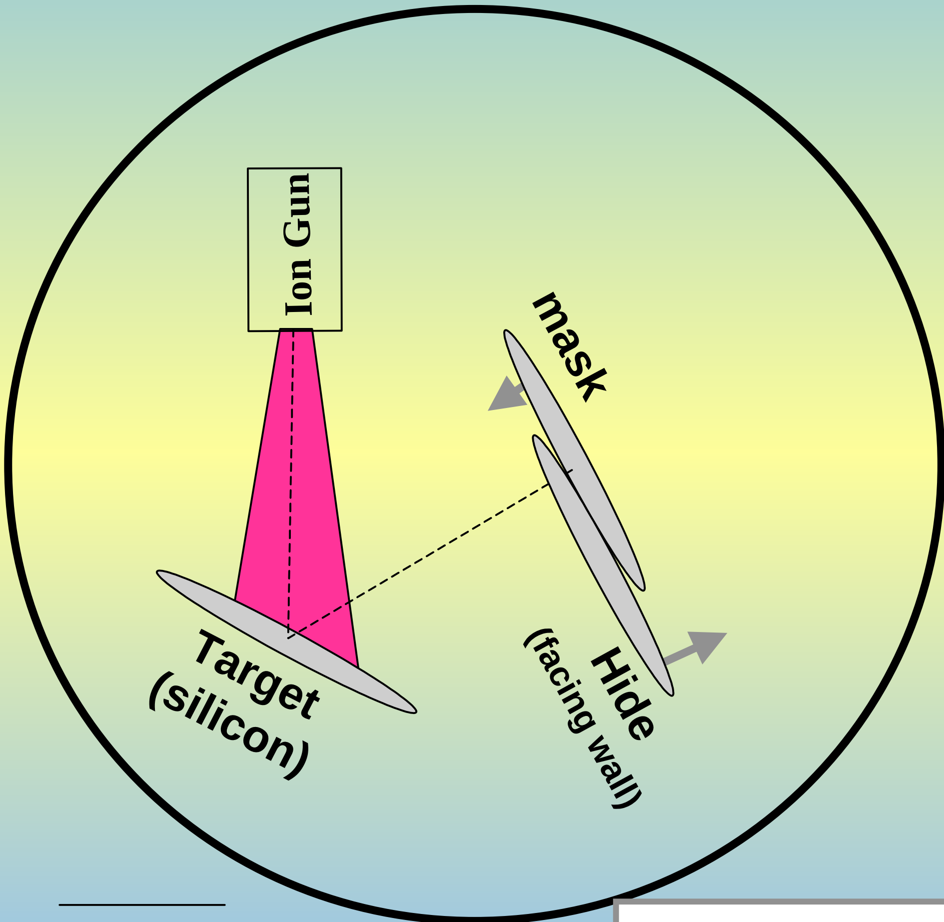
A particle entering the ion beam is deflected by <u>momentum transfer </u>from ions



Simple model for momentum transfer fits data with offset - this treatment used in model.

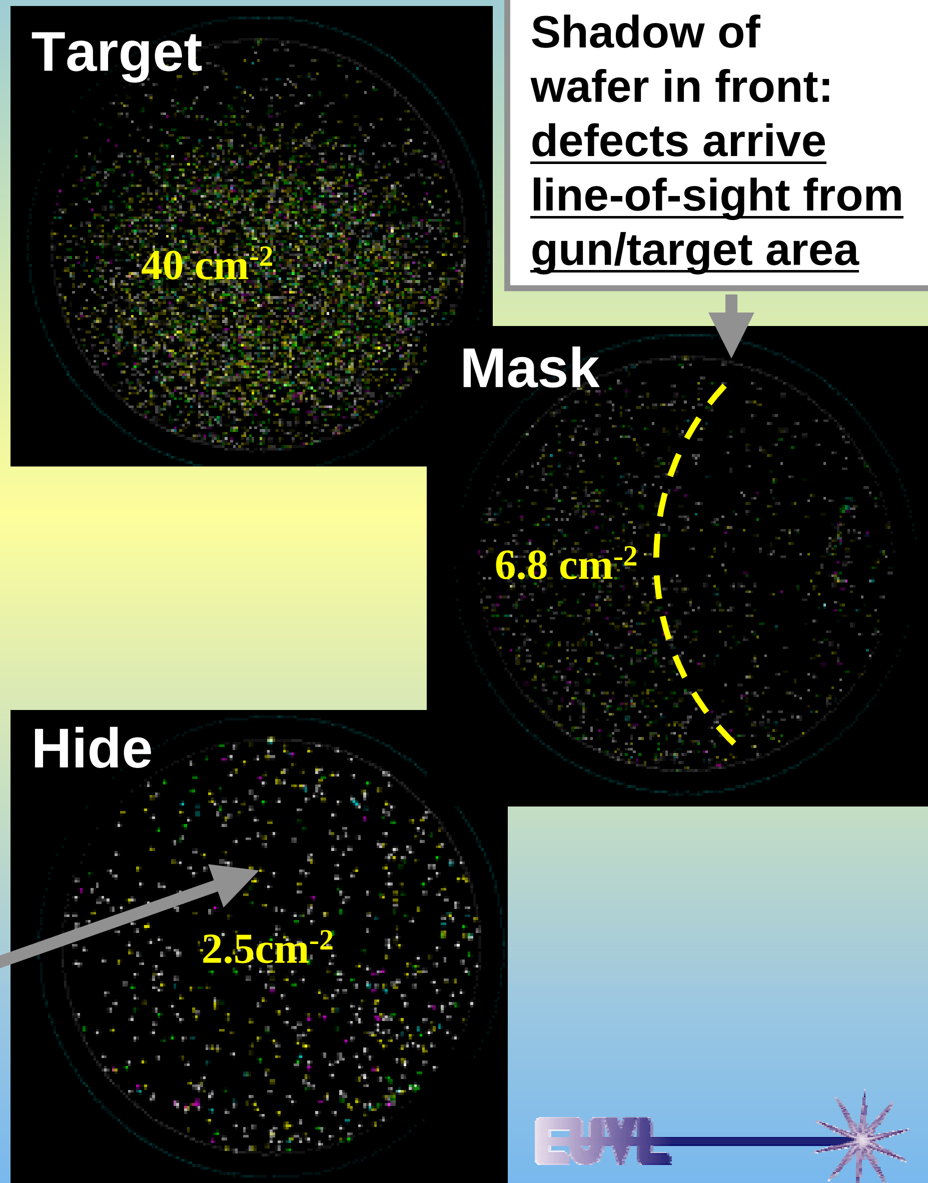
A dedicated “witness-wafer” experiment was done to investigate transport

Experiment in test chamber:
(top view)



10cm

Results (defect maps of wafers**)**

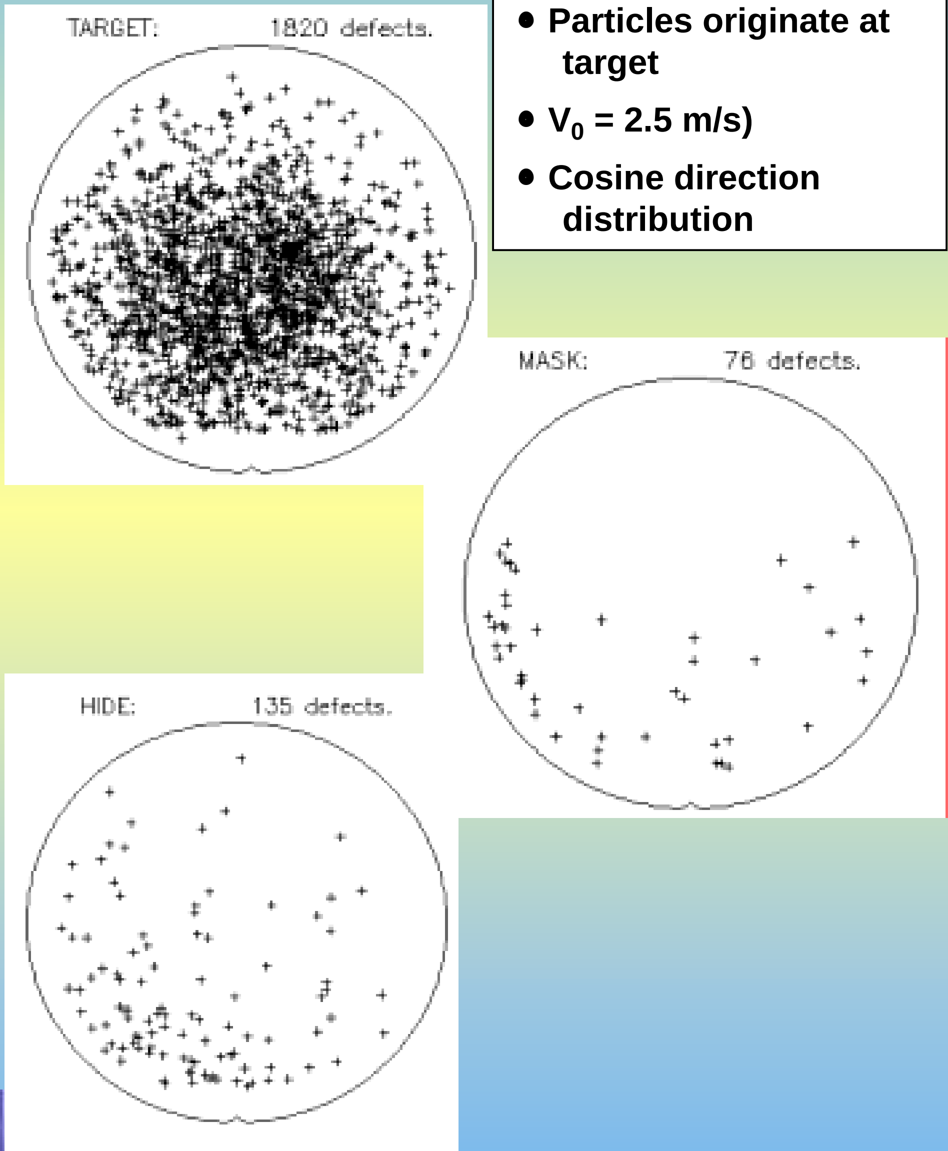


Shadow of wafer in front: <u>defects arrive line-of-sight from gun/target area</u>

Adders reach back surface: <u>some bounce occurs also</u>

Model partly reproduces particle distributions in witness-wafer experiment

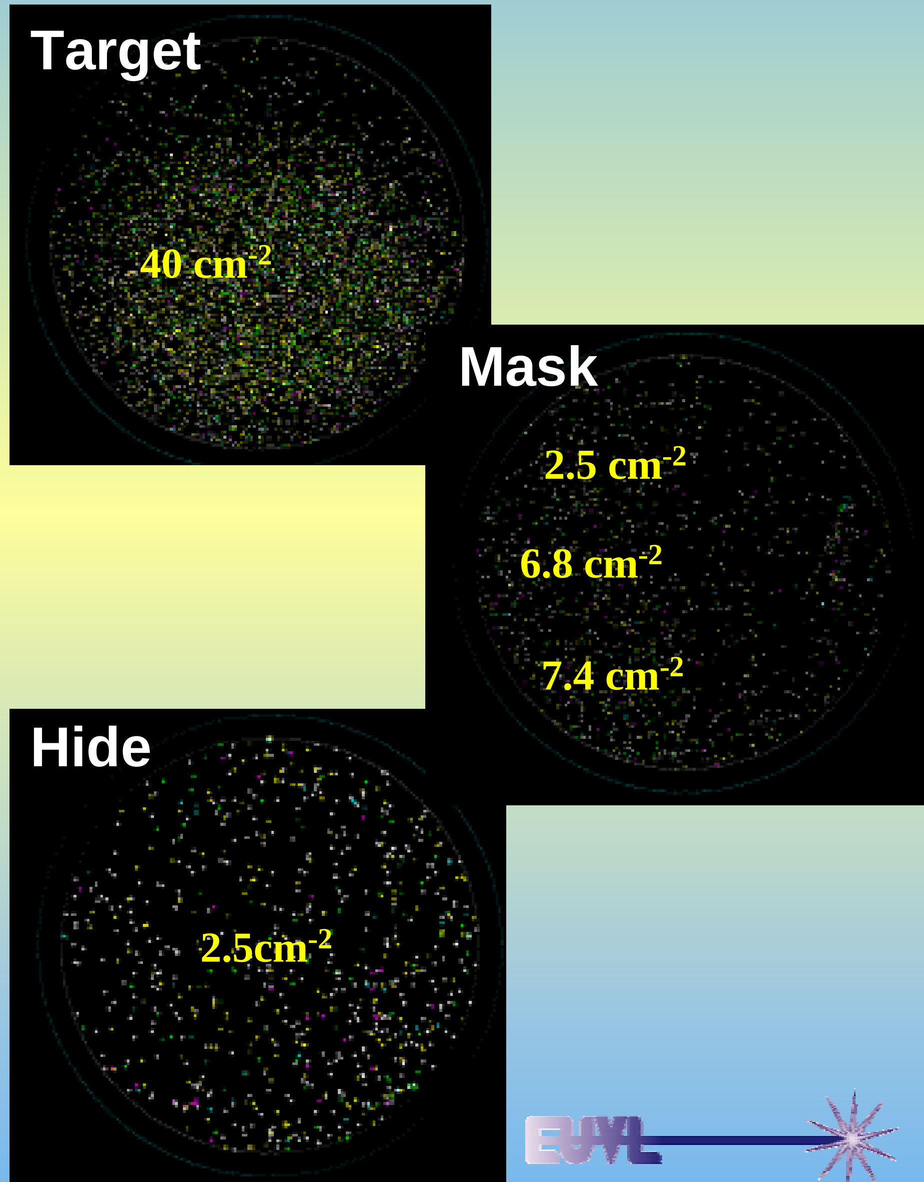
Simulation:



Scenario modeled:

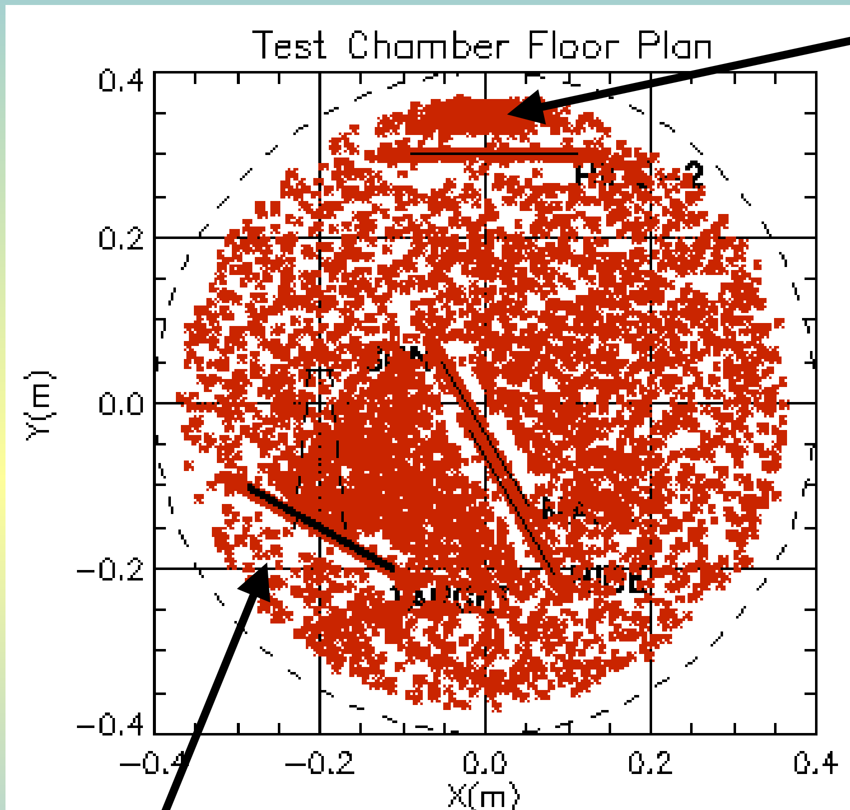
- Particles originate at target
- V_0 = 2.5 m/s)
- Cosine direction distribution

Experiment:



There is early indication of a particle trapping effect from electrostatic forces

Simulation of multiple particles - final locations



Trapping

Shadowing

- Initial simulation shows trapping and shadowing effects of the wafer or target when near the walls. When understood, these phenomena can be exploited for reducing particle exposure at the mask.

Future work will focus on chamber design

Future work:

A. Completion of model

- Further work improving treatment of electrostatic forces
- Treatment of reflected neutral Ar atoms from target
- Langmuir-probe plasma measurements

B. Chamber design:

- Improvements in chamber geometry
- gun-target distance
- gun-target angle
- target-substrate distance
- Exploitation of particle trapping effects

Summary

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- Data on transport of particle contaminants (from experiments and literature) incorporated into numerical transport model
- Some initial validation against experiment, but further work is needed.
- Results indicate important role of electrostatic forces, and possible particle trapping effects