# Engineering Tests Stand (ETS) Updates: Lithographic and Tool Learning

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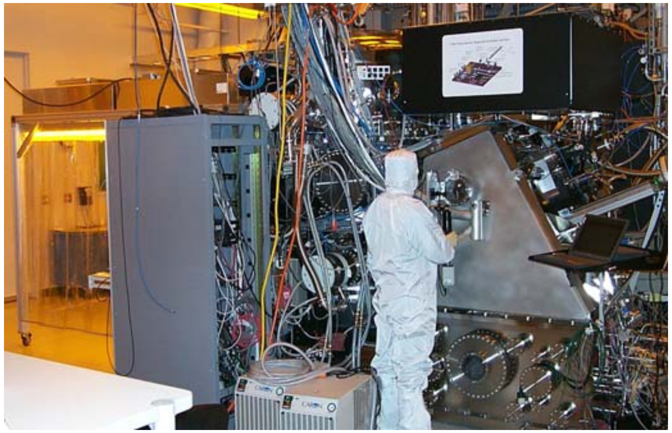
# outline

**Objective: Summarize this year's lithographic and tool learning obtained using the ETS.**

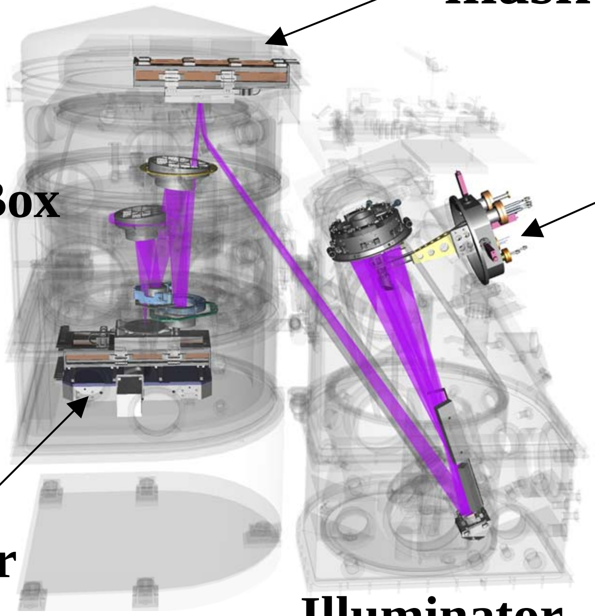
- **Introduction:**
  - **Top-level ETS specifications**
  - **ETS goal and major learning**
- **Experiments from the ETS user facility**
  - **Intel**
  - **AMD**
  - **Motorola**
  - **Infineon**
- **Conclusion**

# ETS top-level specifications

| | |
|---|---|
| • Critical dimension | CD = $k_1 \lambda/NA$ = 100 nm dense at $k_1$ = 0.75 |
| • Field Size | 24 x 32.5 mm (scanned) |
| • Operating wavelength | 13.4 nm |
| • Numerical aperture | 0.1 |
| • Depth of focus | ± 0.5 μm |
| • Wafer Size | 200 mm |



Right View



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# Major goal for the ETS was to demonstrate the feasibility of EUVL technology

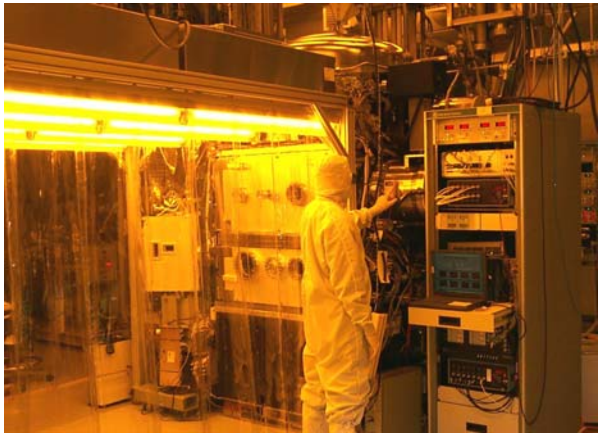
- **World's first fully-integrated, full-field scanning EUVL exposure tool designed, built and tested**

**→ Industry wide recognition of EUVL technology**

- **All sub systems tested and verified in vacuum**
  - **LTEM mask substrates**
  - **Ultra-thin resist process developed to replace TSI approach**
  - **Highest average brightness laser developed by TRW**
  - **40x increase in LPP source power achieved**
  - **First high-throughput EUV condenser developed**
  - **Hydrocarbon control in ETS for long-life optics**
  - **Achieved <3 nm jitter in full-speed scanning maglev stages**
  - **Control system with 15 controllers and 433 components developed**
- **No major surprises!!**

# The ETS has been an important tool to accelerate EUVL learning

- <u>Lithographic learning</u>
  - Static and scanned imaging
  - Flare measurements
  - Resist characterization
  - Dose control
  - Process window measurement
  - Reticle characterization
- <u>Environmental learning</u>
  - Condenser lifetime
  - Contamination mitigation
  - Projection system lifetime
  - In-situ cleaning
  - Resist outgassing
- <u>System learning</u>
  - Vibration environment
  - Thermal management
  - Vacuum system development



- <u>Source characterization</u>
  - Conversion efficiency
  - EUV output stability
  - Thermal testing
  - New source configurations
- <u>Sensor development</u>
  - EUV dose sensors
  - Aerial Image Monitor (AIM)
  - Through-the-Lens imaging
  - New EUV sensor testing

# ETS as an user facility

**ETS system operation this year has focused on member-company experiments, but tool learning continued…**

- **4 LLC companies performed various experiments to learn EUV specific issues.**
  - **AMD, Infineon, Intel, and Motorola**
- **Tool learning continued.**
  - **Response of system to environmental perturbations**
  - **Stability of LPP source operation**
  - **Condenser erosion**
  - **Dose control using sensor measurements**
  - **Dose uniformity (scan and cross-scan directions)**
  - **Reticle e-chuck performance**
  - **Resist performance**
- **10 standard masks were printed with the ETS during the half-year period**



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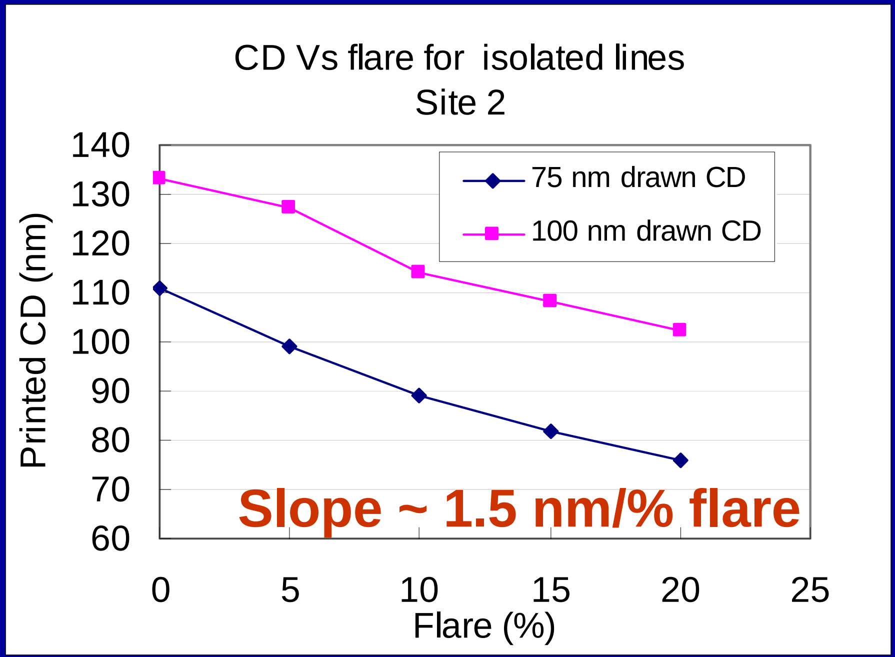
# Intel ETS exposure runs

- Flare measurements and characterization
- Flare variation compensation experiments
- Process window measurements with flare
- Line defect study
- Negative tone resist

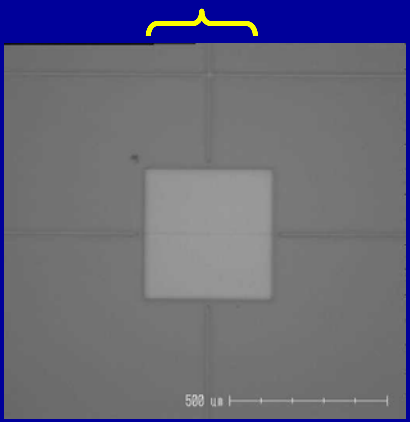
Manish Chandhok, Wed 10/2, 9:05AM, Optics I

"Measurement of the Impact of Flare on Line Width Roughness and Correlation with Aerial Image Metrics"

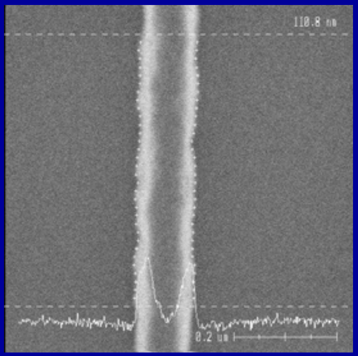
# Flare characterization: CD sensitivity to flare



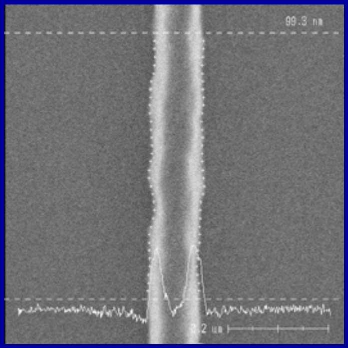

**Vary window size to increase flare**



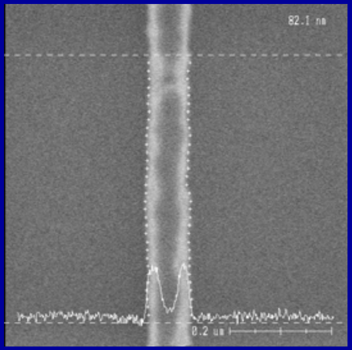

**0% flare**



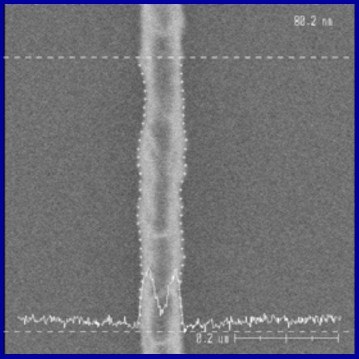
**5% flare**



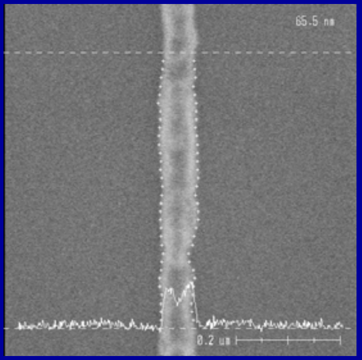
**10% flare**



**15% flare**



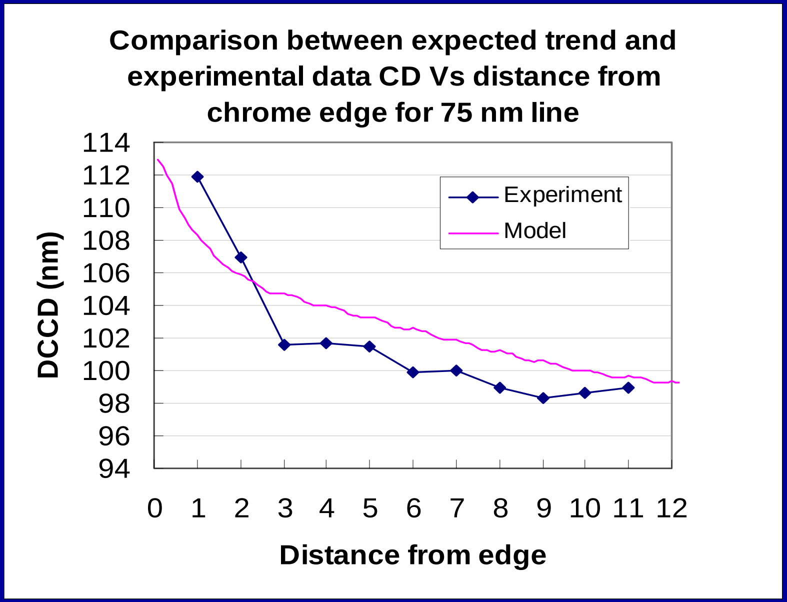
**20% flare**



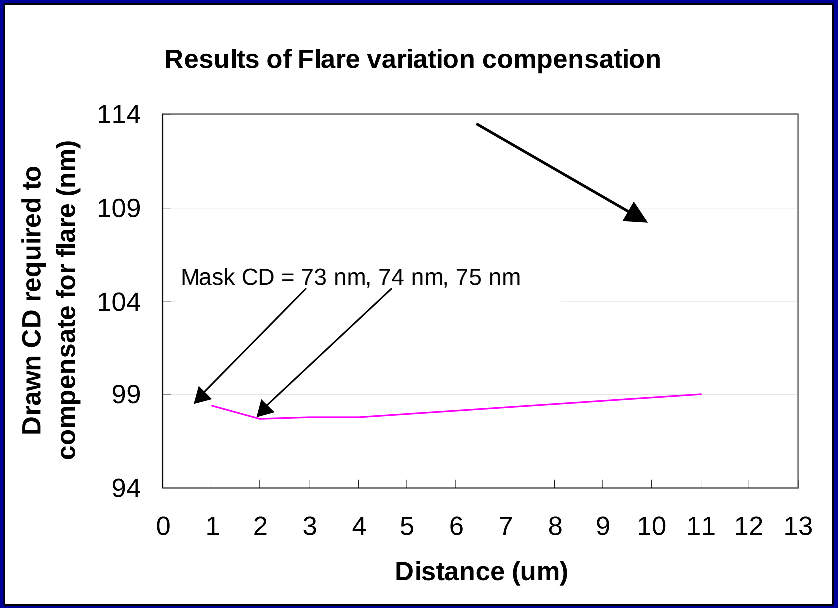
# Flare Variation Compensation (FVC)

$$CD_{new} = CD_{drawn} + \frac{\partial CD}{\partial Flare}\Big|_{Flare_{local}} \times \left(Flare_{nominal} - Flare_{local}\right) / MEEF$$

**No compensation, flare range ~ 6%**
**CD range = 13 nm**




**With Flare Variation compensation,**
**<u>CD range = 1.3 nm</u>**

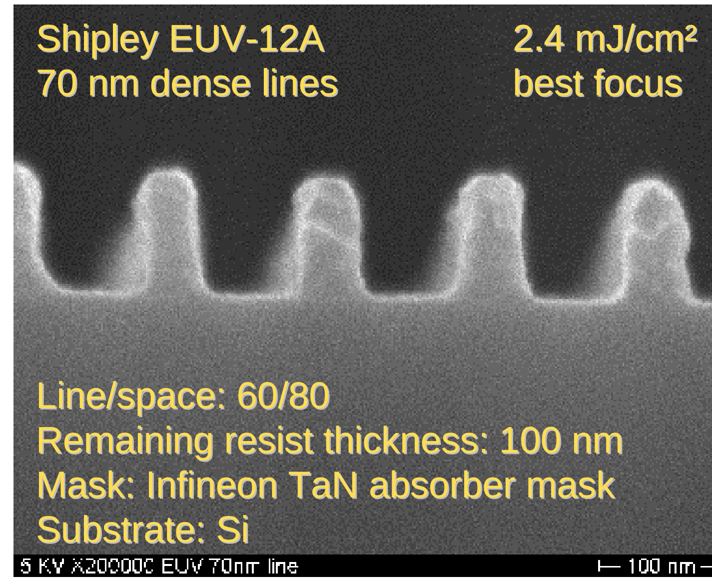



**Using the model based FVC techniques, the target CD variation can be achieved in the presence of flare.**

**For the ETS, CD range after FVC = 1.3 nm (a factor 10 decrease)**

# Infineon ETS Exposure Runs

- **<u>Cr and TaN absorber masks</u>**
- **<u>Process window analysis</u>**
- **Si and hardmask substrates**
- **Shot noise investigations**

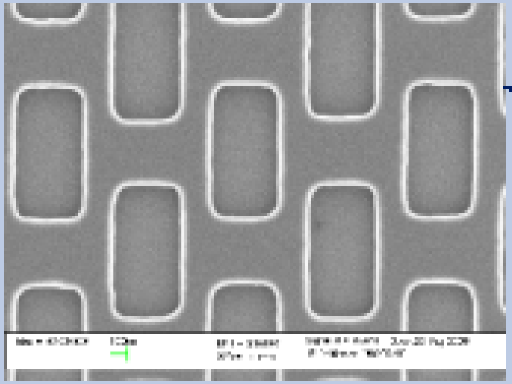


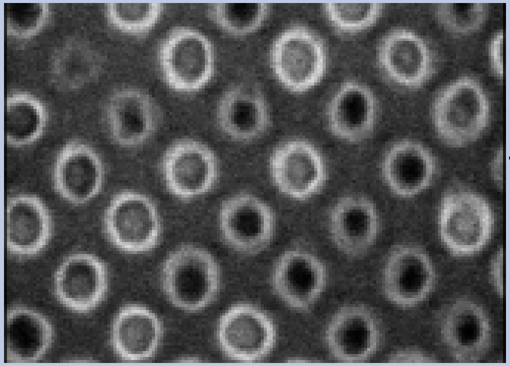

Stefan Hirscher, Wed 10/1, 9:45AM, Tool I

"Advances in EUV Lithography Development for Sub-50nm DRAM Nodes"

# Cr & TaN Absorber Mask Performance Comparison

70/140 nm long holes





TaN absorber mask

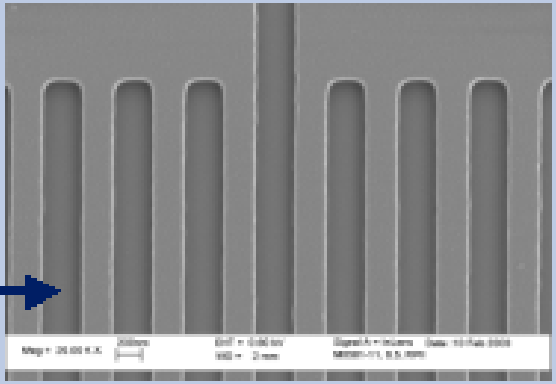
Cr absorber mask

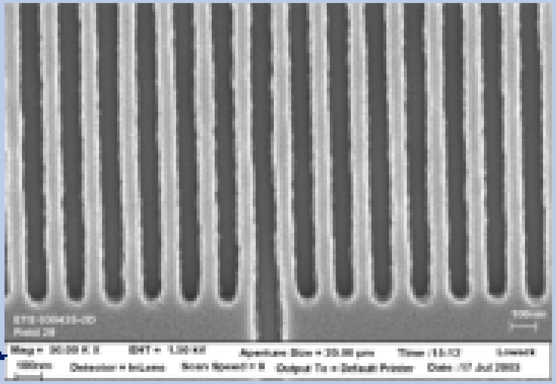
examples of different experimental settings

70 nm holes on hardmask

Shipley EUV-2D resist

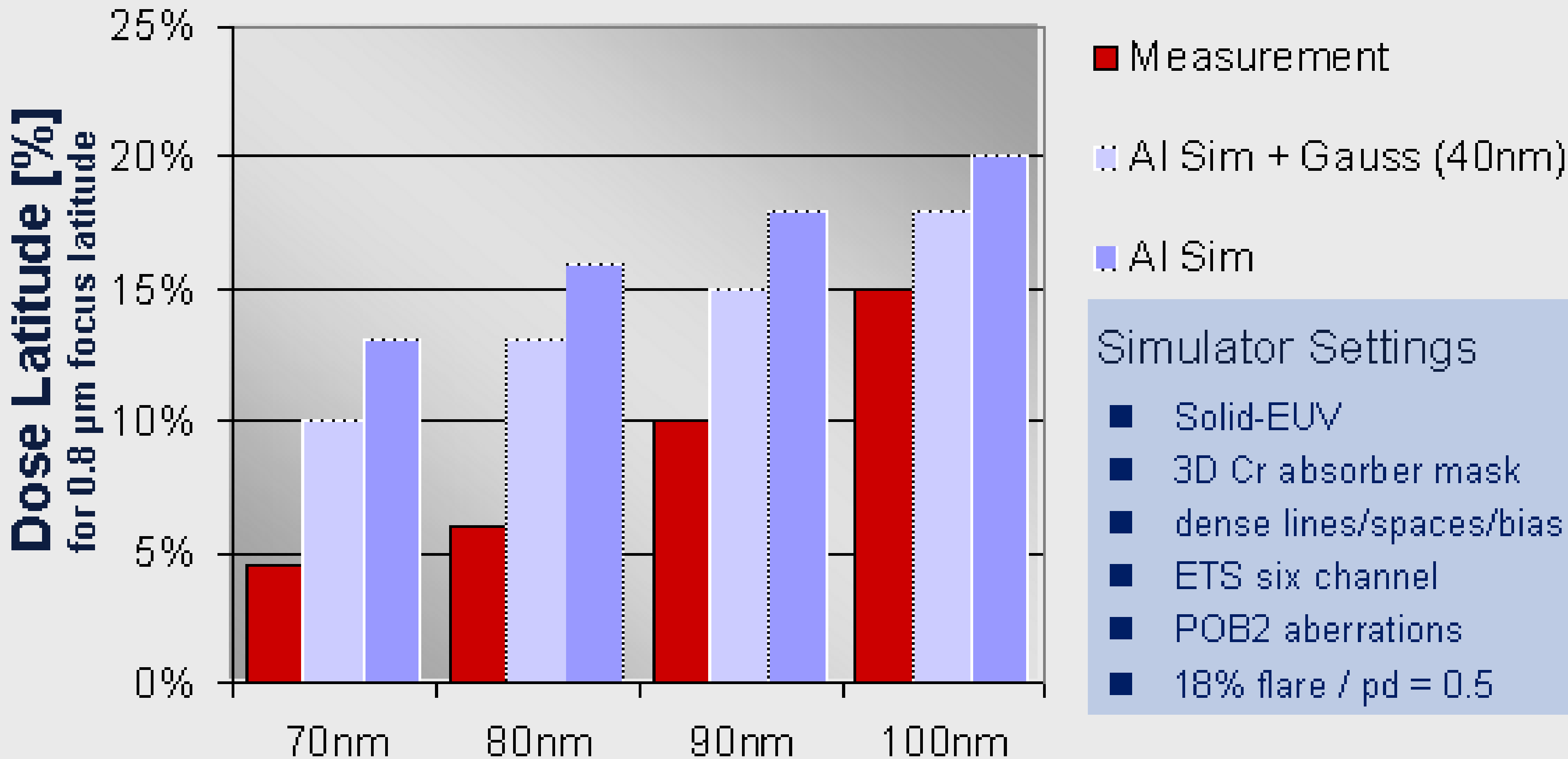
75 nm dense & iso lines





- Performance of Cr- and TaN-absorber masks comparable
- Ultimate resolution limit: 70 nm

# Process Window Comparison of Simulation and Experiment




Simulator Settings

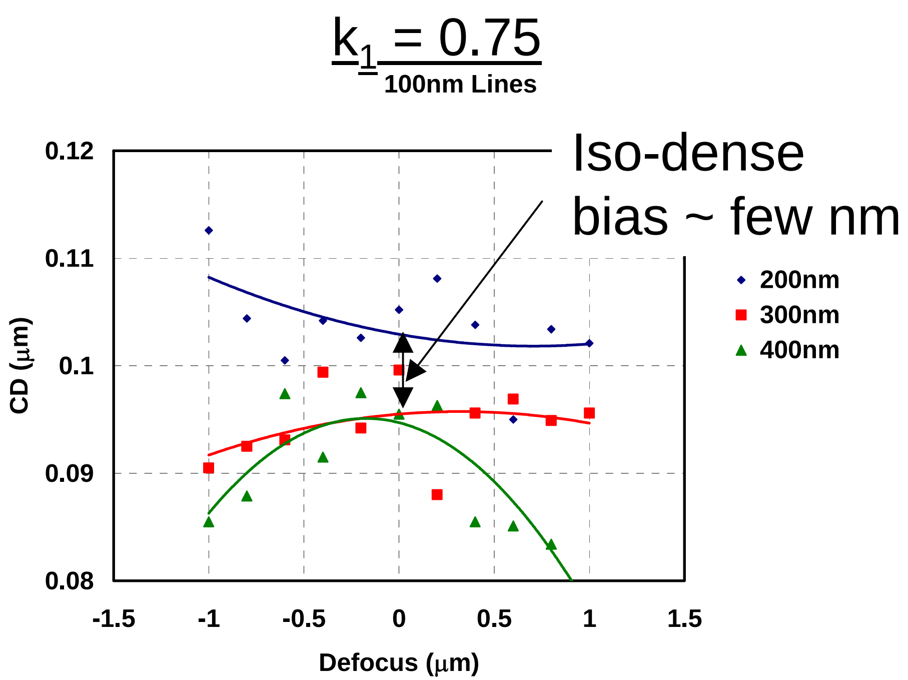
- Solid-EUV
- 3D Cr absorber mask
- dense lines/spaces/bias
- ETS six channel
- POB2 aberrations
- 18% flare / pd = 0.5

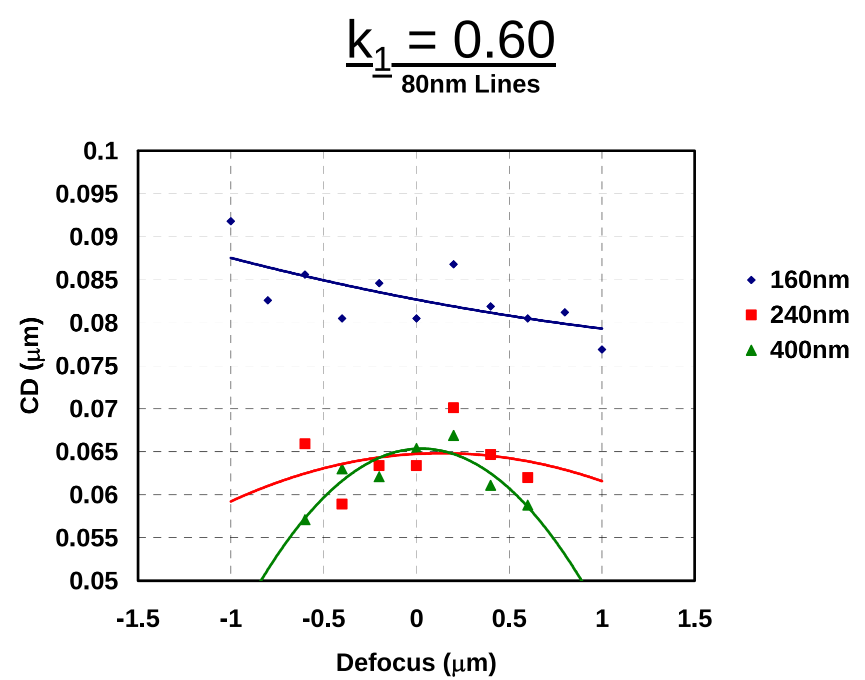
- **Wafer process consumes 25 – 50 % of the process window**
- **IMPROVE RESIST PROCESS**

# Motorola ETS exposure runs

- <u>Process window study for iso and dense features</u>
- <u>Printing of SRAM bitcells</u>
- Line-end shortening measurements
- Flare compensation experiments
- Defect printability study

# CD's as a Function of Nominal Size and Pitch through Defocus




- Process windows limited by more isolated features (min. DoF for $k_1$ = 0.75 is ~ 1.25 μm)
- For 32nm node technology, 1D-OPC may be required for CD control, independently of flare compensation

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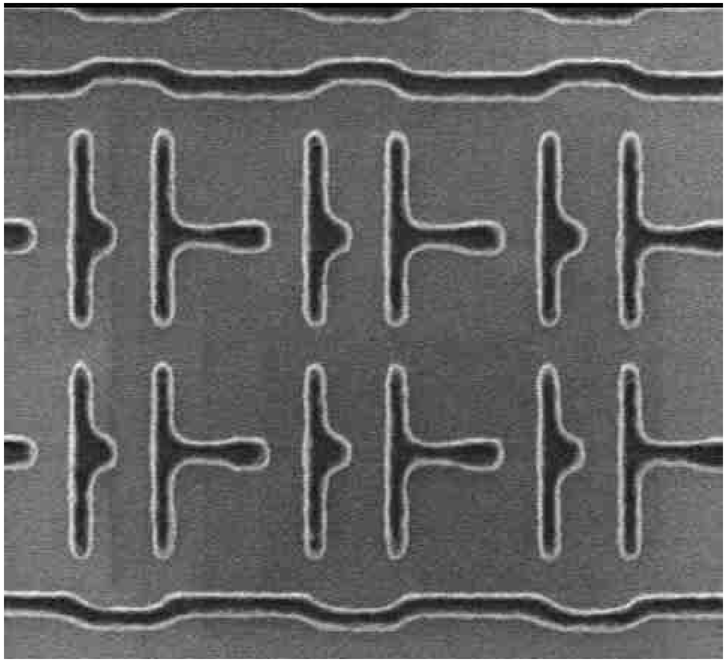
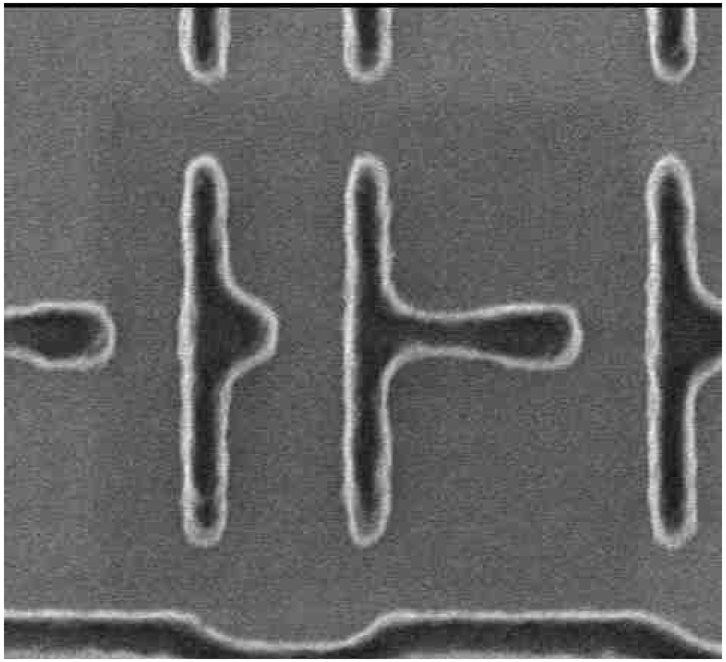
# SRAM Bitcell Lithography

**First demonstration of SRAM bitcell printing with EUV lithography.**





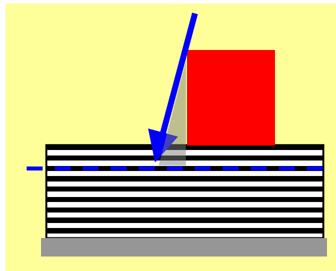
- **Drawn line size = 100 nm, drawn pitch = 340 nm**
- **No OPC applied**
- **Measured line size = 100 nm**

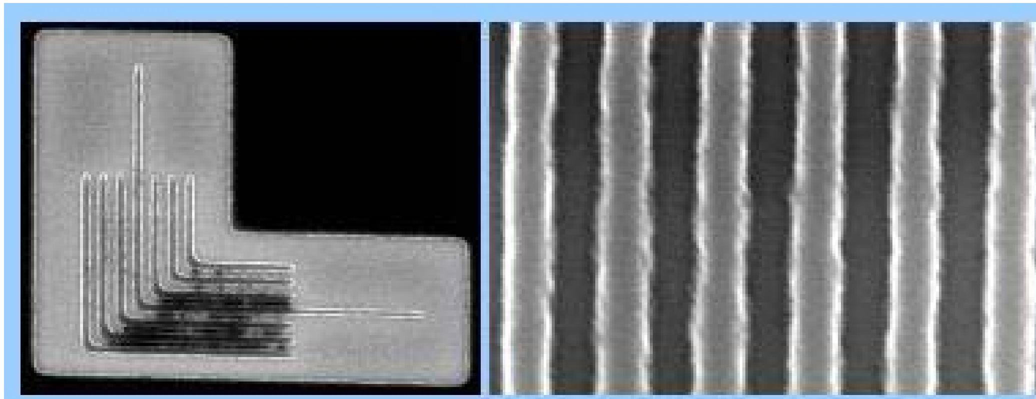
# AMD ETS exposure run

- **Comparison of imaging performance with a $Cr/SiO_2$ absorber mask and an etched-multilayer binary mask (EMBM).**

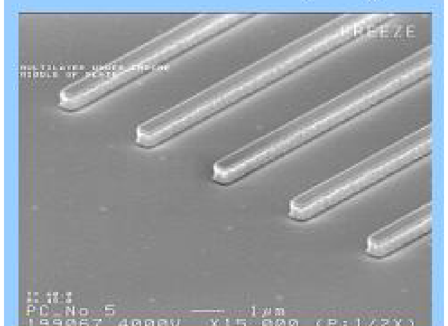
# Comparison of Cr/$SiO_2$ mask with etched-multilayer binary mask (EMBM)

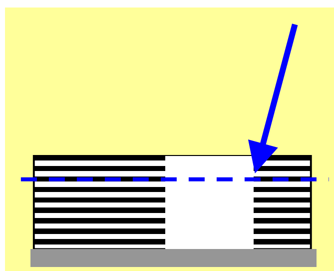
Cr/$SiO_2$ mask used for ETS printing

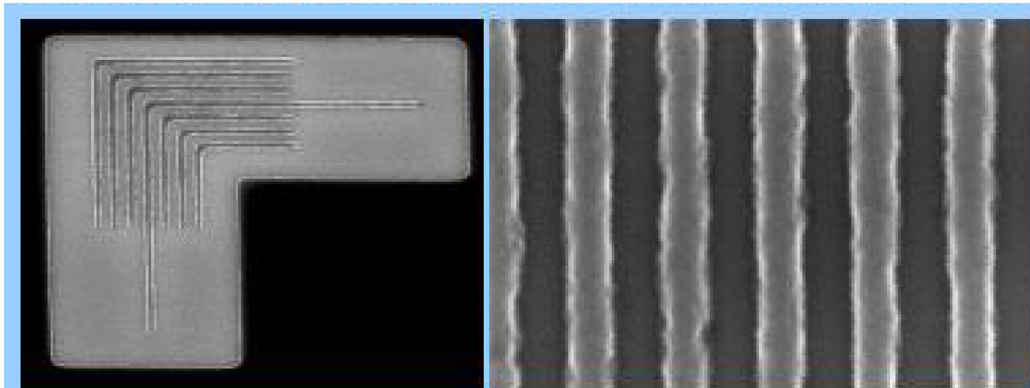





EMBM mask used for ETS printing





**Masks used**

**Schematic of shadowing effect**

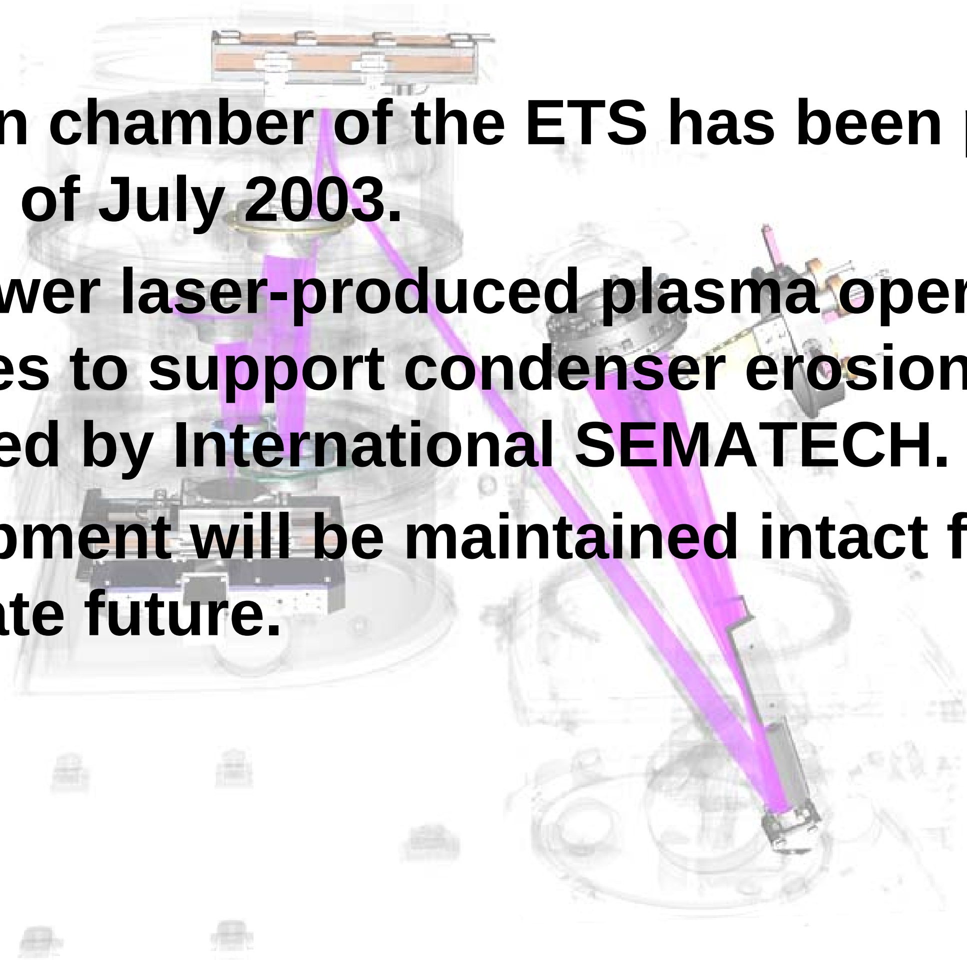
**ETS prints in the center of the process window**

**Shadowing effect –**
**Larger H-V bias observed for absorber masks than for etched-multilayer masks (EMBM)**



AMD

# Current status and future of ETS



- The main chamber of the ETS has been put to sleep as of July 2003.
- High-power laser-produced plasma operation continues to support condenser erosion studies supported by International SEMATECH.
- All equipment will be maintained intact for the immediate future.



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# ETS wins 2003 R&D 100 award

# Key message

***The ETS completed its original task.***
***Two years of the ETS operation has shown that EUV has no surprises!***

- **All aspects of EUV lithography have been successfully demonstrated in the ETS– components, metrology, masks, control, etc.**
- **Various experiments were performed by LLC member companies, and much lithographic learning has been obtained.**
- **All lithographic experiments have been verified with modeling.**



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# Acknowledgement

**Adam Pawloski, Harry Levinson**
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**Scott Hector, Sang-In Han, Bing Lu, Pawitter Mangat, Richie Peters, Sergei Postnikov, James Wasson, Eric Weisbrod**

**Donna O'Connell, Steve Haney, Luis Bernardez, Terry Johnson, Dan Folks**