High Resolution EBI for Pattern Fidelity Metrology

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Hermes Microvision, an ASML company

3/23/2017

AGENDA

- Overview of E-beam Inspection (EBI) System and Application
- Pattern Fidelity Inspection
- High Resolution EBI
- EBI Pattern Fidelity Metrology Case Study
- Summary

Overview of e-beam Inspection (EBI) System

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Cleanroom

Main system

Sub-fab

High Performance Compute platform

EBI = SEM + Defect Detection Algo

- Low Noise Platform
- Electron optics
- Deflection system
- Image system
- Algorithms

EBI for Voltage Contrast (VC) Defect Inspection

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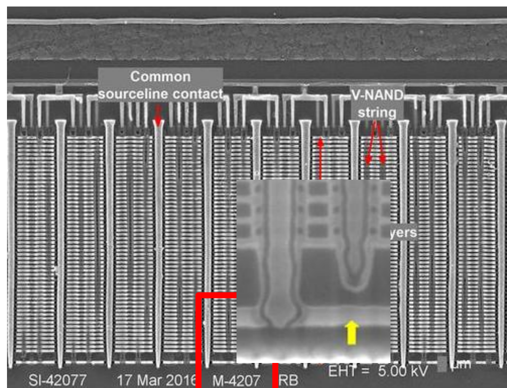
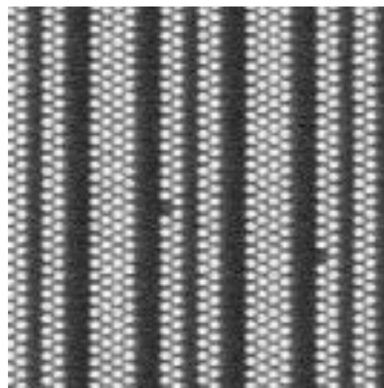
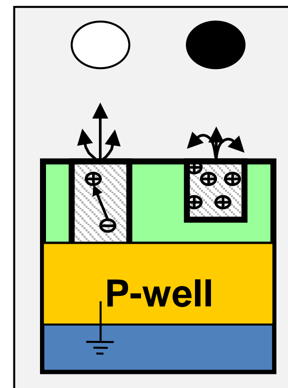
- VC inspection rely on the build-up of surface potential difference exerting field to influence the trajectories of secondary electrons
  - Perfectly etched contact could drain most electrons, i.e., no surface potential build-up
  - Totally un-opened contact accumulate excess positive charge (positive mode) to inhibit returns of secondary electrons *(Dark VC)*



Cross section



Top down SEM image under VC mode



VC Model

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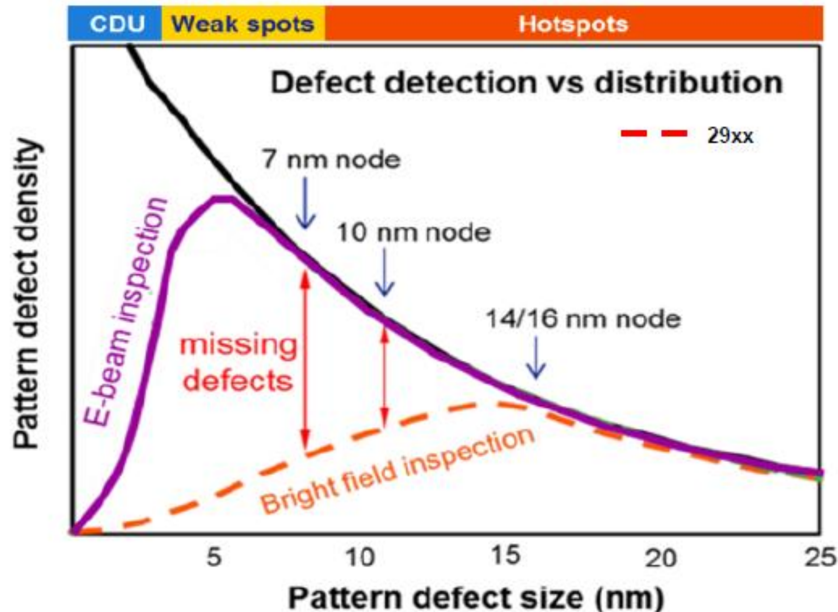
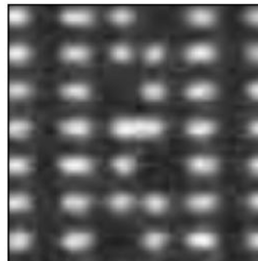
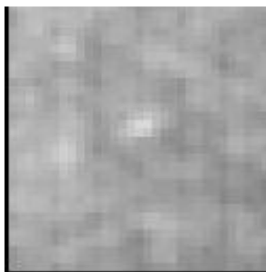
EBI for Physical Defect Inspection

- EBI has been widely used to detect small physical defects that Optical Inspection is lack of sensitivity

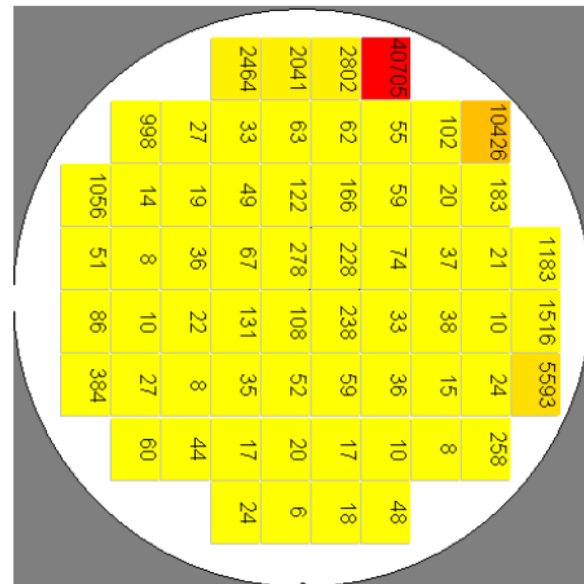




EBI Patch Image



BFI Patch Image



Wafer map by EBI

Oliver D. Patterson and etc.,, E-Beam Inspection for Detection of Sub-Design Rule Physical Defects, ASMC 2012

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Pattern Fidelity

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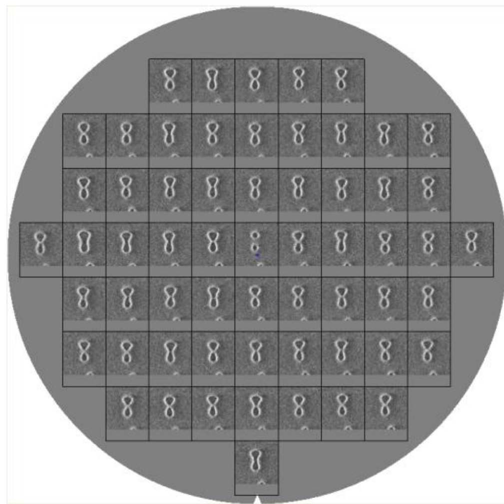
- Edge placement error becomes a major limiting factor for device scaling in advanced node
- "Patterning Fidelity is the pursuit of edge placement as close as possible to design intent without defects"
- <u>Problem is "What're the criteria of the defects"</u>
  - Defect Mode: Pixilated grey level value difference, or
  - CD Mode



Eric Solecky and etc.,, In-line Ebeam Metrology and Defect: Industry Reflections, Hybrid E-beam Opportunities and Predictions, SPIE Advanced Litho 2017

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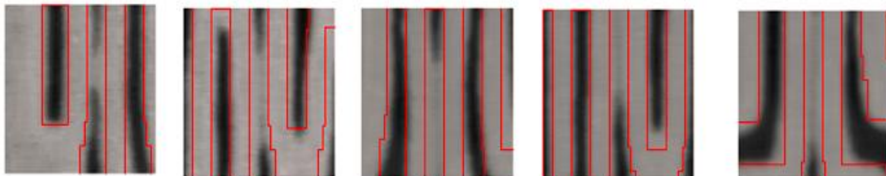
Pattern Fidelity Metrology By Defect Mode

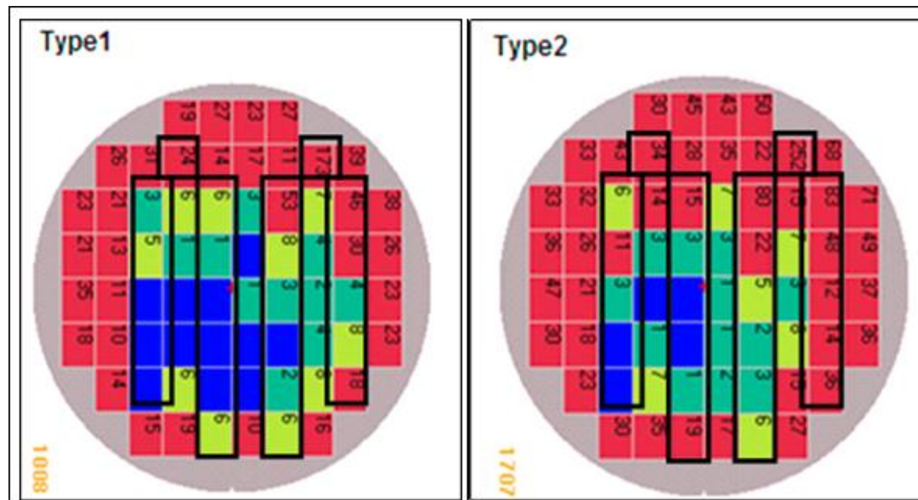
- Trench full broken vs. partial broken “by pixilated grey level value difference”
  - Hard to distinguish full broken with partial broken
  - Extremely difficult in category partial broken by extent of trench necking

Type 1: Defined as full broken



Type 2: Defined as partial broken

Process: after metal 2 liner
Dark pattern: trench
Red polygon: GDS



Blue color: zero defect die

Oliver D. Patterson and etc.,, E-beam inspection system for comparison of wafer and design data, SPIE Advanced Litho 2012, Proc. SPIE 8324

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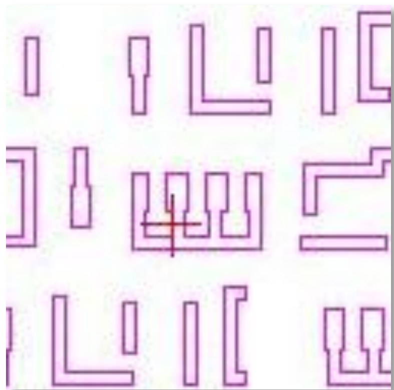
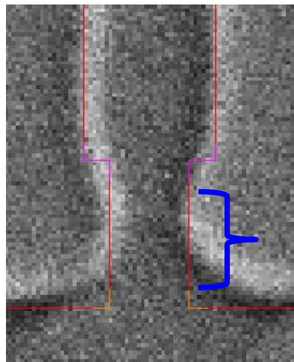
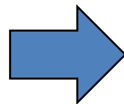
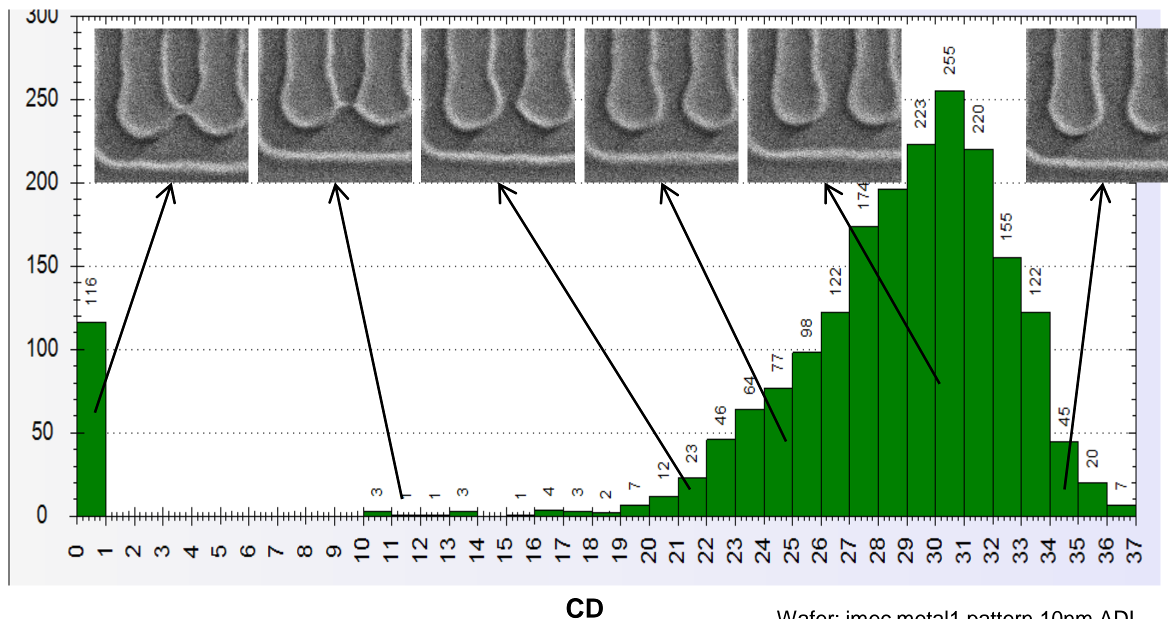
Pattern Fidelity Metrology by CD Mode

- Once EBI can measure with accuracy and precision, pattern fidelity metrology becomes possible









Wafer: imec metal1 pattern 10nm ADI

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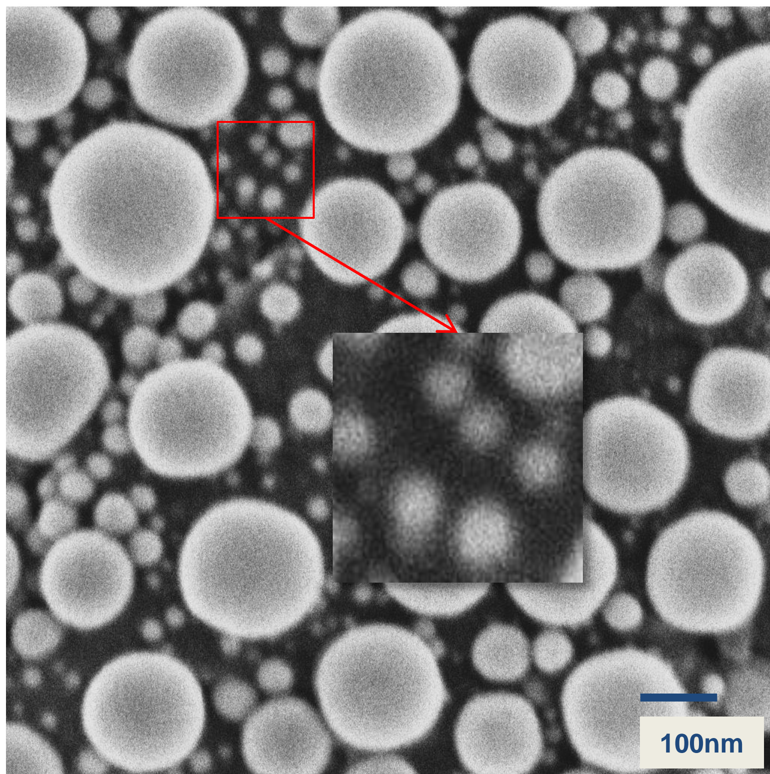
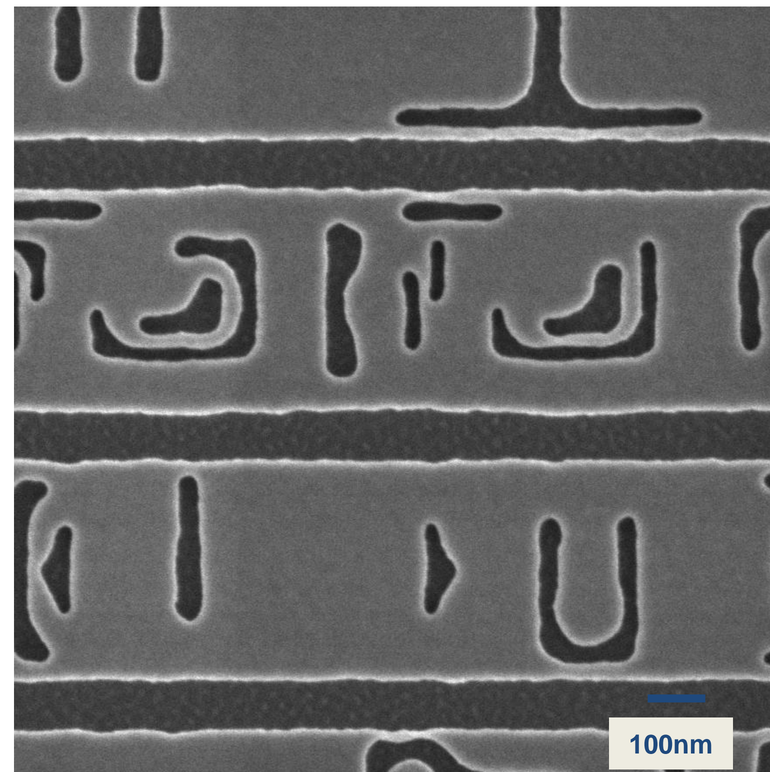
EBI Enters sub 2nm Resolution Era

- Resolution of EBI continues improvement to sub-2nm regime





Wafer: imec metal1 pattern 10nm AEI

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Precision Analysis

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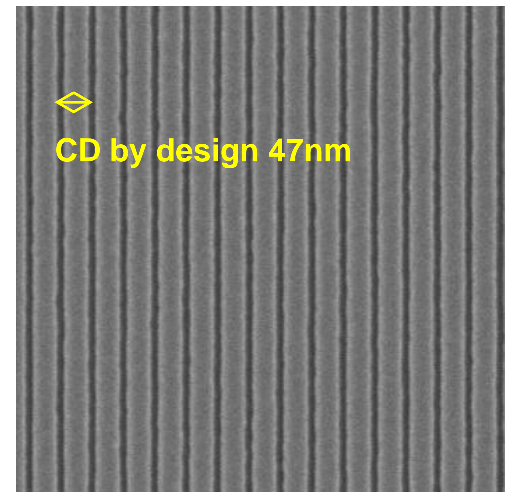
- **Dynamic Repo**
  - Measure 10 sites per run
  - 10 runs with wafer load/unload
- **Result**
  - Precision 0.17 nm

		Sites									
		1	2	3	4	5	6	7	8	9	10
Run	1	24.17	23.29	23.39	23.25	23.68	24	23.65	23.66	23.6	23.57
	2	24.33	23.38	23.53	23.36	23.77	24.12	23.73	23.77	23.7	23.67
	3	24.38	23.46	23.6	23.43	23.86	24.19	23.78	23.86	23.77	23.76
	4	24.32	23.48	23.58	23.39	23.84	24.18	23.76	23.82	23.75	23.75
	5	24.29	23.4	23.56	23.41	23.82	24.16	23.76	23.83	23.74	23.74
	6	24.31	23.41	23.55	23.35	23.78	24.18	23.75	23.86	23.73	23.72
	7	24.27	23.42	23.52	23.37	23.78	24.15	23.75	23.82	23.72	23.72
	8	24.23	23.37	23.51	23.36	23.73	24.14	23.74	23.8	23.7	23.69
	9	24.24	23.38	23.53	23.33	23.72	24.15	23.72	23.8	23.67	23.67
	10	24.17	23.36	23.47	23.34	23.7	24.14	23.72	23.79	23.65	23.65
3 sigma		**0.21**	**0.16**	**0.18**	**0.15**	**0.18**	**0.16**	**0.11**	**0.17**	**0.15**	**0.17**
Precision		**0.17**									



Wafer: imec metal1 pattern 10nm AEI

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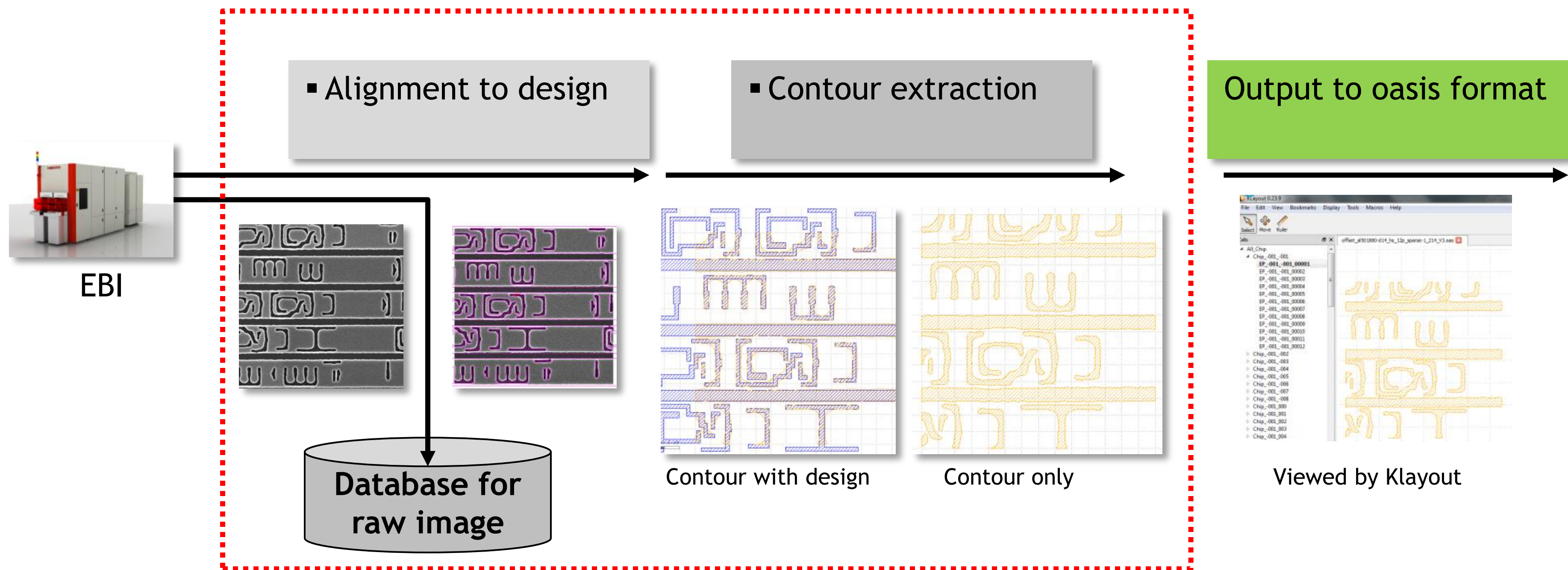
Contour Extraction for 2D Pattern Analysis



45 deg Scan to Collect X & Y CD in One Shot

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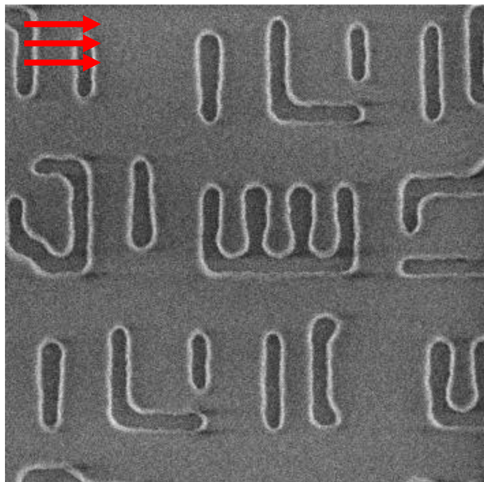
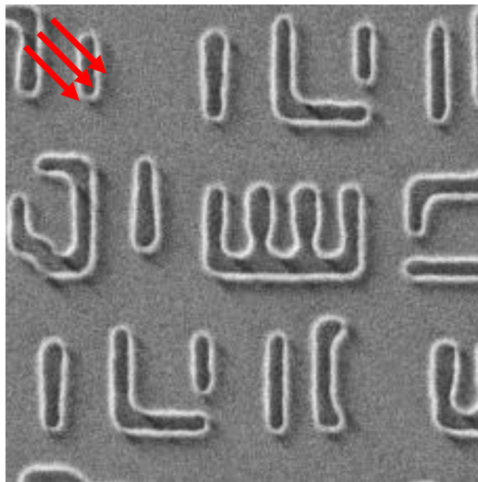
- Unique 45 deg raster scan avoid double image collection

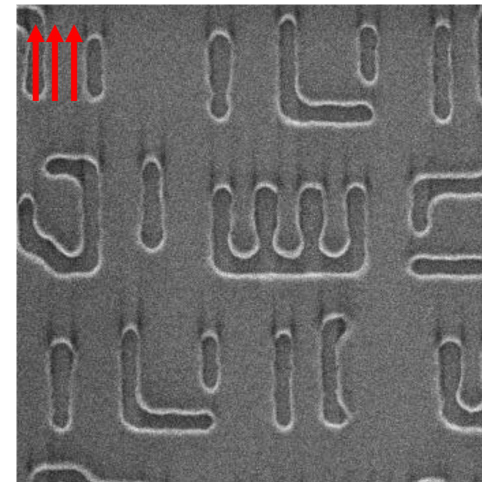
Raster Scan: 0 deg



Raster Scan: 45 deg



Raster Scan: 90 deg



Wafer: imec metal1 pattern 10nm ADI

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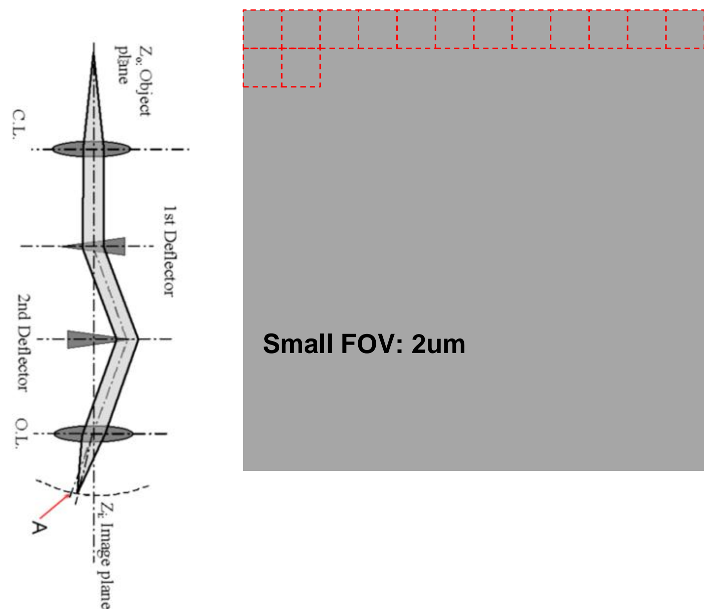
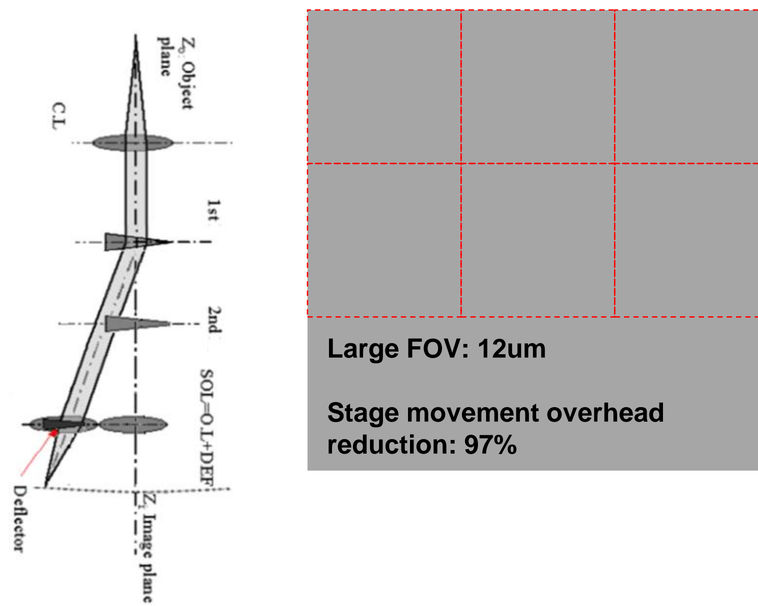
Large Field of View (LFOV) Boost Throughput

- Large field of view provide higher throughput, which is important for area scan

Traditional SEM



HMI's SORIL



LFOV Uniform

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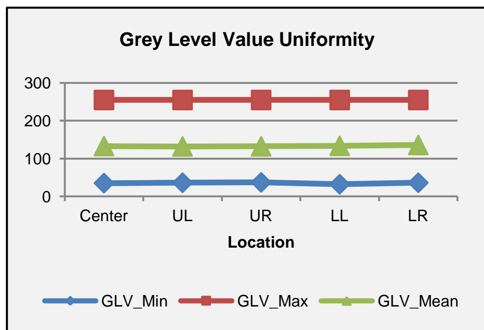
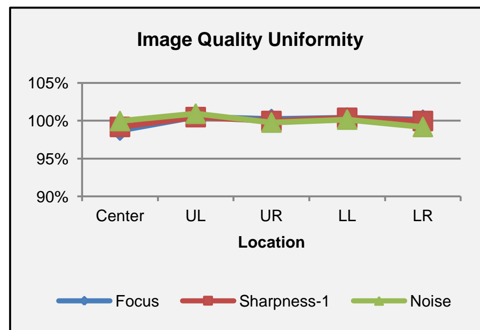
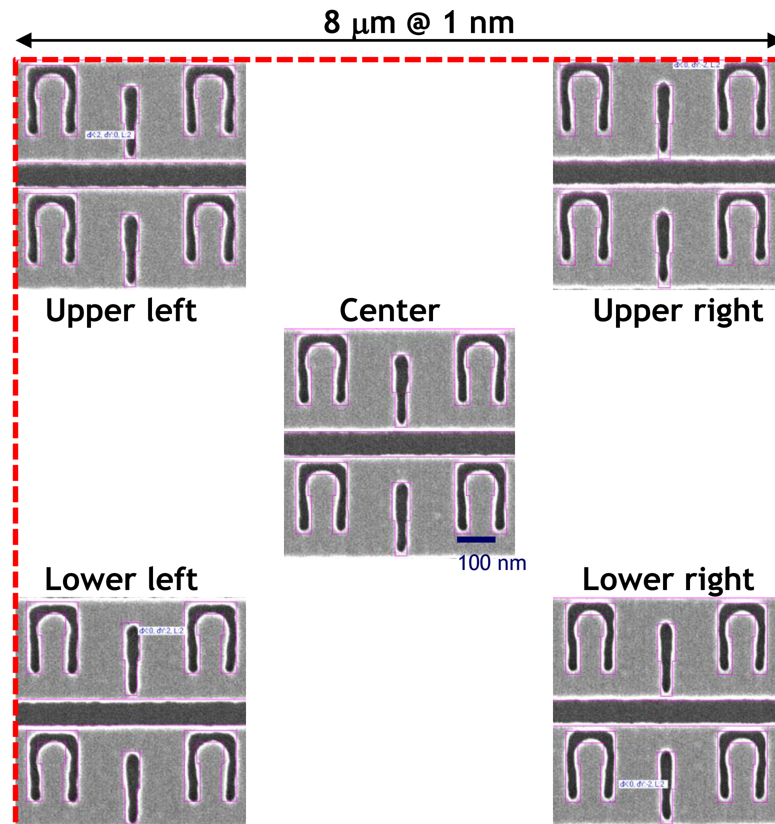
- **Highly uniform LFOV to provide trustable metrology data**
  - Scan linearity
  - GLV uniformity
  - Image quality uniformity







Wafer: imec metal1 pattern 10nm AEI

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SkyScan™ Image Acquisition

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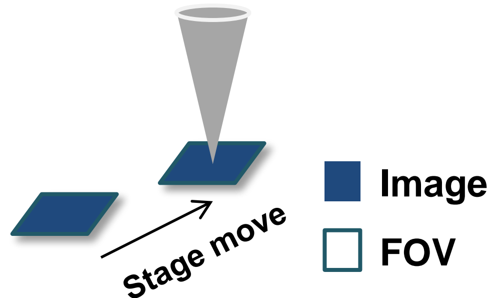
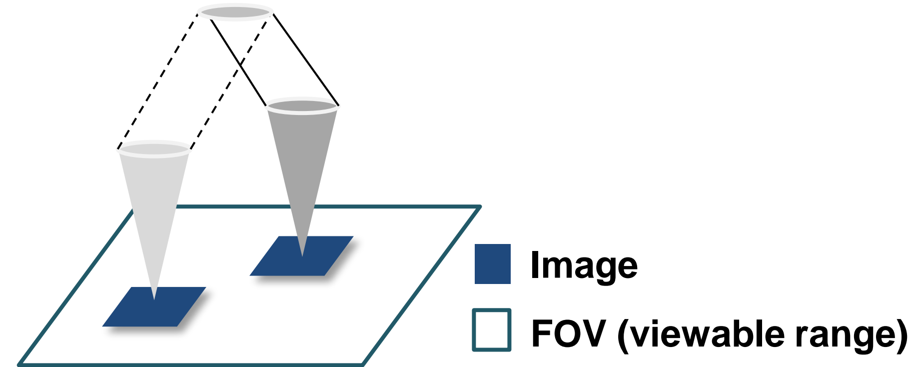
- Throughput optimization for high density image acquisition

Traditional acquisition



- Stage moves for every image
- Image size = FOV
- Throughput = n x (t_{stage} + t_{image})

SkyScan™ acquisition



- Multi-image capture per stage move
- Image and FOV sizes are independent
- Throughput = t_{stage} + n x t_{image}

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Case Study-1: Across Wafer CD Fingerprint (>5k Data)

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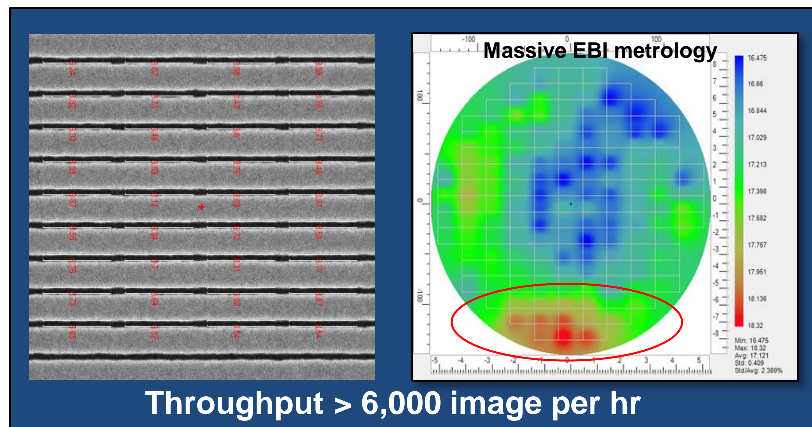
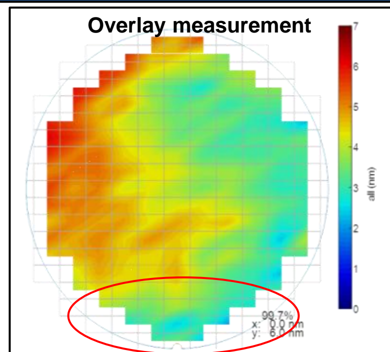
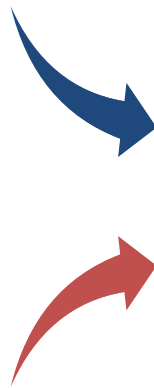
- **Massive EBI metrology data uncover hidden root cause of defect failure map**
  - CD uniformity caused by process chamber

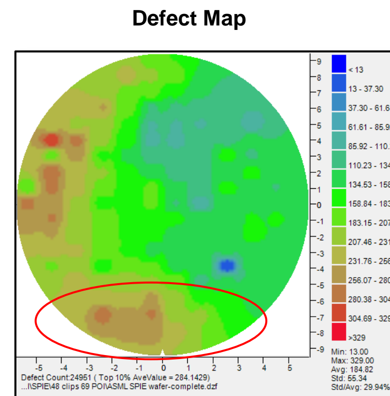


Throughput > 6,000 image per hr

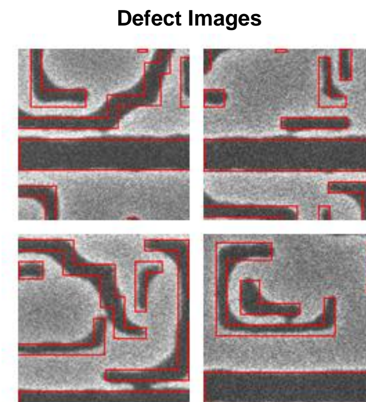




Defect Map



Defect Images



Fei Wang and etc., Process window and defect monitoring using high-throughput e-beam inspection guided by computational hot spot detection, SPIE Advanced Litho 2016, Proc. SPIE 9778

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Case Study-2: Intra-field CD Fingerprint (>17k Data)

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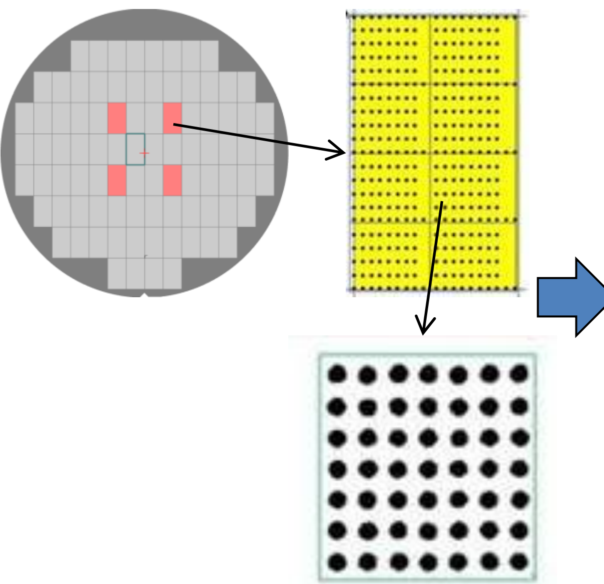
- Dense intra-field CD measurement to collect shot base CD uniformity, for
  - Mask qualification
  - High order correction



Frequency

1600
1280
960
640
320
0

-3σ = 37.47
-2σ = 38.42
-1σ = 39.37
μ = 40.32
1σ = 41.27
2σ = 42.23
3σ = 43.18

36 36.7 37.4 38.2 38.9 39.6 40.3 41 41.8 42.5 43.2 43.9 44.6

Throughput > 9,000 image per hr

Case Study-3: Outlier Detection (>200k Data)

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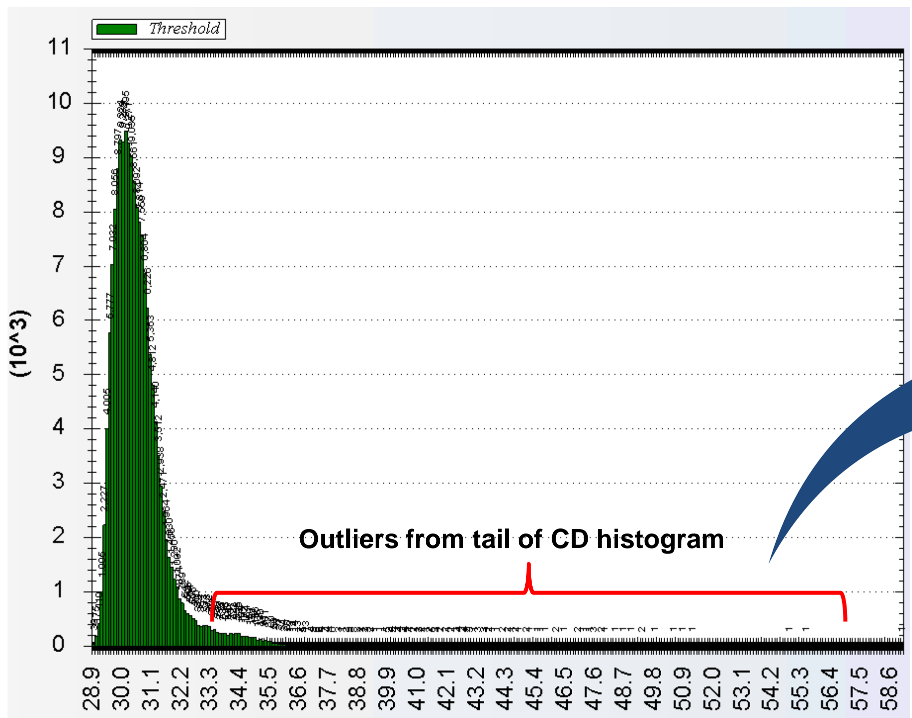
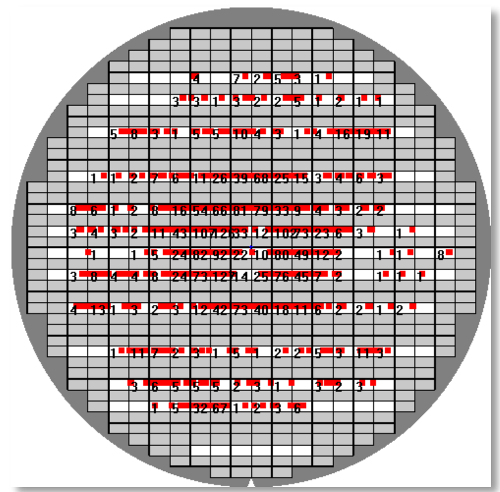
- Measure selected feature through SRAM blocks and detect outliers through CD histogram analysis





Defect map

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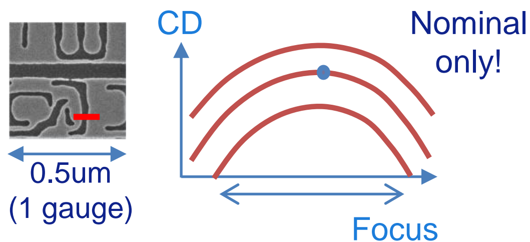
Case Study-4: OPC Model Calibration (>1m Data)

Current OPC data collection



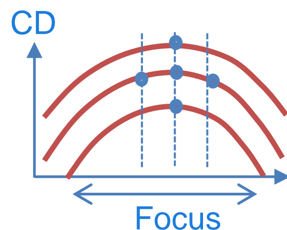
Data plan:

- 20,000 gauges
- Nominal condition only
- 10 samples per gauge
- 200K images total

Cycle time:

- CD-SEM measurement time:
  ~ 14 days (600/hr)
- EBI measurement time:
  ~ 1.2 days (7k/hr)

More Metrology data is needed



Data plan:

- 2,000,000 gauges
- 5 FEM conditions
- 10 samples per gauge
- **1,000K** images total

Cycle time:

- CD-SEM measurement time:
  ~ 70 days (600/hr)
- EBI measurement time:
  ~ 6 days (7k/hr)

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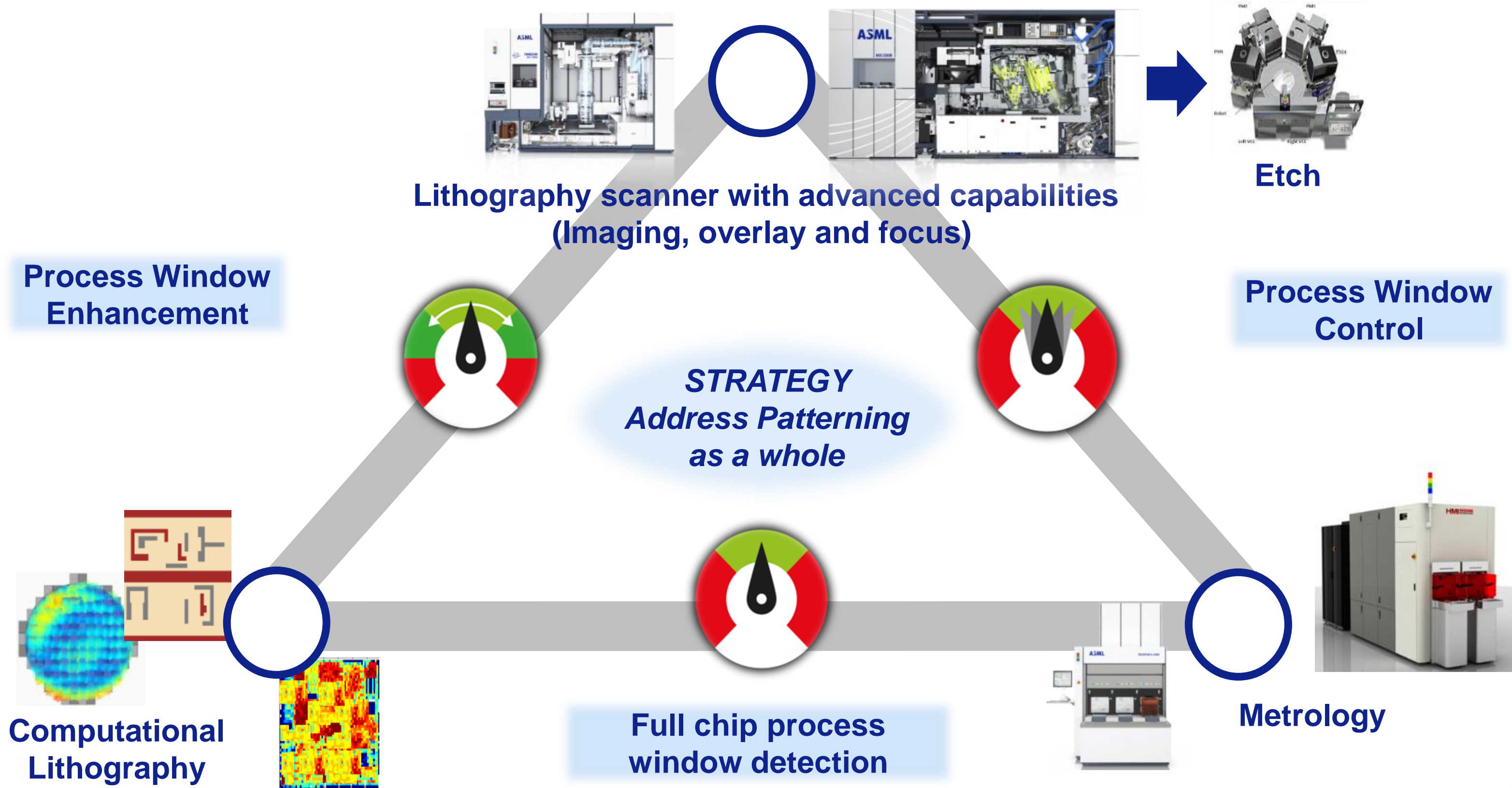
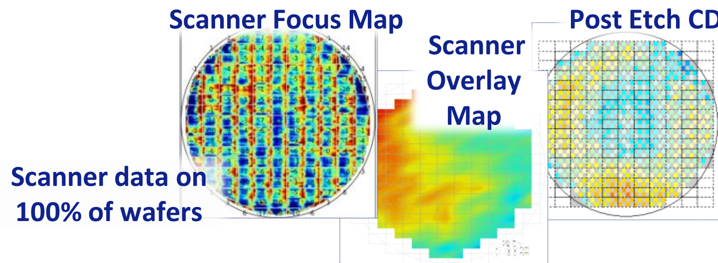
ASML Holistic Lithography approach seeks to maximize patterning process performance and control



Pattern Fidelity Monitoring: Defect prediction and verification

Holistic lithography enables systematic patterning defect prediction with 100% wafer coverage

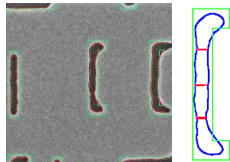


Combine limiting patterns with metrology maps (Focus, CD, Overlay)

Setup

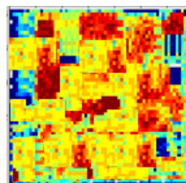
Process limiting pattern detection & characterization

Tachyon simulation

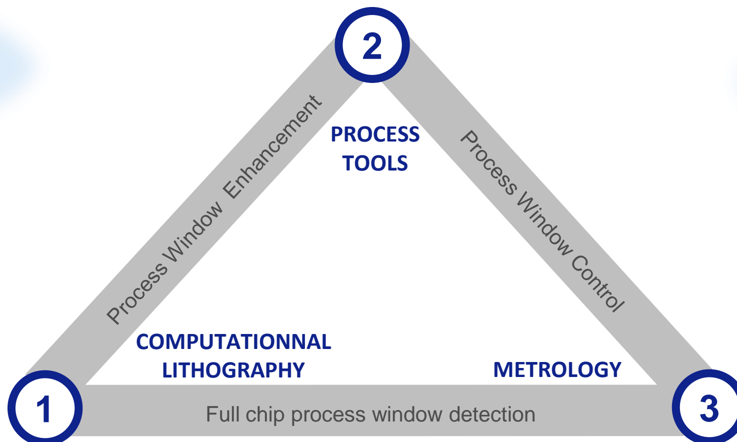


and / or

Customer pattern database



Map of process limiting locations

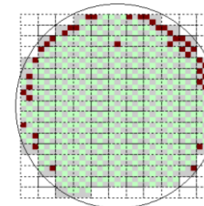


Data source: Imec 10nm metal layer, M. Jochemsen, et al., Proc. SPIE 97781R, 2016

Monitoring & Metrology

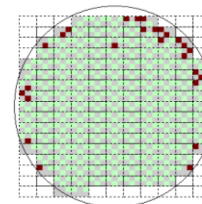
Generate defect wafer maps for 100% wafers

Predicted defects



Verification of defect wafer maps

Verified defects

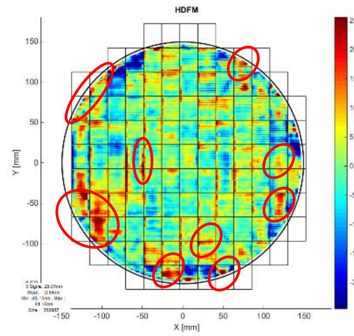


ST life.augmented

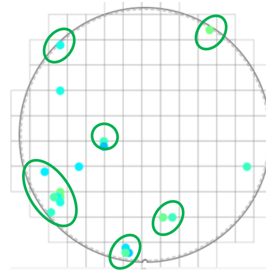
Patterning Fidelity Monitoring verifies the predicted defects on wafer using CD metrology tools

Also established good correlation between dense focus map and measured pattern defects

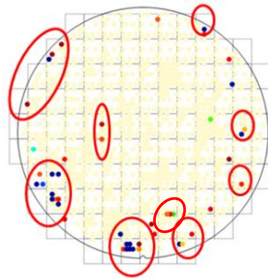
HDFM focus map

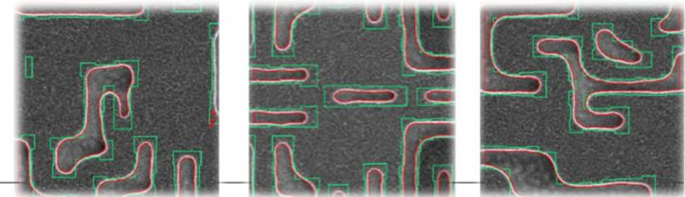


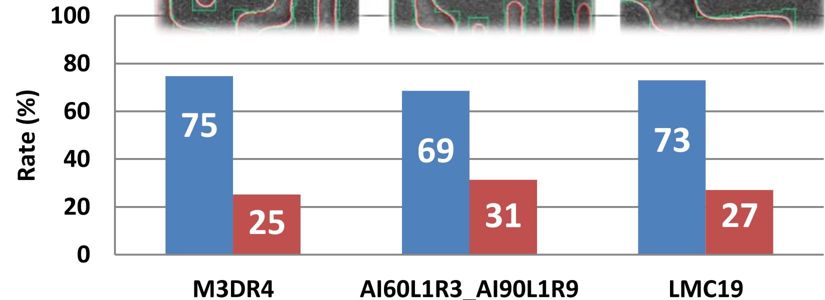
Defect prediction

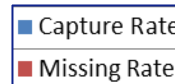


Defect observation









Capture rate: Percentage of successfully (verified) predicted defect locations

AGENDA

- Overview of E-beam Inspection (EBI) System and Application
- Pattern Fidelity Inspection
- High Resolution EBI
- EBI Pattern Fidelity Metrology Case Study
- Summary

Summary

Confidential
Public

- **Edge placement error has become a major limitation factor for device scaling**
- **High accurate and precise CD measurement is needed for Pattern Fidelity Metrology**
- **Advanced EBI has become core toolset to drive pattern fidelity improvement**
  - Sub-2nm resolution
  - Sufficient image quality for contour extraction
  - Supreme throughput from higher beam current, larger FOV, and SkyScan
- **Fast massive e-beam metrology to enable**
  - Process chamber monitoring through across-wafer fingerprint
  - Mask qualification and high order correction through intra-field fingerprint
  - Outlier defect detection through full CD histogram analysis
  - Improved OPC model accuracy and reduced number of mask cycles for OPC calibration
- **Integrated intelligence (model) brings additional value into EBI based Pattern Fidelity Metrology**

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