# Advanced Mask Inspection Technologies for 22 nm and Beyond

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# Agenda

- Motivation
- Latest Reticle Inspection Advances
- Latest EUV Inspection Results
- EUV Actinic Patterned and Blank Mask Inspector Introduction
- Summary


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# Motivation

Provide mask inspection solution to enable advanced patterning technologies

| *Table LITH6 EUVL Mask Requirements* | | | | | |
|---|---|---|---|---|---|
| *Year of Production* | *2013* | *2014* | *2015* | *2016* | *2017* |
| *DRAM ½ pitch (nm)* | 28 | 25 | 23 | 20 | 18 |
| *DRAM/Flash CD control (3 sigma) (nm)* | 2.9 | 2.6 | 2.3 | 2.1 | 1.9 |
| *Flash ½ pitch (nm) (un-contacted poly)* | 18 | 17 | 15 | 14 | 13 |
| *MPU/ASIC Metal 1 (M1) ½ pitch (nm)(contacted)* | 27 | 24 | 21 | 19 | 17 |
| *MPU gate in resist (nm)* | 28 | 25 | 22 | 20 | 18 |
| *MPU physical gate length (nm)* | 20 | 18 | 17 | 15 | 14 |
| *Gate CD control (3 sigma) (nm)* | 2.1 | 1.9 | 1.7 | 1.6 | 1.5 |
| *Overlay (3 sigma) (nm) [R]* | 5.4 | 4.8 | 4.2 | 3.8 | 3.4 |
| *Contact in resist (nm)* | 28 | 25 | 23 | 20 | 18 |
| *Generic Mask Requirements* | | | | | |
| Mask magnification [A] | 4 | 4 | 4 | 4 | 4 |
| Mask nominal image size (nm) [B] | 112 | 100 | 89 | 79 | 71 |
| Mask minimum primary feature size [C] | 78 | 70 | 62 | 55 | 49 |
| Image placement (nm, multipoint) [D] | 3.2 | 2.9 | 2.5 | 2.3 | 2.0 |
| *CD uniformity (nm, 3 sigma) [E]* | | | | | |
| Isolated lines (MPU gates) | 2.6 | 2.4 | 2.1 | 2.0 | 1.8 |
| Dense lines DRAM (half pitch) | 2.0 | 1.8 | 1.6 | 1.4 | 1.3 |
| Contact/vias | 1.6 | 1.4 | 1.2 | 1.1 | 1.0 |
| Linearity (nm) [F] | 4.3 | 3.8 | 3.4 | 3.0 | 2.7 |
| CD mean to target (nm) [G] | 2.3 | 2.0 | 1.8 | 1.6 | 1.4 |
| *Defect size (nm)* | **23** | **20** | **18** | **16** | **14** |

- Capture ***"Known"*** and ***"Unknown"*** defects
  - Boost defect signal with illumination
  - New detector development for new types
- Reduce ***"Nuisance"***
  - More complex modeling – Error reduction
  - Reduce imaging and system noise



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# Latest Reticle Inspection Solution

- EUV patterned masks and blanks
  - The best pattern sensitivity
  - Industry benchmark Blank mode (Phasur)
- Optical; Complex OPC, Quartz etch reticles
- For ≥ 10nm Generation

**Teron 630**

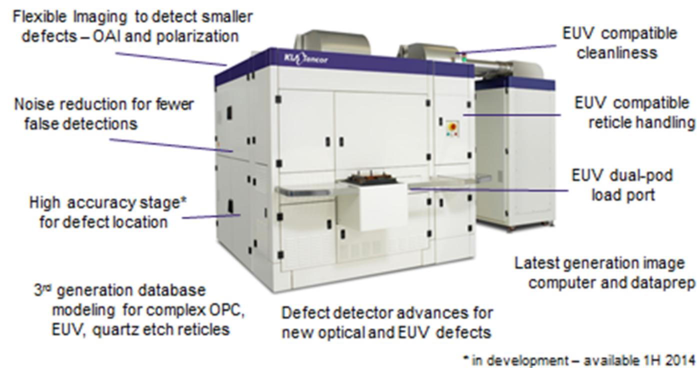
Industry proven sensitivity for advanced optical and EUV Mask inspector

# Recap From PMJ 2013

## Teron 630 Technology Advances discussed

### Latest Reticle Inspection Advances

**Teron 630 Series for 10nm / 1xhp Generation – Optical and EUV**




* in development – available 1H 2014

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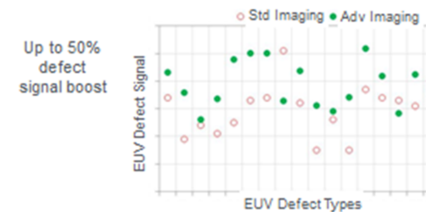
### Latest Reticle Inspection Imaging Advances

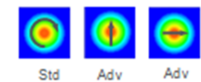
**Imaging advances to boost defect signal / reduce noise**

- Flexible imaging conditions – NA, sigma, pupil, polarization
- Reduced aberrations, vibration, focus error
- EUV demonstrated – applicable to optical




630 Flexible Apertures

630 Flexible Polarization

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### Latest Database Modeling Advances

***new* Gen3 modeling for EUV, quartz etch, complex OPC**

- Advanced physics-based 3D modeling
- Models complex EUV and quartz etch illumination physics
- Low errors for best defect detection SNR – find small defects
- Optimized for high speed reticle inspection (10x10cm in ~2hr)
- Extendable to standard optical reticles with aggressive OPC

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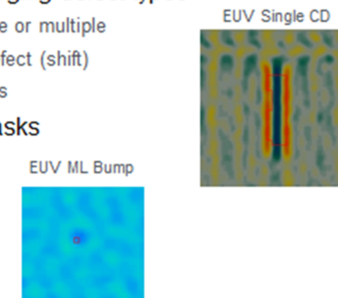
### Latest Defect Detector Advances

**Detect emerging reticle defect types – local CD, shift, etc.**

- Detect reticle defects with ≥10% ΔCD/CD litho impact
- *new* detectors for emerging defect types
  - local CD defects – single or multiple
  - mis-placed geometry defect (shift)
  - CD or shift defect stripes
- Detectors for blank masks
  - particles
  - pits and bumps

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# Latest Database Modeling Advances

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- Low errors for best defect detection SNR – find small defects
- Optimized for high speed reticle inspection (10x10cm in ~2hr)
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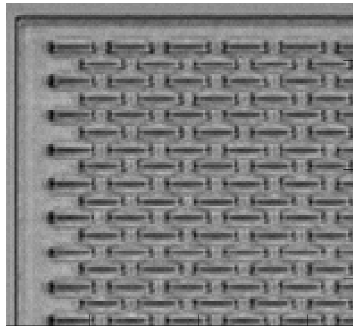
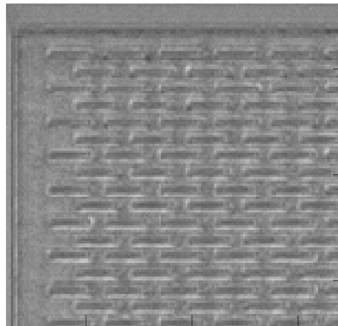
Gen2 modeling error



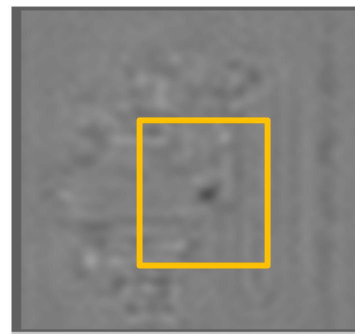
50% RMS lower errors

Gen3 modeling error

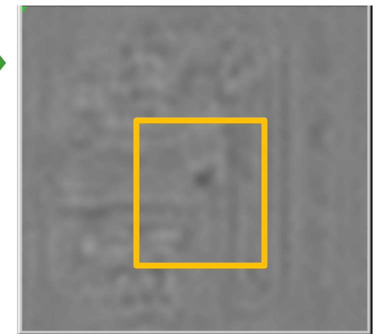


EUV 14nm reticle

Gen3 Initial release



Gen3 2nd release



25 to 30% further noise reduction



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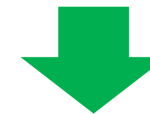
# Latest EUV Die-to-Die Algorithm Advances

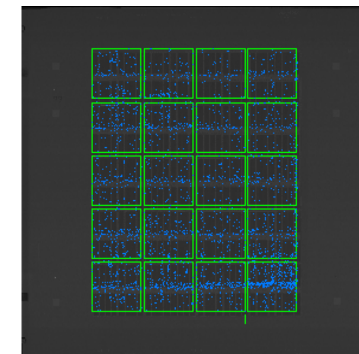
- New Advanced EUV Die-to-Die Algorithm developed
  - In-house testing completed
  - Recent Beta site installation
- Technical advances for die-to-die
  - Optimized imaging – OAI and polarization
  - New autofocus method - reduces false
  - EUV defect detectors
- Sensitivity expected to meet process development requirements

Previous Die-to-Die result

False issue

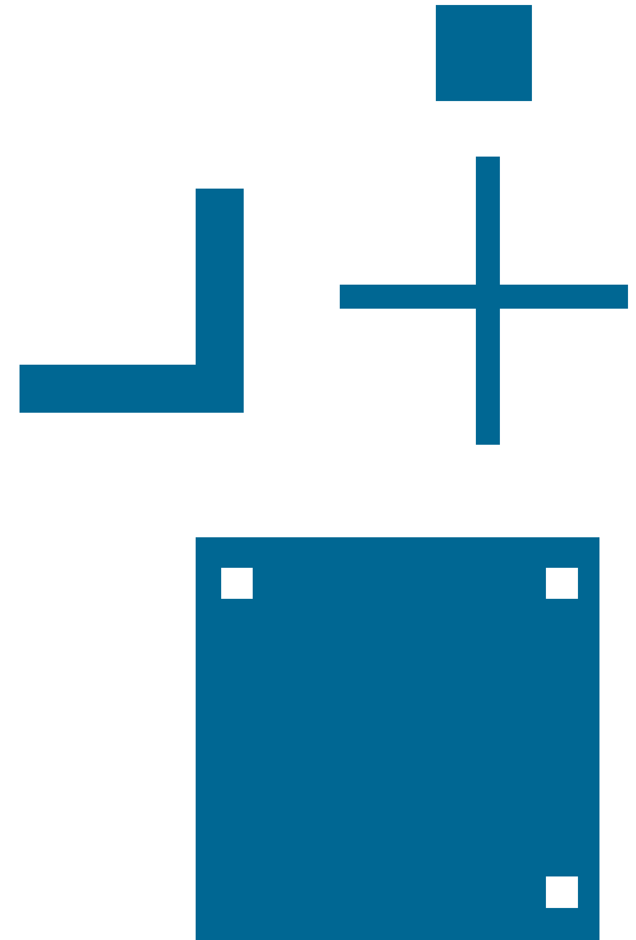


Advanced die-to-die result



# Latest Phasur (EUV Blank) Mode Advances
## Joint work with blank & pattern generator supplier

- New, very flexible alignment algorithm for Phasur
- Accommodate cross, square box, or L-shaped alignment target
  - Requires only one corner
  - Minimum width 3 um
  - Maximum width / length – unlimited
- Templates can be stored and re-used easily
- Scale and orthogonality errors are corrected



**Enabling defect location accuracy improvement**



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# ML Phase Defect Location Accuracy Advances

| Location Accuracy (nm) | Timing | Change | Platform |
|---|---|---|---|
| ~ 1000 - 3000 | Q4 CY10 | Initial capability | 610 |
| ~ 200 - 250 | Q2 CY11 | 2 pt alignment (plate rotation) | 610 |
| ~ 100 -120 | Q4 CY12 | 3 pt alignment, scale, ortho compensation, template matching | 610 / 630 |
| ~ 50 | 1H CY14 | HW improvements | 630 |
| ~ 30 | 1H CY15 | Algorithm / sw development | 630 |

Continuous improvements to support industry needs

# 630 EUV Die-to-database Sensitivity Verification based on 10% ΔCD Wafer Print-line

## Advanced EUV Sensitivity Verification Mask Test Results

### 6x nm Pitch Via 630 EUVdb vs. wafer print line

| Type | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Print line | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 630 DDB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Sensitivity setting – less than 44 off-grid false / nuisance

**630 EUVdb meeting wafer print line sensitivity**
**Continues to further improve sensitivity to meet all requirements**

db or DDB = die-to-database PD = Programmed Defect CR = Capture Rate

Mar-2013

# EUV Die-to-DB, Die-to-Die Sensitivity Characterization

L/S Extrusion

large — small

| Defect type | Design | Designed defect size (nm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L/S 1:1 Ext. | node (nm) | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 630 DD | 20 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |
| 630 DD | 24 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |
| 630 DD | 30 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |

L/S Intrusion

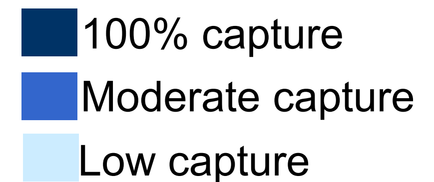
large — small

| Defect type | Design | Designed defect size (nm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L/S 1:1 Int. | node (nm) | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 630 DD | 20 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |
| 630 DD | 24 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |
| 630 DD | 30 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |

L/S Intrusion

large — small

| Defect type | Design | Designed defect size (nm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L/S 1:2 Int. | node (nm) | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 630 DD | 20 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |
| 630 DD | 24 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |
| 630 DD | 30 | | | | | | | | | | | |
| 630 DB | | | | | | | | | | | | |




EUV Die-to-Die results looks promising. Further study planned with partner

Max sensitivity capability with <100 false/nuisance per run criteria



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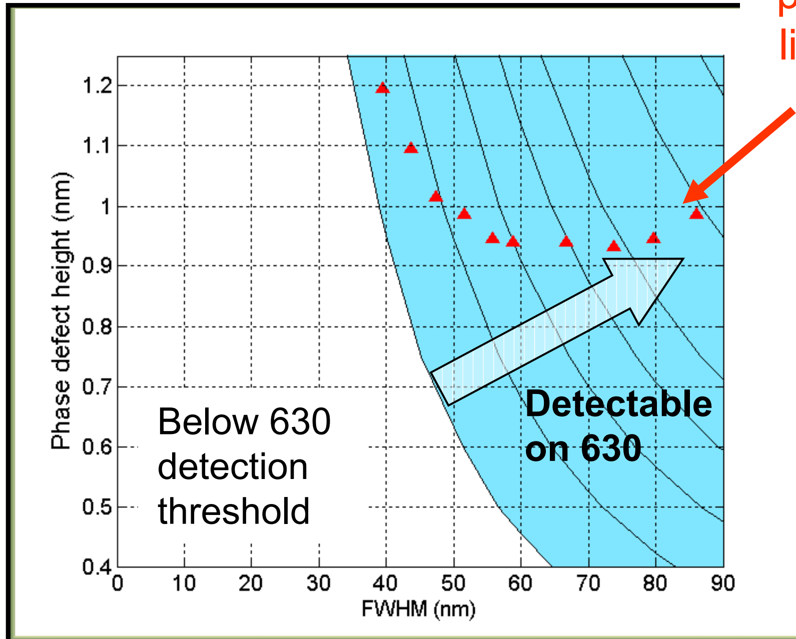
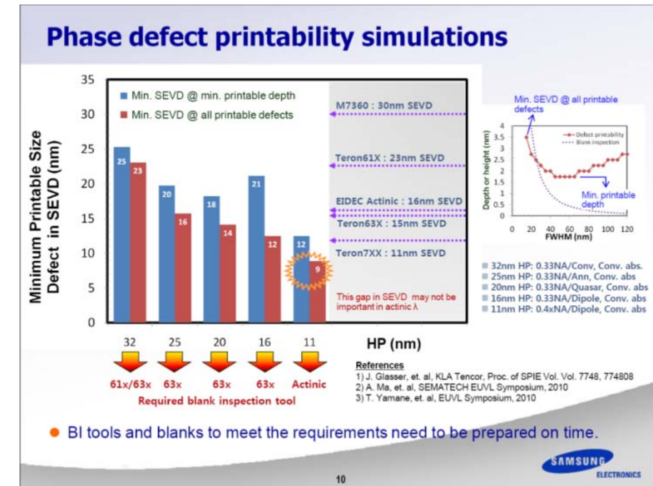
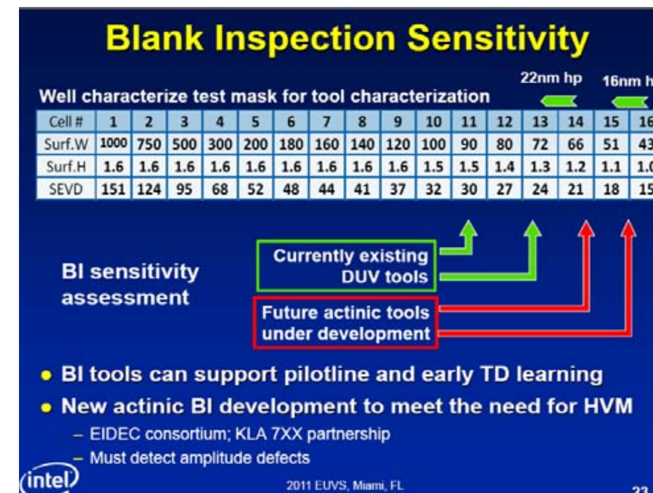
# Teron 630 Phasur (Blank) Mode Sensitivity Validation

## Sensitivity Validations – 23 SEVD confirmed

Sematech printability line for 16 nm HP




| Cell # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surf.W | 1000 | 750 | 500 | 300 | 200 | 180 | 160 | 140 | 120 | 100 | 90 | 80 | 72 | 66 | 51 | 43 |
| Surf.H | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.5 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.0 |
| SEVD | 151 | 124 | 95 | 68 | 52 | 48 | 44 | 41 | 37 | 32 | 30 | 27 | 24 | 21 | 18 | 15 |

Performance validated by many – Samsung, Intel, Toppan, Hoya, etc.

Phasur is available now and used for process development



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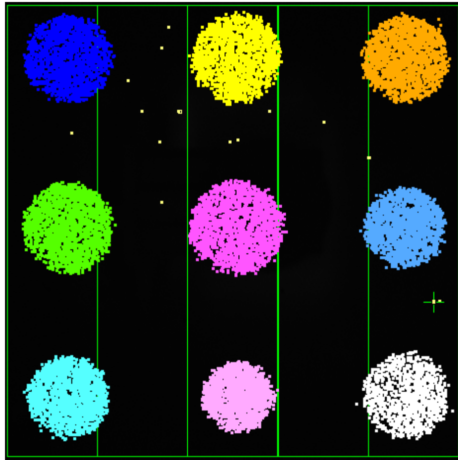
# Particle Mode Sensitivity Characterization

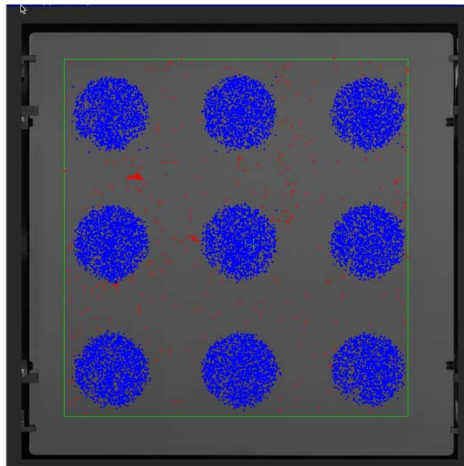
## High capture rate down to 30 nm size

SiO2 on Quartz



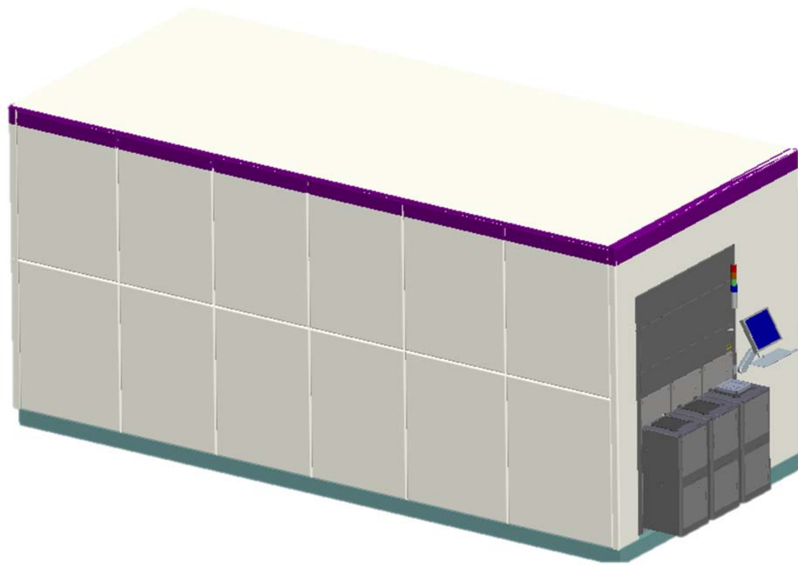
| SiO2 on Quartz | | |
|---|---|---|
| Particle size | Color | Capture rate |
| 90 | Dark Blue | 100 |
| 70 | Yellow | 99.5 |
| 60 | Orange | 99.9 |
| 55 | Green | 99.7 |
| 50 | Bright Pink | 99.8 |
| 45 | Blue | 99.6 |
| 40 | Light Blue | 99.9 |
| 35 | Pink | 100 |
| 30 | White | 100 |

SiO2 on ML



| SiO2 on ML | |
|---|---|
| SiO2 Size | Capture rate |
| 90 nm | 100% |
| 70 | 100% |
| 60 | 100% |
| 55 | 100% |
| 50 | 100% |
| 45 | 100% |
| 40 | 100% |
| 35 | High capture |
| 30 | High capture |

# EUV Actinic Patterned Mask and Blank Inspection Tool



- EUV actinic inspection is a must for EUVL High Volume Manufacturing due to:
  - Phase defects
  - Contamination defects
  - Throughput
  - Through-pellicle inspection

# 7xx Program

The world's only EUV Actinic Patterned Mask Inspection System



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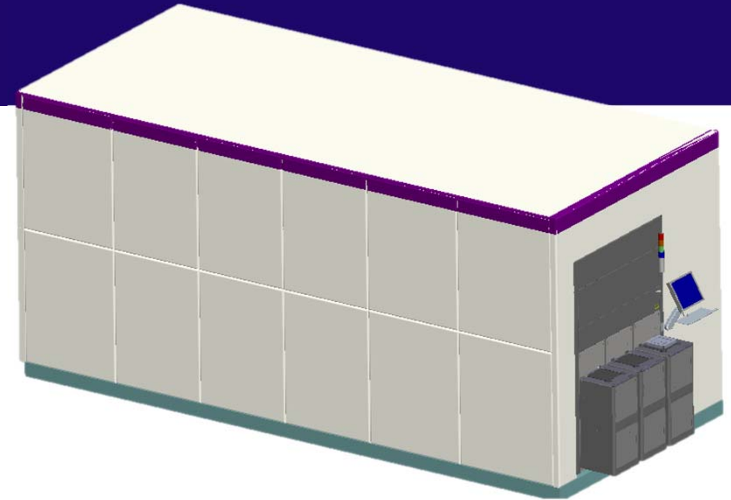
# 7xx Program Status



**Actinic platform requirements**

- Target node – 16-nm and 11-nm HP node
- Target throughput – 2 to 5 hour inspection per mask
- All defect types capture including Phase defects, ML Blank defects, Contamination defects which impact wafer patterning

**Partnership in place to accelerate Actinic Patterned Mask Inspector production readiness**



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# Summary

- Latest DUV reticle inspector – 630 Series released and supporting early EUV defectivity learning
  - platform extensions planned for 10nm / 1xhp generation

- EUV Actinic Patterned and Blank Mask Inspector development in progress with collaboration with key customers
  - target 7nm / 1xhp generation high volume manufacturing and below

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