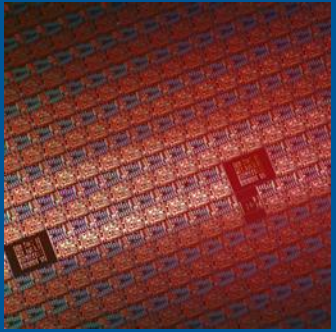
Accelerating the next technology revolution

Characterization and detailed understanding of the EUV mask blank deposition process



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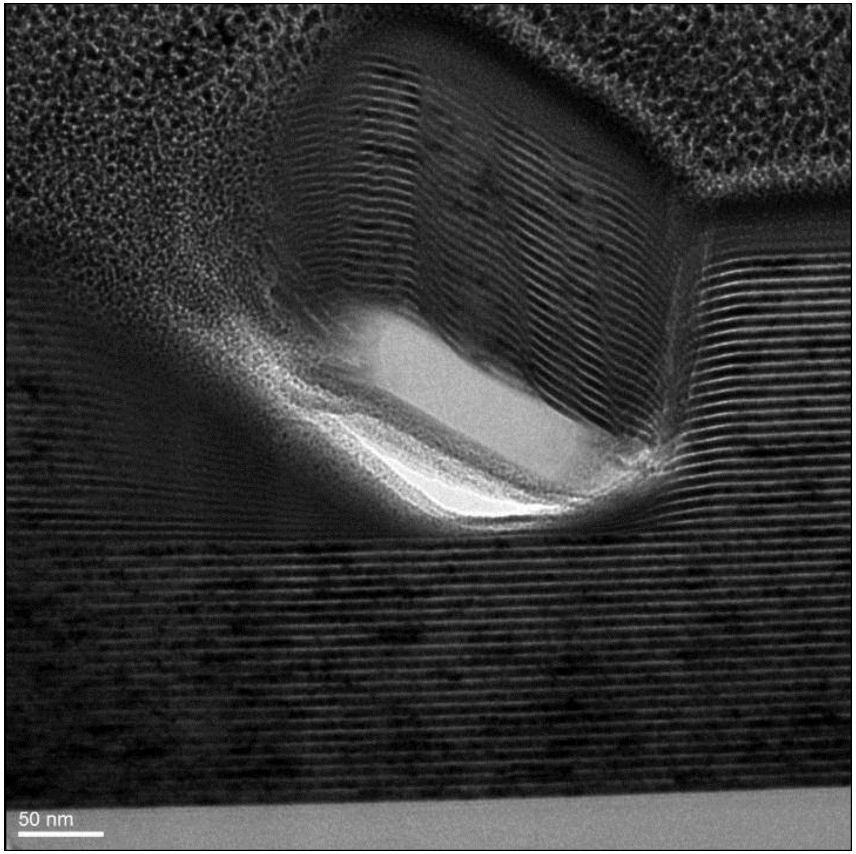
EUVL Symposium 2011 – Miami

19 October 2011

EUV mask defect problem



- This talk focuses on trying to eliminate defects added during multilayer deposition.
- Other types of defects occur (substrate, pattern, etc.), but for EUVL to be successful the number of multilayer adders must be reduced.

SEMATECH is working with the industry to reduce EUVL mask blank defects

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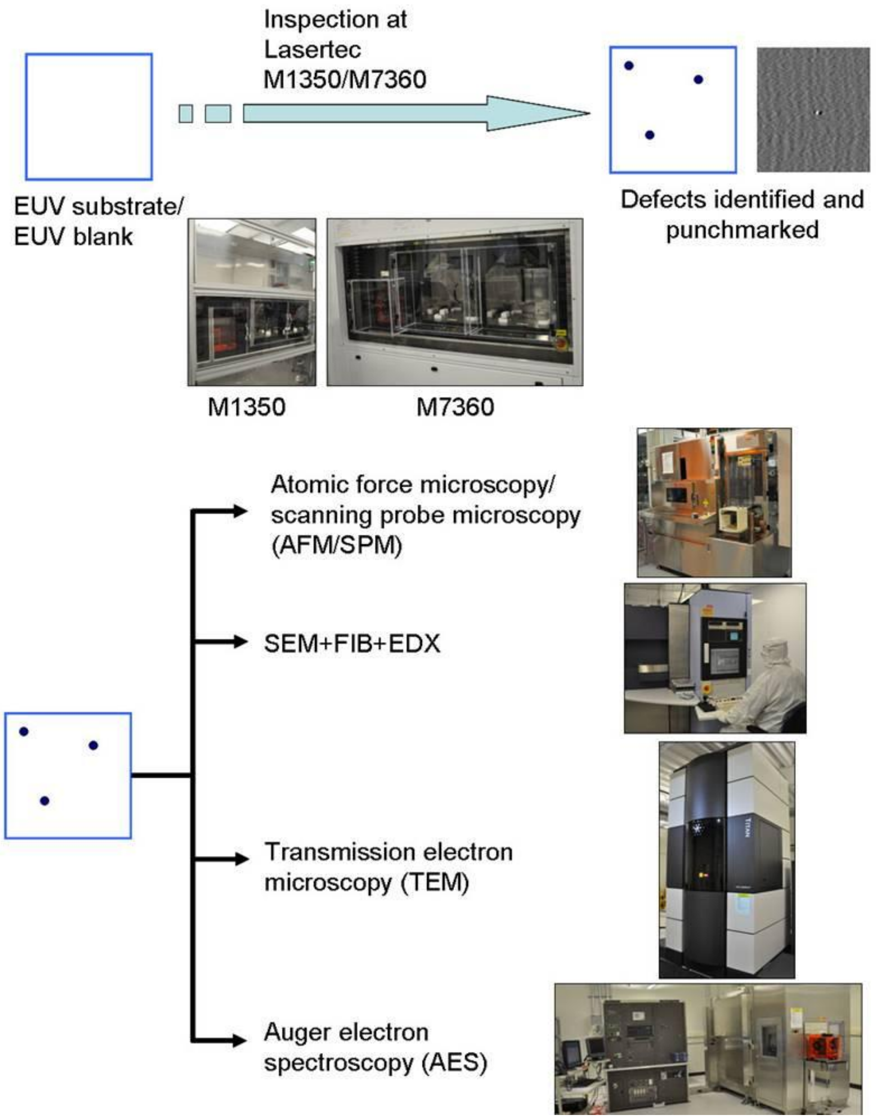
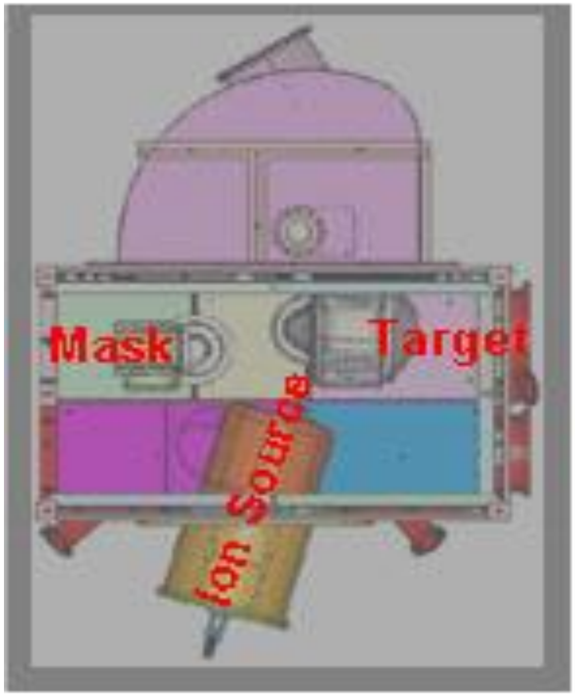
- SEMATECH has a full suite of EUVL mask tools
  - Inspection
  - Cleans
  - Deposition
  - Failure analysis
  - EUV metrology
- See poster “Failure analysis and defect characterization for EUV mask blanks” for more information

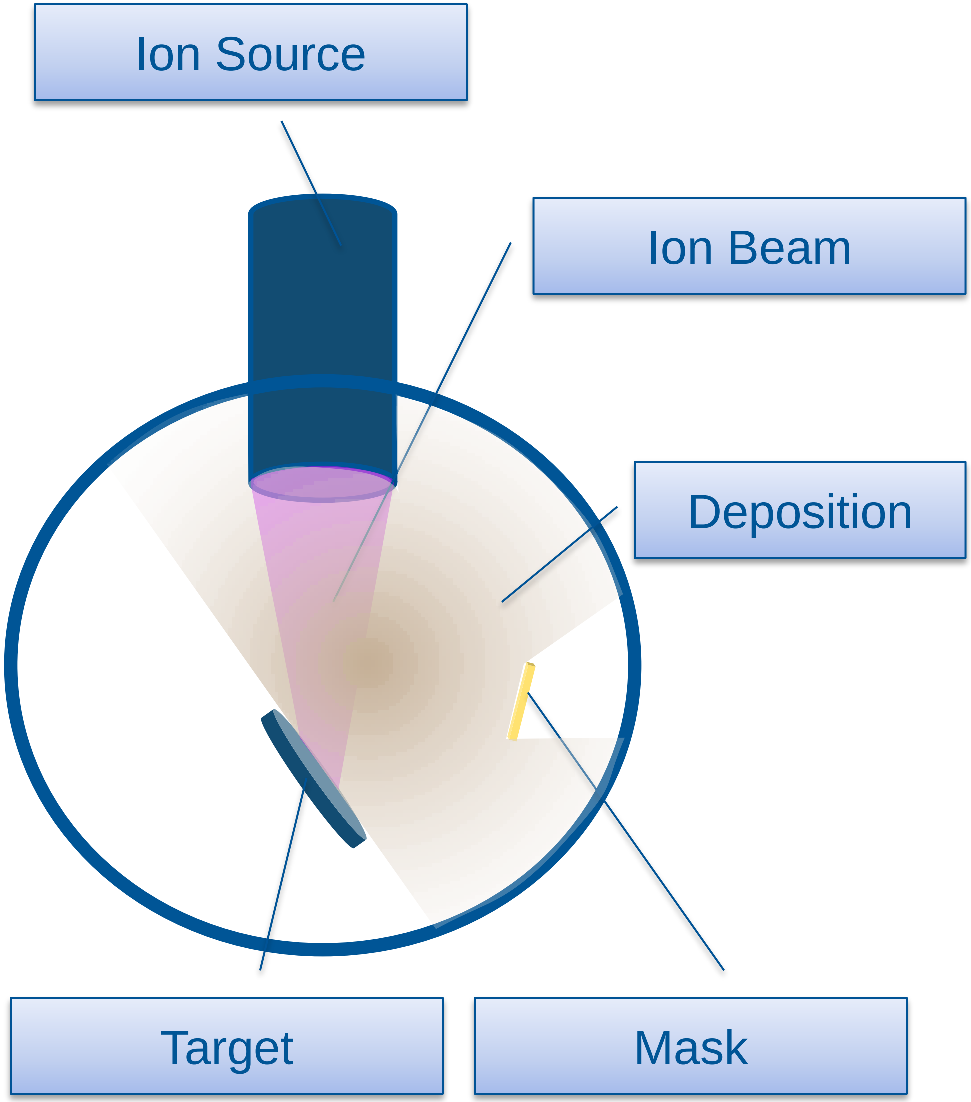


Veeco Nexus low defect EUVL mask blank deposition tool



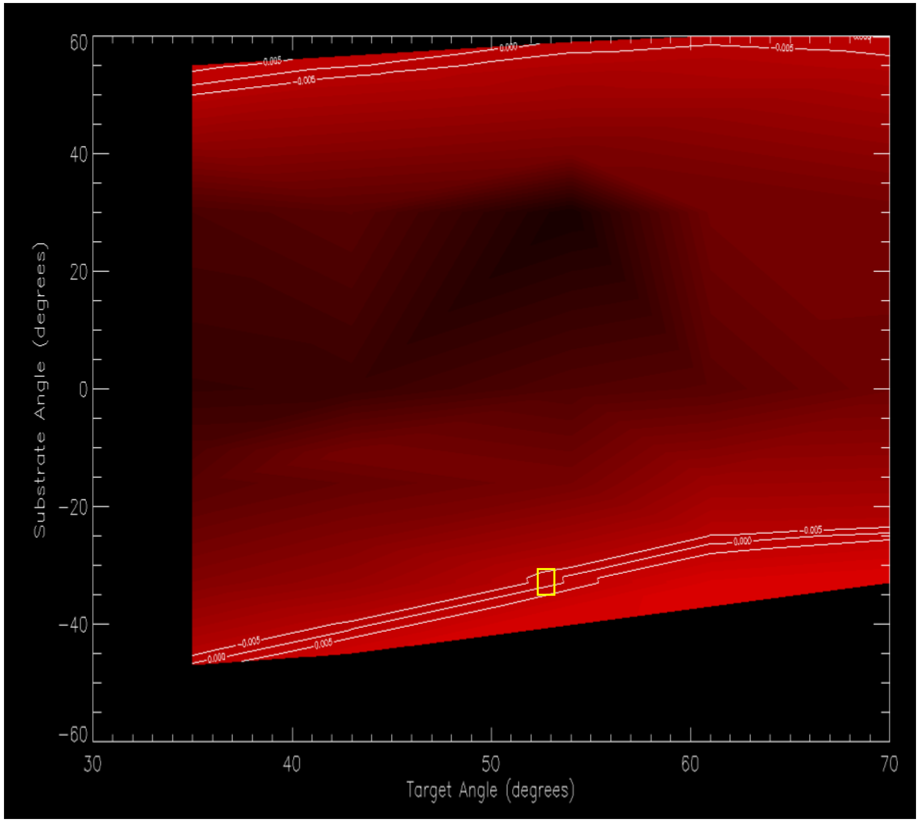
- **Vast** majority of EUV mask blanks are produced with Veeco Nexus tools.
- Tool is ion beam sputtering tool designed for clean operation.

Basic Nexus tool operation



- Ion source
  - 600-1200 V
  - 100-400 mA
  - Single charged
- 4 Targets
  - Mo, Si, Ru + experimental target
- Deposit in 1-2 hours/blank
  - 3 nm Mo, 4 nm Si, 2-3 nm Ru
- Vacuum
  - Base 10-9 Torr
  - Operating 0.05-0.3 mTorr
- Target and substrate can tilt around vertical axis

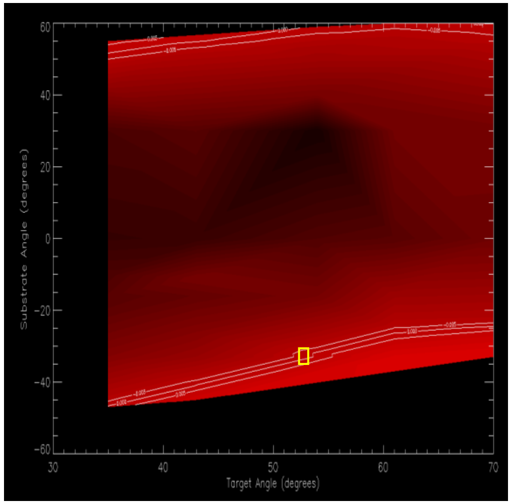
Measured uniformity in current Nexus tool



- Measured for all target and substrate tilts at current substrate position.
- Substrate pointed directly at target always gives films that are thin on the edge of the mask.
- Must tilt mask away from target to get uniformity to meet specification.
- White lines enclose operating points that meet uniformity specification.
- Upper branch yields films that are too rough to use.
- Must operate on the lower branch.

- Current tool has very narrow process window.
- No easy way to test uniformity at other substrate positions.

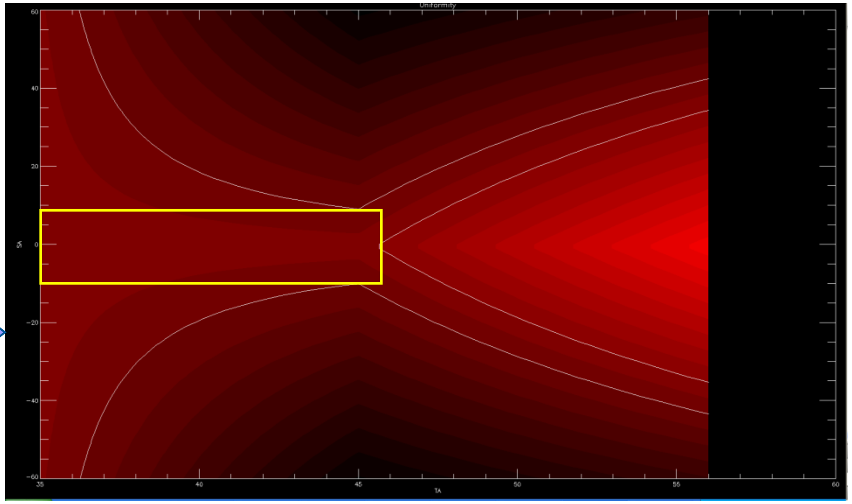
Predicting uniformity of other substrate locations



Current process window:
Target angle=1 degree
Substrate angle=4 degrees

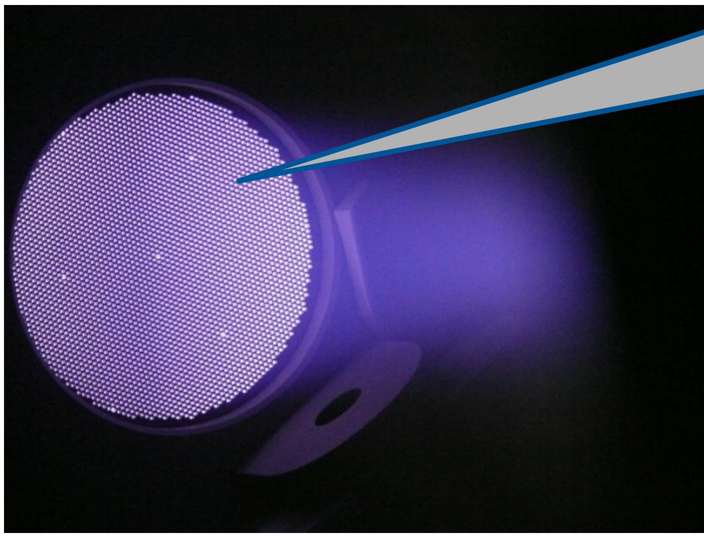
Alternative operation point process window prediction:
Target angle=11 degrees
Substrate angle=18 degrees

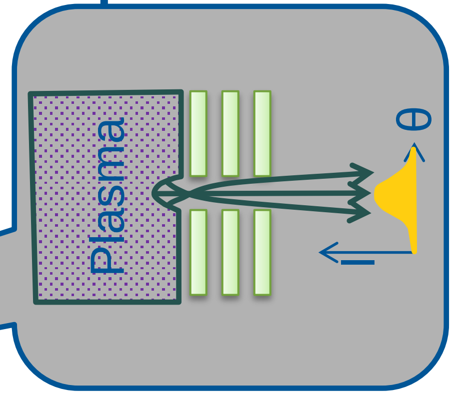
Requires moving the substrate 15" and changing the tilt direction from horizontal to vertical.



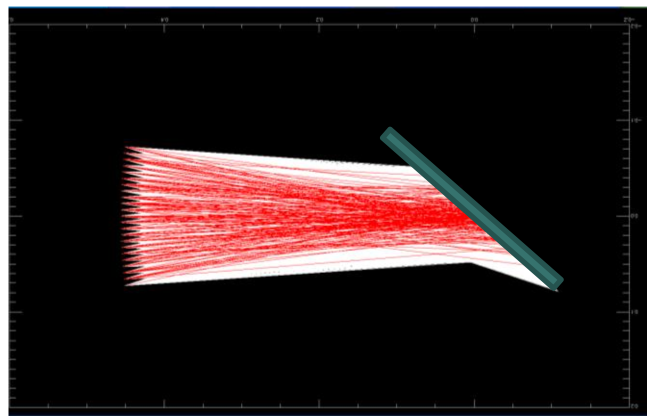
Ion beam, geometry and footprint

The ion beam is extracted through many holes in the grids; each hole creates a beamlet, and the beamlets combine to form the whole beam.

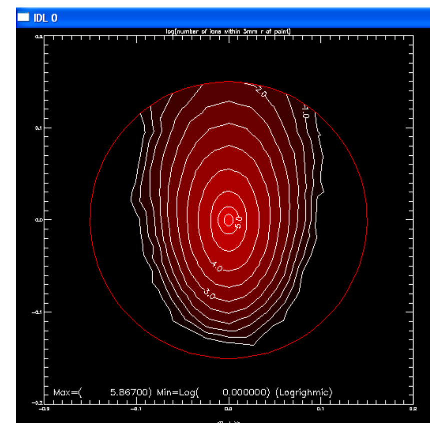




One beamlet



Many beamlets make one beam

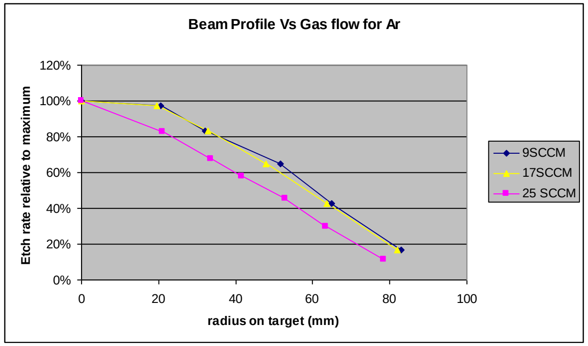


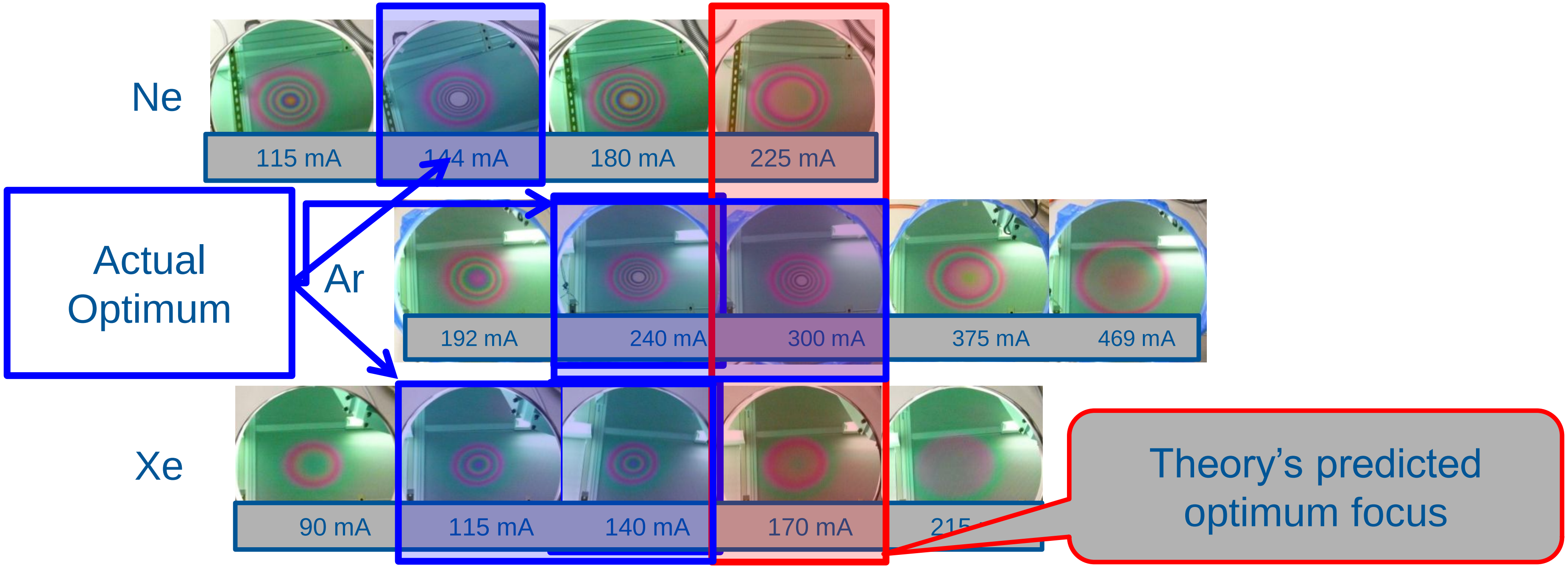
Net effect of beam on target

- Divergence of individual beamlets contribute to width of etch pattern on target.
- Divergence depends on source voltages, currents, and gas type and flow.
- Current theory cannot predict divergence accurately.

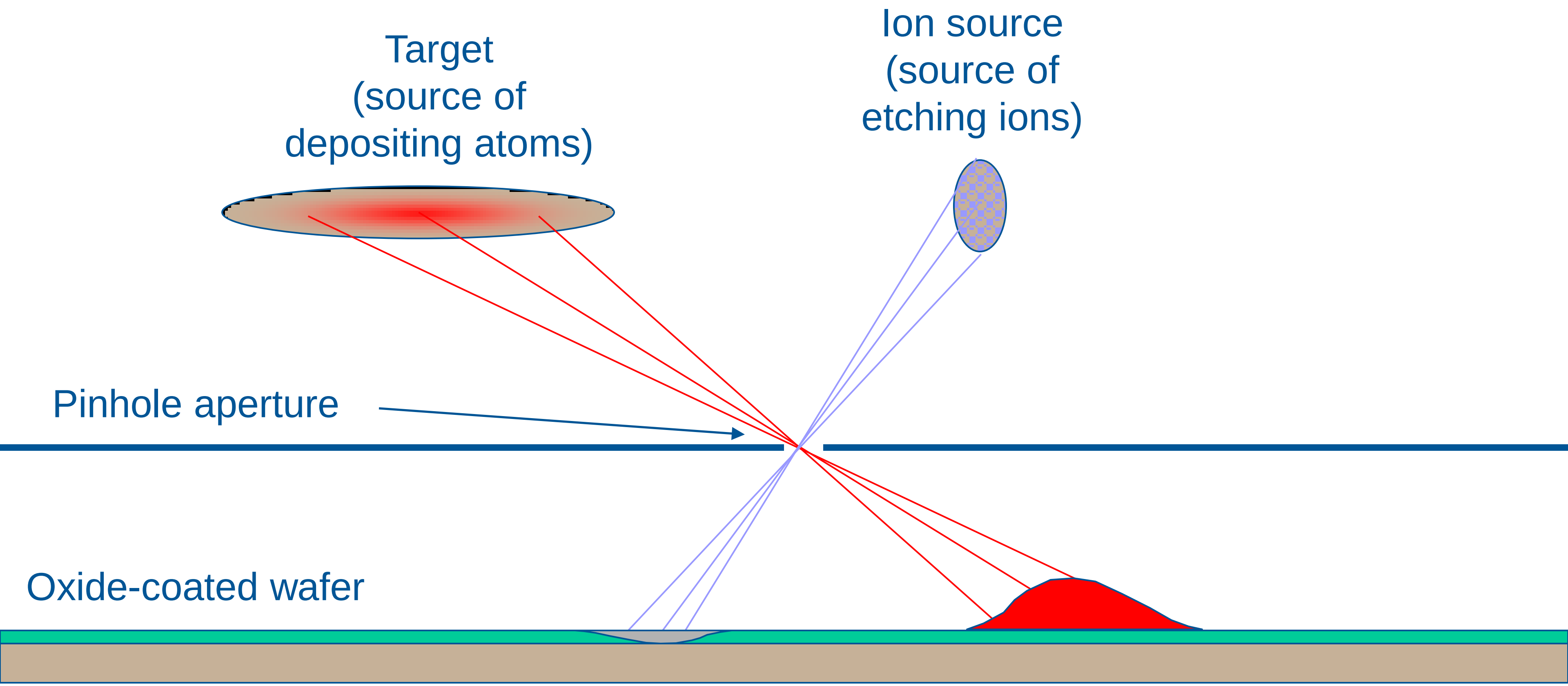
Ion beam theory gets us close, but final optimization requires measurements

- Two examples:
  - Ar flow rate – should not matter.
  - Beam current for different gas types - optimum values wrong.





Using pinhole cameras to image where ions missing the target are coming from

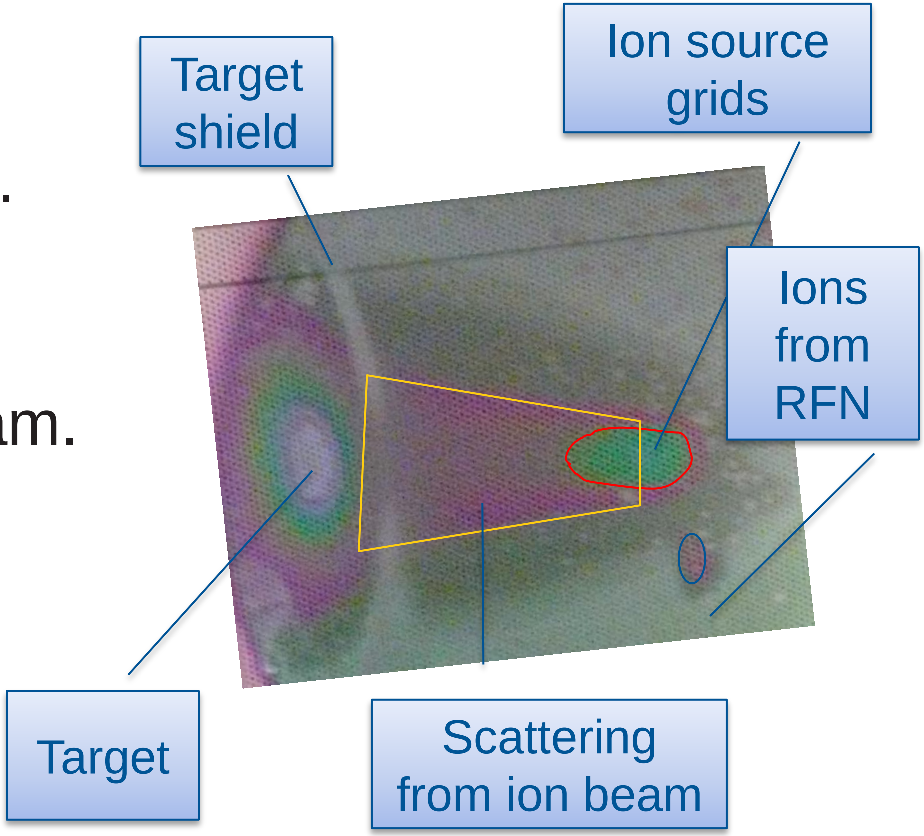


Assumes ions and atoms move in strait lines. Alternately gives an image of the last collision the atom/ion had.

Can indicate where ions/atoms are coming from.

Quantitative pinhole camera data

- Deposition
  - From large area on target.
  - From shields around target.
- Etch
  - Directly from ion source.
  - Ions scattered from ion beam.
  - RFN (neutralizer) (small amount)
  - Ions scattered from beam etch ~ 4X those direct from beam.



Much of the ion beam misses the target

- Much of this is due to ions scattering gas in the ion beam.
  – This is relatively simple to simulate for any process conditions.
- Some ions come directly from the ion source.
  – Not predicted by the theory.
  – Possible causes:
    - Inaccuracy in Kaufmann model
    - Scattering off grids
    - Other physics (charge exchange collisions, etc.)
- Plan:
  – Experimentally map scattering vs. process parameters.
  – Improve ion source theory.

Improving ion source theory

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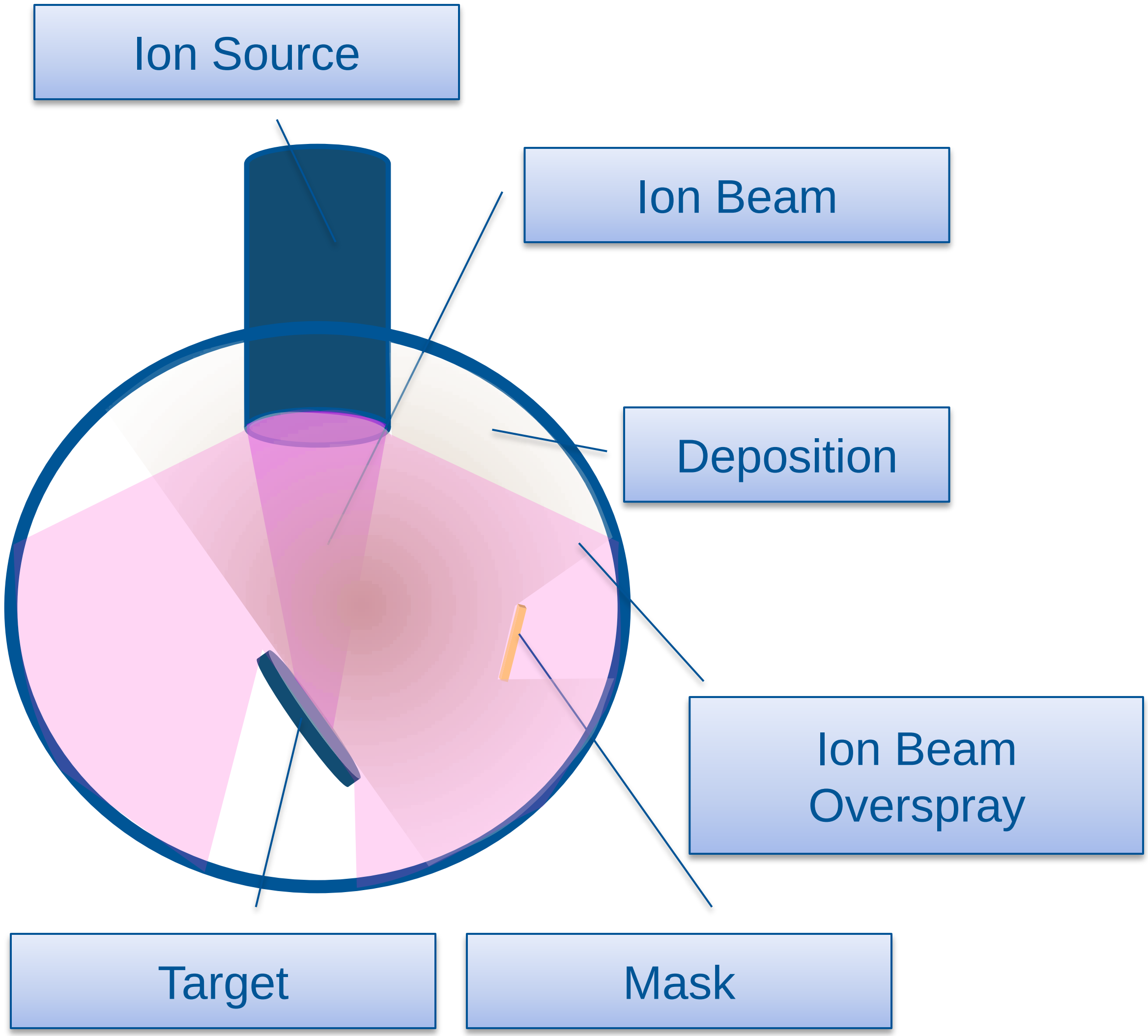
- Working to improve the theory with Tech-X.
- See their poster here "**Simulation of Defect Mitigation in Mask Blank Deposition**."
- Simulations will include the following:
  - Full electrostatic treatment
  - Gas scattering
  - Charge exchange collisions
  - First time the theory has included these terms
- Should have results in early 2012.
- Goal is to predict where the ions hit.

Broad tail of the ion beam etches the shields and leads to many types of defects



- Tool components need to be designed to handle the etch:
  - Shields
  - Target surface
  - Target edge

Defect implication of broader than predicted ion beam

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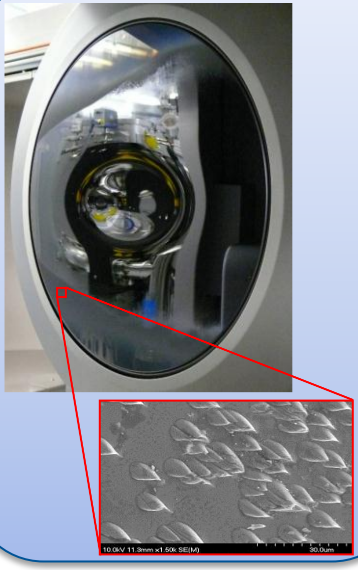
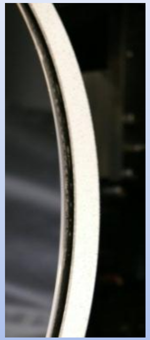
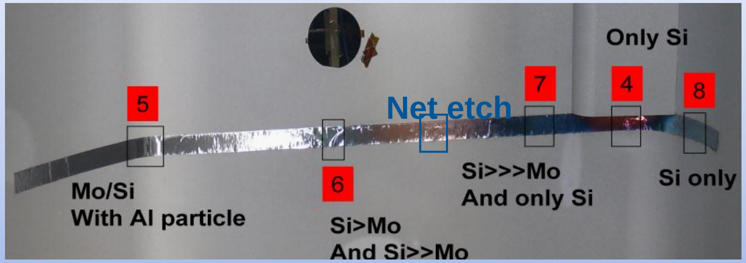
- Target periphery roughens, leading to crystalline Si defects.



- Edge of target and target holder are etched, causing
  - Stainless steel defects from target holder
  - Copper defects from backing plate
  - Ru defects from edge of target



- Shields are etched, causing
  - Mo/Si defects from shields
  - Amorphous Si defects from shields
  - Alumina defects from shield texturing
  - Stainless steel defects from shield material



Crystalline Si defect generation

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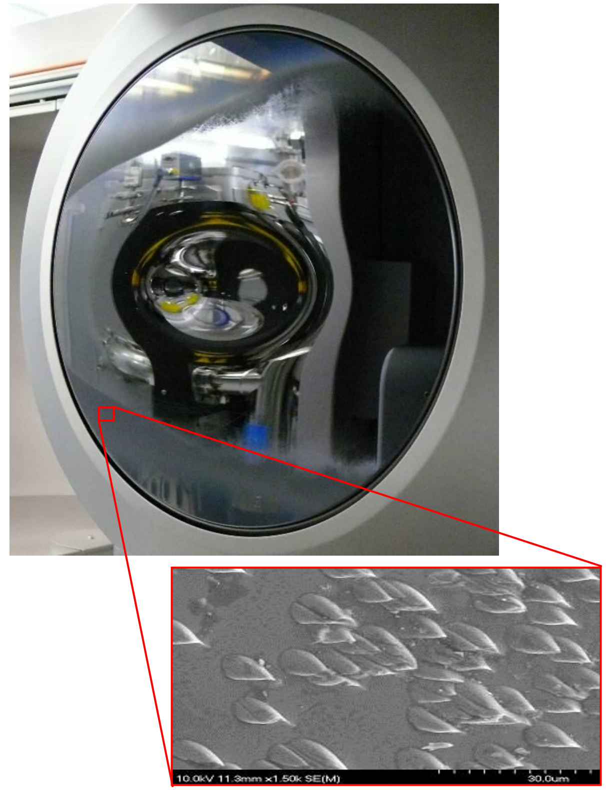
- Periphery of target roughens due to ion etch.
- Nodules form, which lead to single crystal Si defects.



- See poster "**Reducing EUV mask blank defects originated at target surface during ion beam deposition process**" for discussion of how nodules form and some ways of eliminating them.

Other gases for mask deposition

- SEMATECH's standard process uses argon ions to sputter the mask layers.
- We have experimented with using xenon and neon ions.
- Neon
  - Requires high gas flow and source power for operation.
  - Achieved reasonable reflectivity with little optimization.
  - Fear the high source power and gas flow will lead to defects.
- Xenon
  - Low gas flows and source power gave stable operation.
  - Achieved reasonable reflectivity with little optimization.
  - Good candidate for future experiments to measure defectivity.

Conclusion

- SEMATECH has an active program to improve EUVL mask defect levels.
- Tool geometry
  - Model can predict uniformity and rate for any substrate target geometry.
  - Have found substrate locations that give a much larger process window than current location.
- Ion beam characterization
  - Have measured beam footprint on target for many process conditions and found shortcomings in the source operation model.
  - Have developed a pinhole camera technique to quantify the origins of ions that miss the target.
  - Working with Tech-X to develop model of ion source including key effects that we believe will explain the number of ions that miss the target.
- We believe that this unpredicted ion beam behavior contributes to several defect sources we see in our tools.
- We are working to find process conditions that minimize the tails of the ion beam that miss the target.