Simulation-Based Mask Inspection and Review for the 10nm Node and Beyond

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D2S, Inc.

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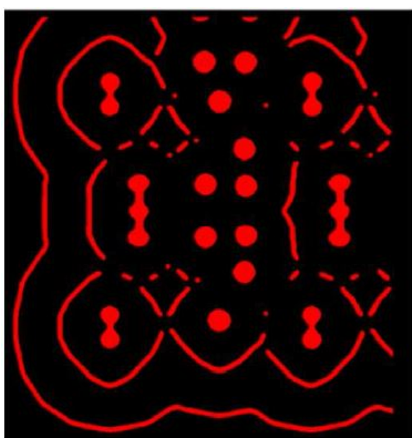
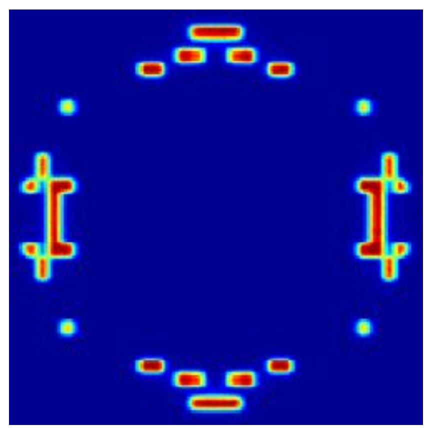
Managing Company Sponsor

193i Needed to be Extended…and Extended

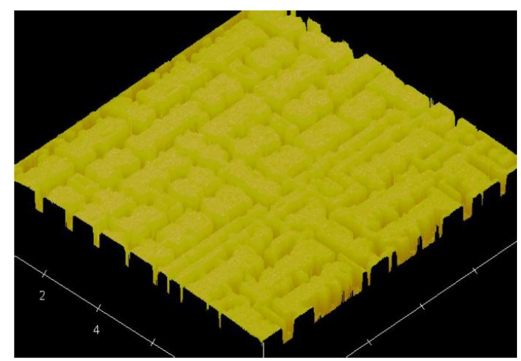
- Inverse Lithography Technology (ILT), Source-Mask Optimization (SMO), and Pixelated Masks invented
- The enabler is mask with small (assist) or/and complex features



Source: SPIE 8680-3

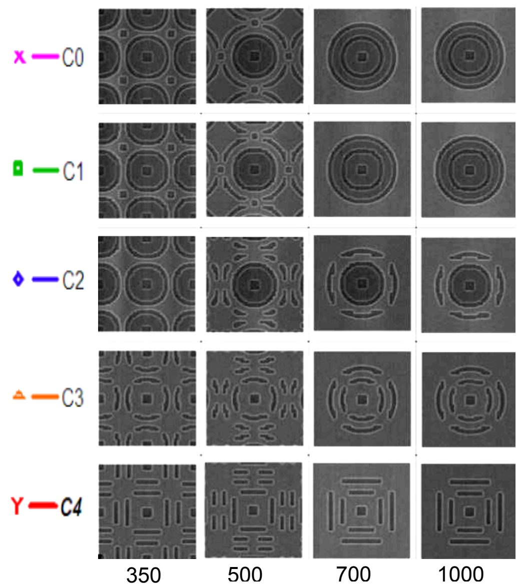


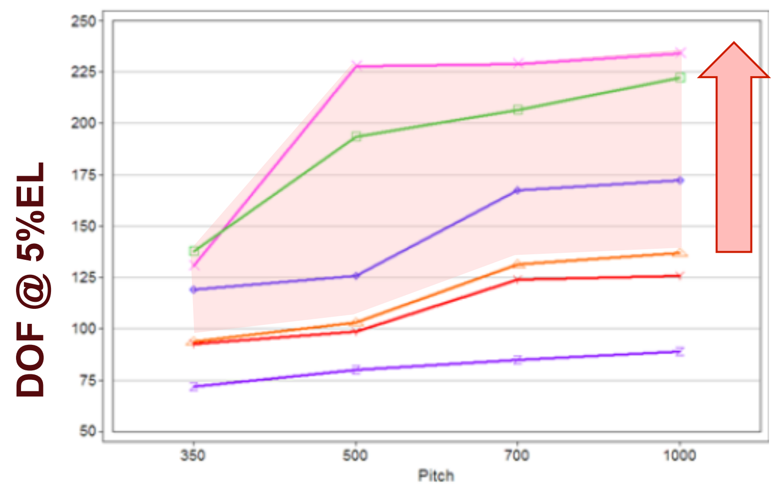
Source: SPIE7640-4



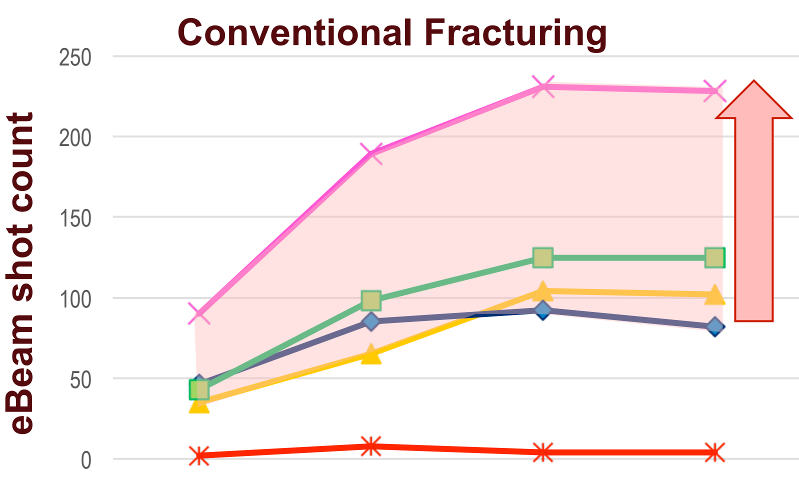
Source: SPIE6924-13

ILT : Biggest Challenge is Mask Writing





Much better DOF possible with unconstrained shapes

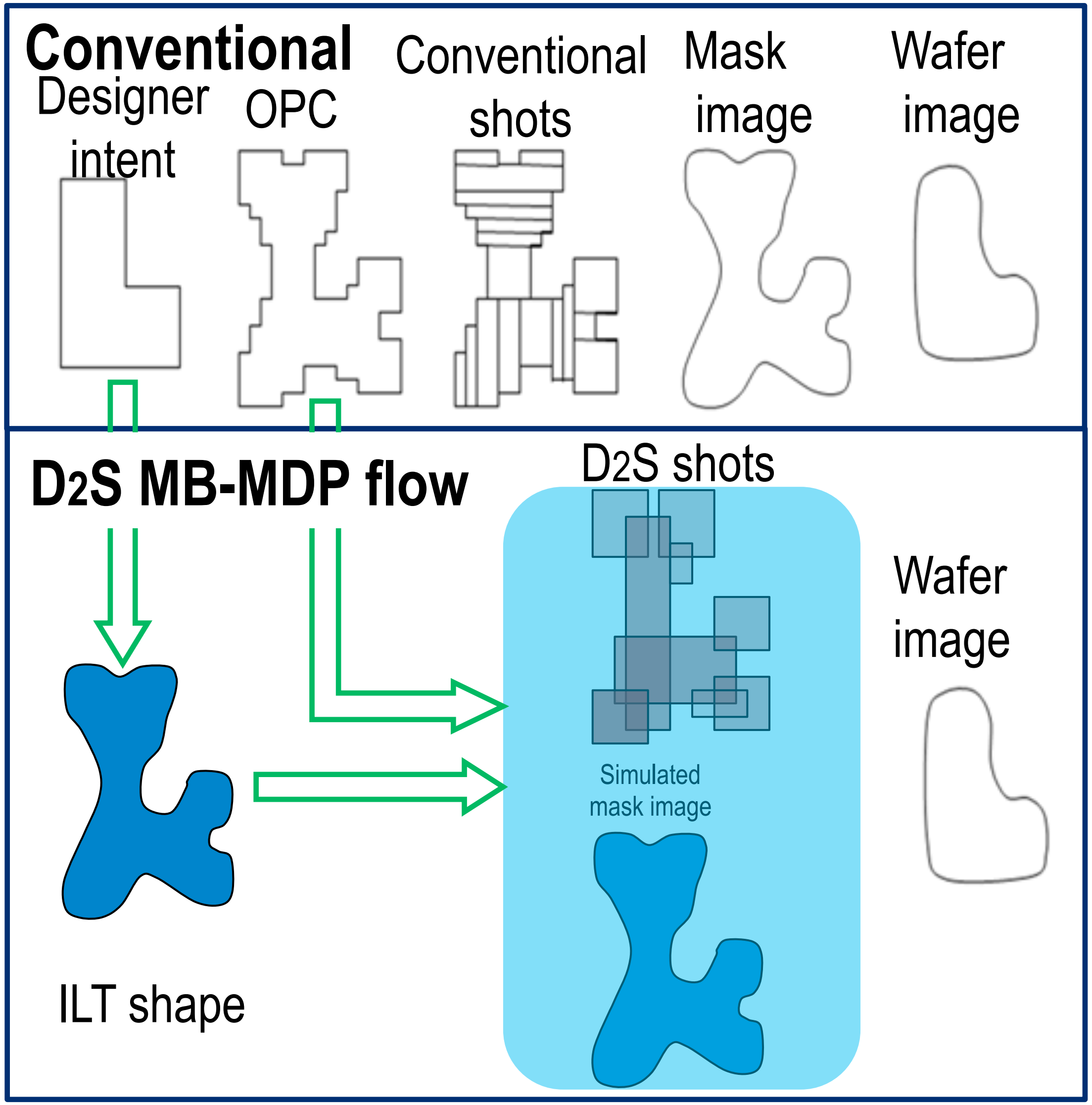


But Mask Write Times Explode

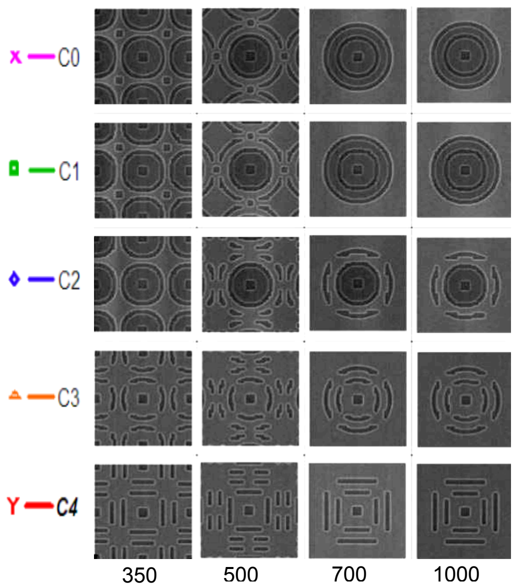
The base study on conventional fracturing is courtesy of Byung-Gook Kim, et al., PMJ 2009

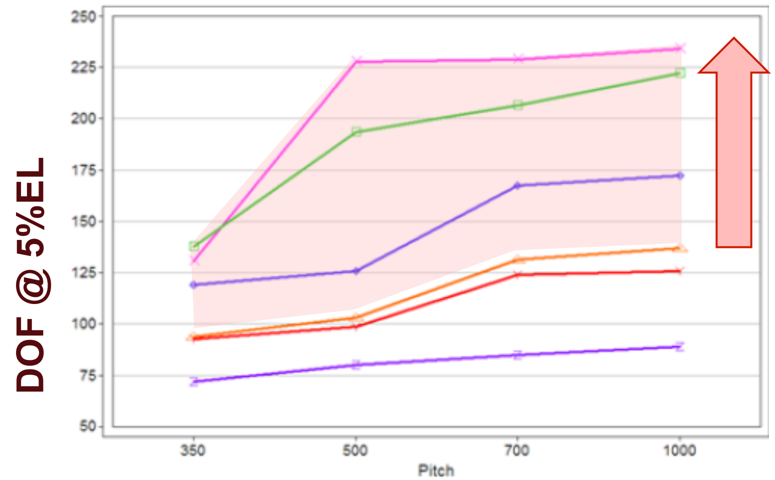
Writing Complex Masks Is Possible:
MB-MDP (Near Term) and MultiBeam (Long Term)

- MB-MDP benefits over conventional MDP:
  - Model-based, better CDU control
  - Utilizes overlapping shots to maximize shot contribution to the final mask shapes
  - Less shot count and better mask fidelity



MB-MDP Enables ILT Today





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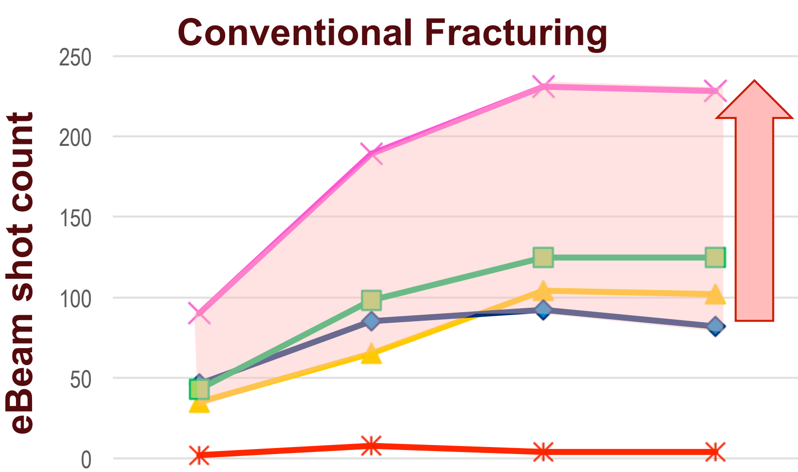
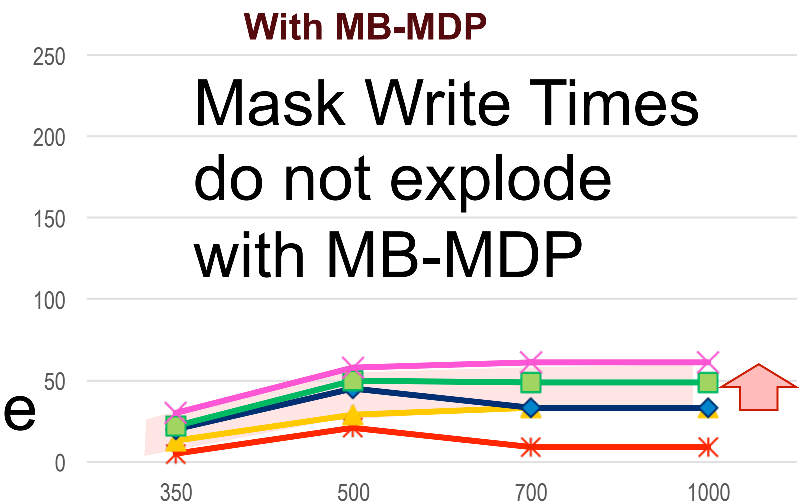
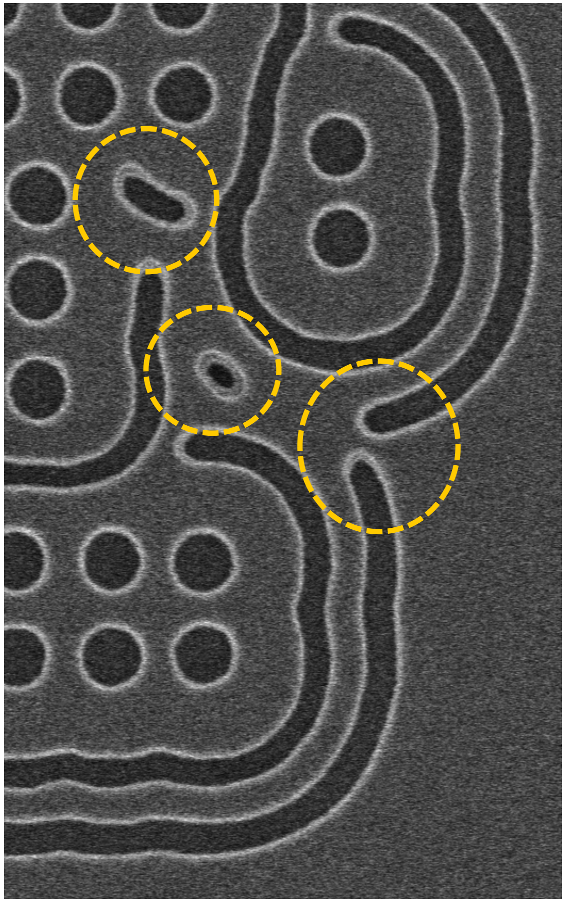


But Mask Write Times Explode

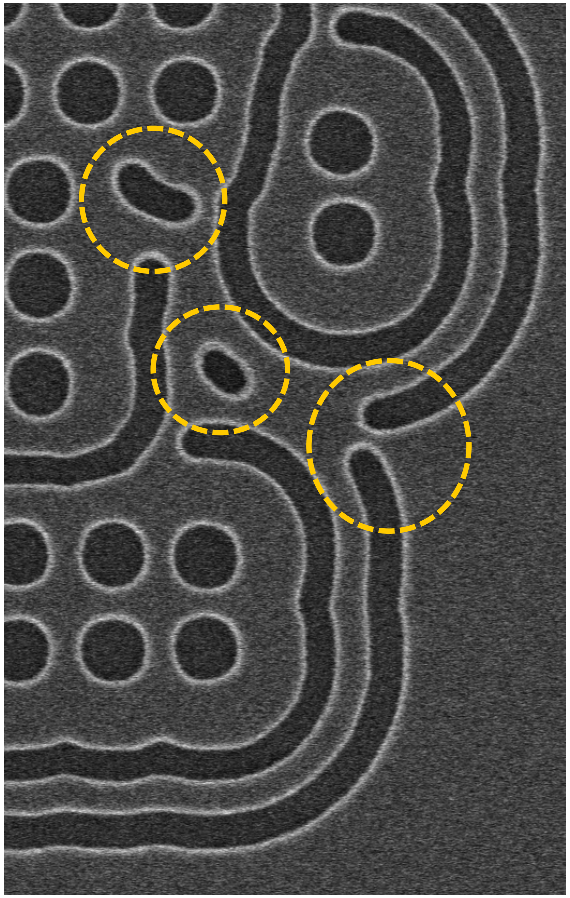


The base study on conventional fracturing is courtesy of Byung-Gook Kim, et al., PMJ 2009

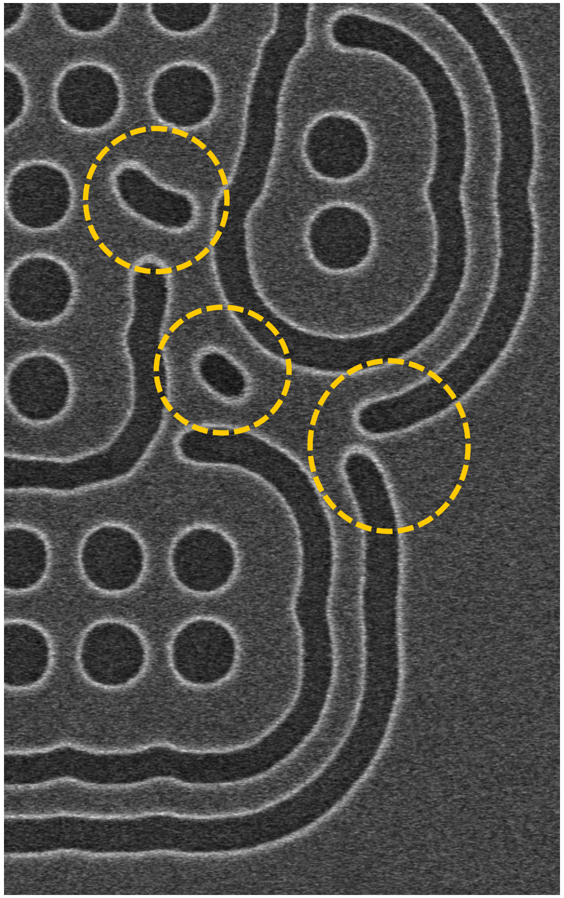
Then the Question is:
How to Inspect & Review Such Complex Masks



Conventional MDP



Shot Number driven MB-MDP



CDU driven MB-MDP

B.G. Kim, et al., "Improving CD Uniformity using MB-MDP for 14nm and beyond", BACUS, 2012

Mask Qualification Challenges

Requires

Challenge		Requires
Mask features getting smaller	→	Higher resolution
Mask features getting unintuitive & complex	→	Wafer printability Free form source
Pattern fidelity and dose margin getting worse	→	Auto, fast, accurate dispositioning

Mask Inspection Tools are Adding Aerial Image Inspection Mode

KT Teron™ 630

Selectable imaging modes to provide the necessary signal-to-noise ratio (SNR) to ensure defect-free 1Xnm generation reticles, whether optical reticles with complex OPC or EUV reticles (Source: KT website)

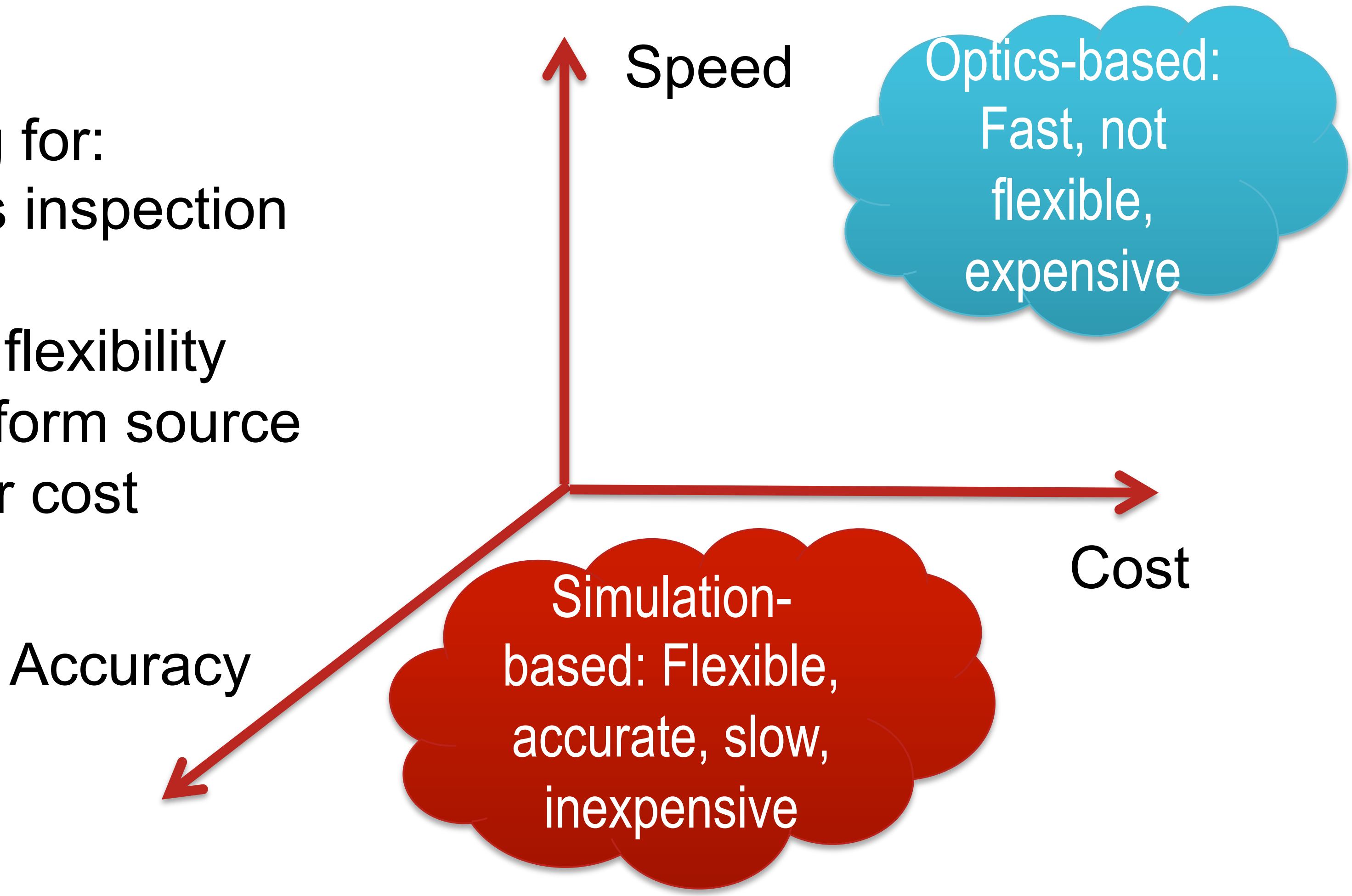
Applied AERA™4

Designed to emulate a scanner, the Aera4 system delivers superior first-time inspection success rate over other high-resolution inspection systems on advanced masks, including those with aggressive OPC, such as inverse lithography. (Source: KT website)

Is Optics-Based Aerial Image Inspection Enough? –Not Really

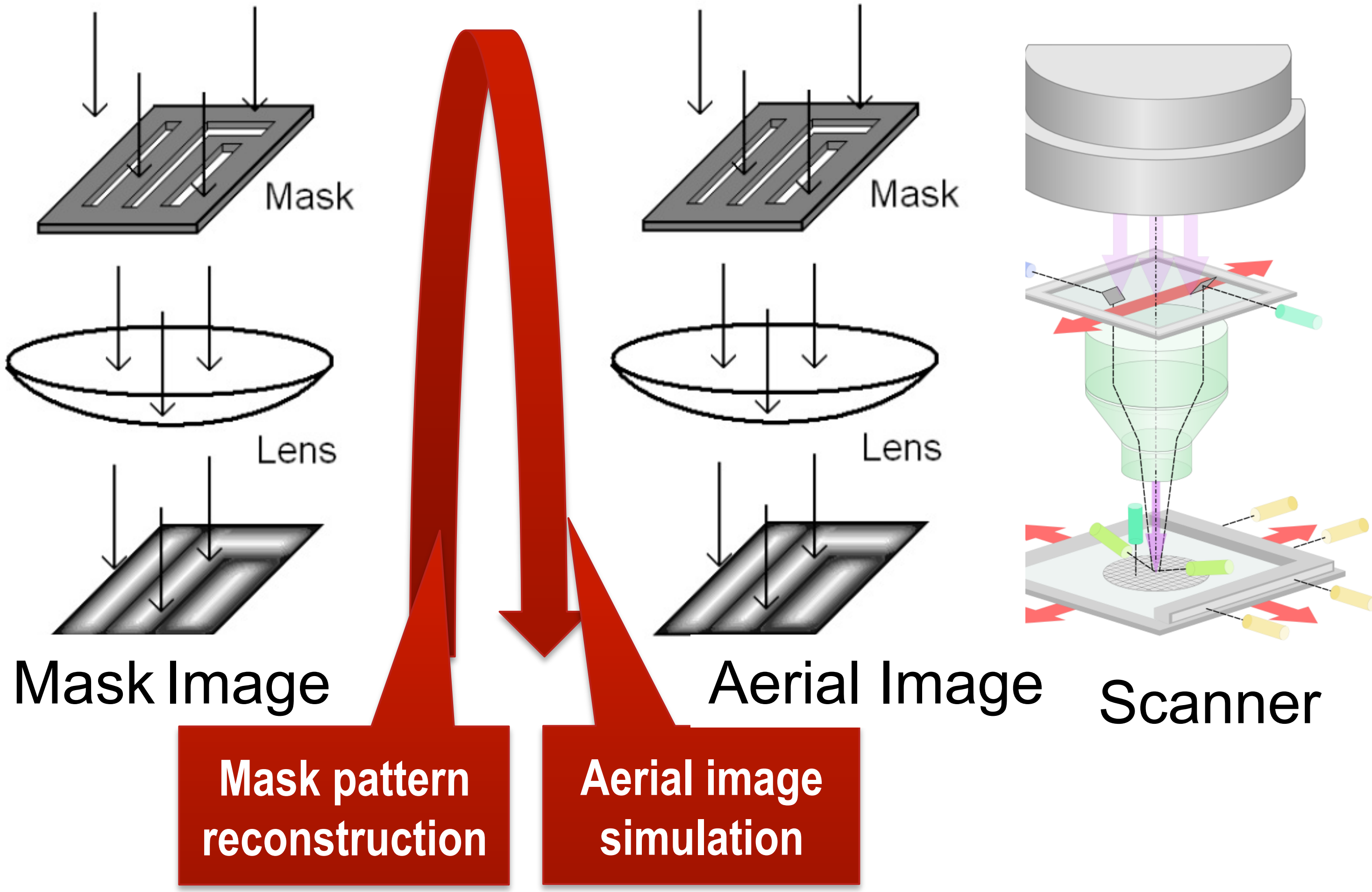
Looking for:

- Cross inspection tools
- More flexibility
- Free form source
- Lower cost



Simulation Can Provide Aerial Image from Mask Inspection Image

Mask inspection system

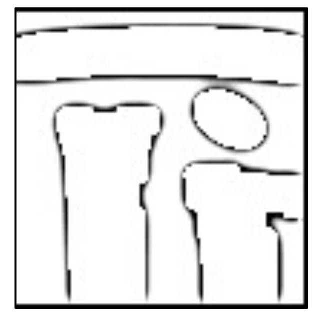


Simulation Can Also Provide Aerial Image from High Resolution SEM Image

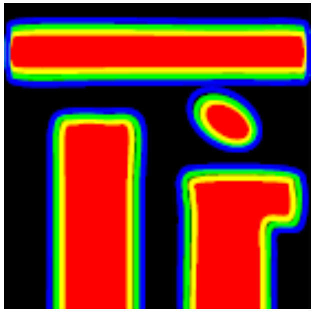
SEM

SEM Image

Contour



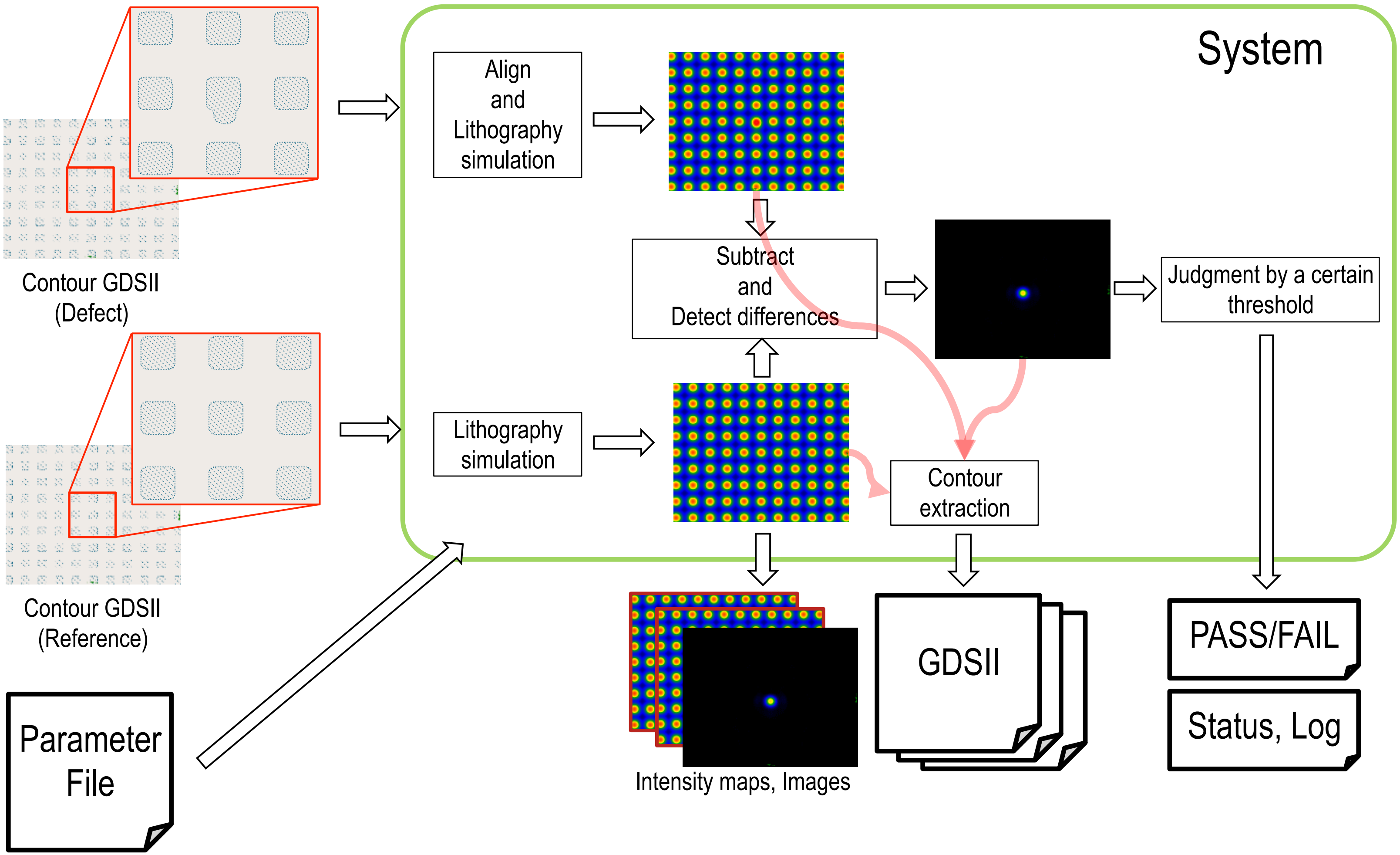
Aerial Image



SEM Contour Extraction

Aerial Image Simulation

Followed by Aerial Image based Defect Review and Dispositioning



Simulation and Aerial-based Defect Review Is Already in Production

Mask Defect Auto Disposition based on Aerial Image in Mask Production

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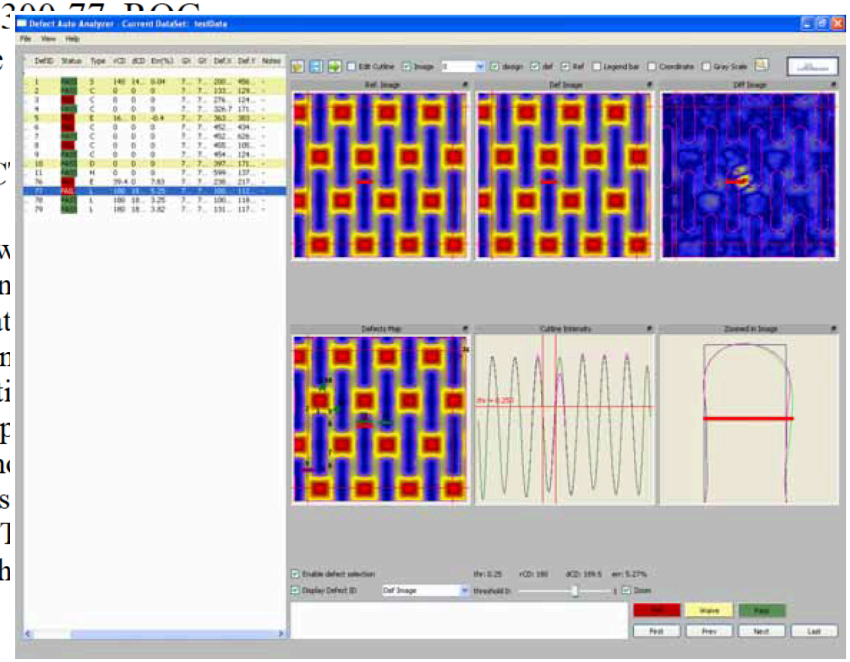
[a]E-Beam Operation Division, Taiwan Semiconductor Manufacturing Company (TSMC), 25 Li-Hsin Rd. Hsinchu, Taiwan 300-77, ROC
[b]Luminescent Technologies, Inc., 2471 East Bayshore

ABSTRAC

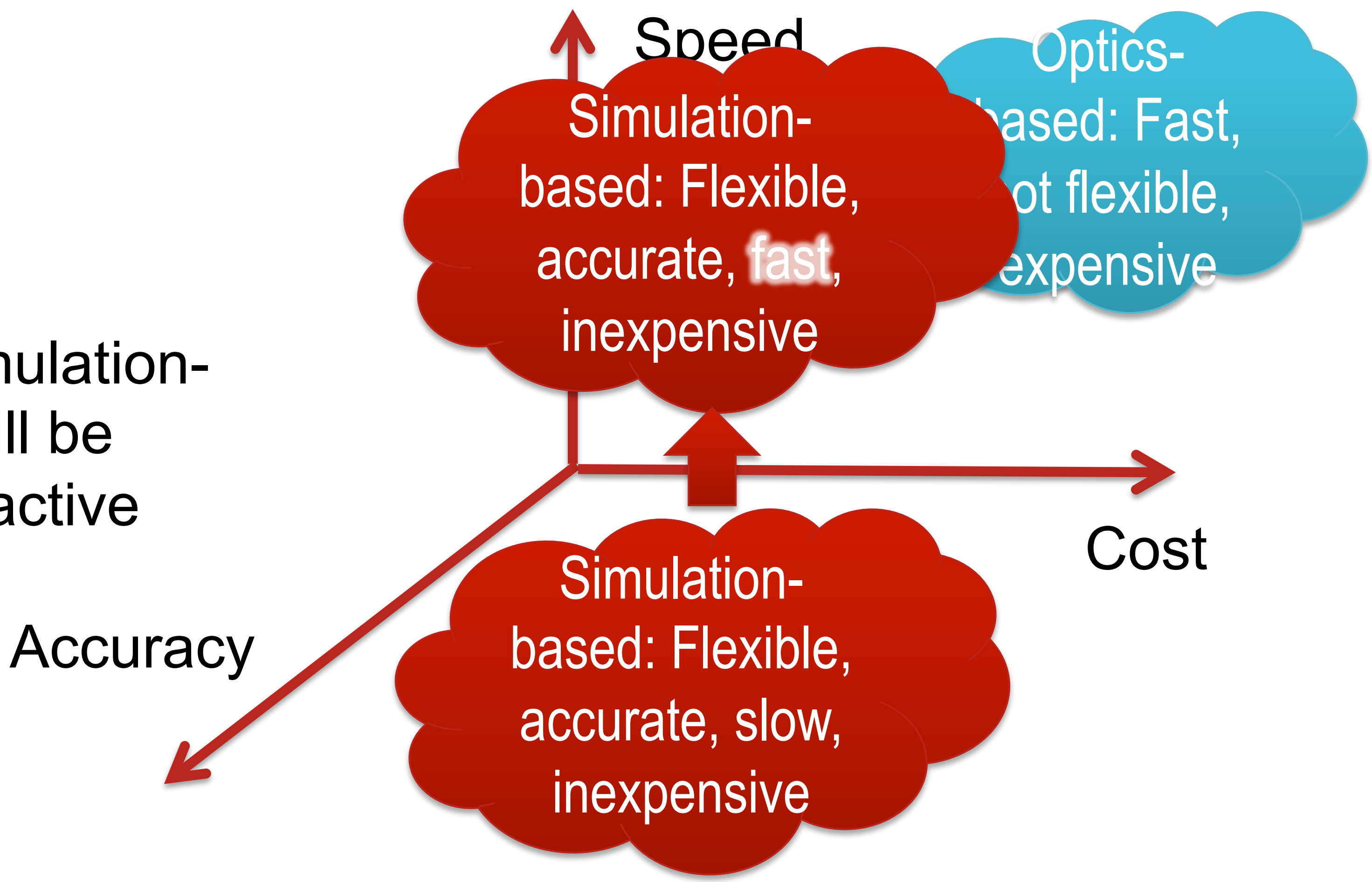
At the most advanced technology nodes, such as 45nm and below (SRAFs) are required. However, their use results in significan disposition more challenging than ever. In an attempt to mitigat that rely on hardware emulation and software simulation to obtain however, automatic mask disposition based on aerial image is sti final resist CD or contour, which are commonly used in lithograp automated mask defect disposition system that remedies these sh for mask production, works in both die-to-die and die-to-databas AIMS™ and aerial-image-based inline mask inspection tools. T plane CD variance. The system also connects to a post-OPC lith CD specs, which are then used in the mask defect disposition.



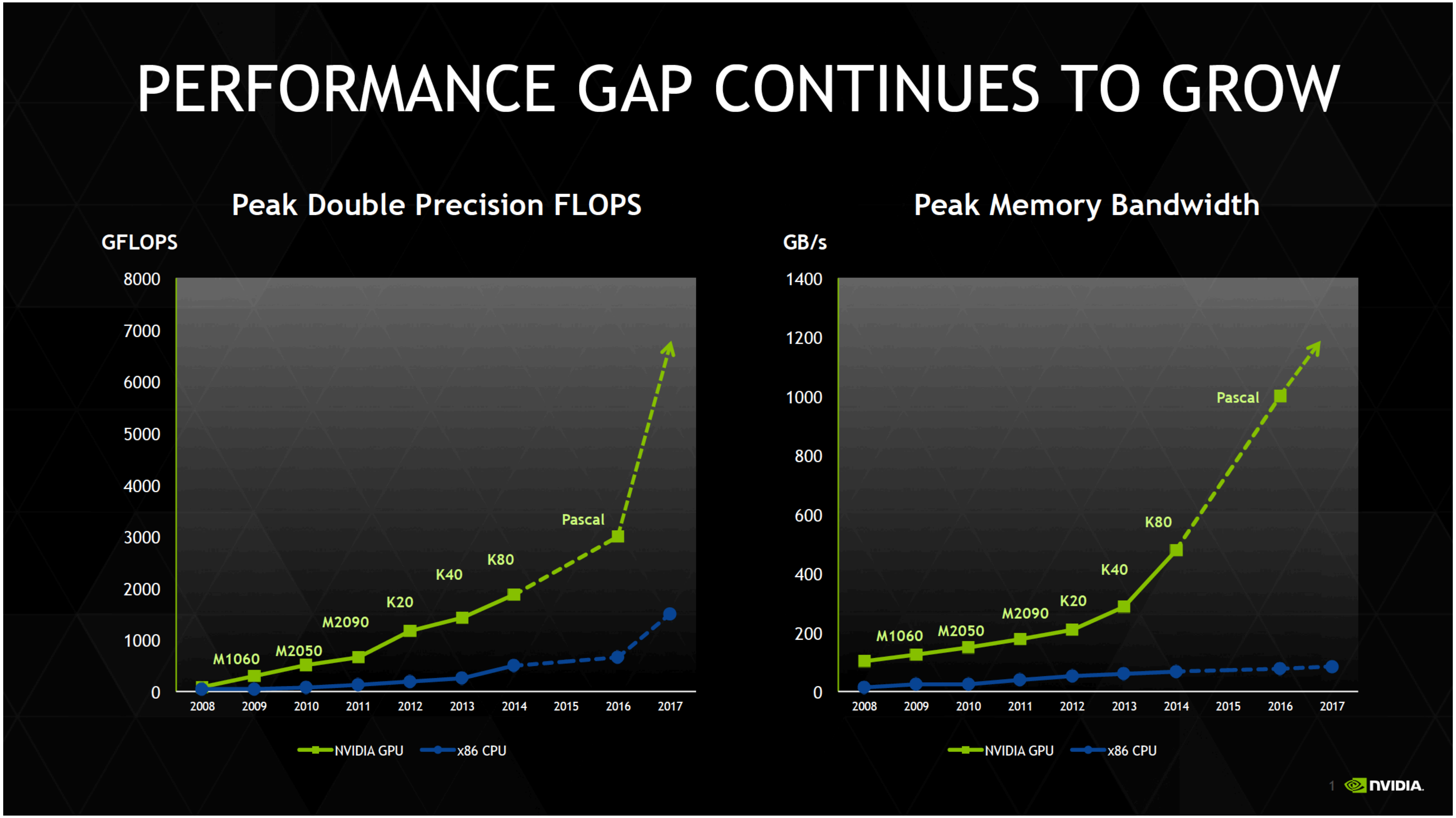
Ref: C. Y. Chen, et al., "Mask defect auto disposition based on aerial image in mask product", Proc. SPIE 7379, Photomask and Next-Generation Lithography Mask Technology XVI, 73791F (May 11, 2009); doi: 10.1117/12.824292; http://dx.doi.org/10.1117/12.824292

Imagine the Simulation is 10X Faster

Then simulation-based will be very attractive



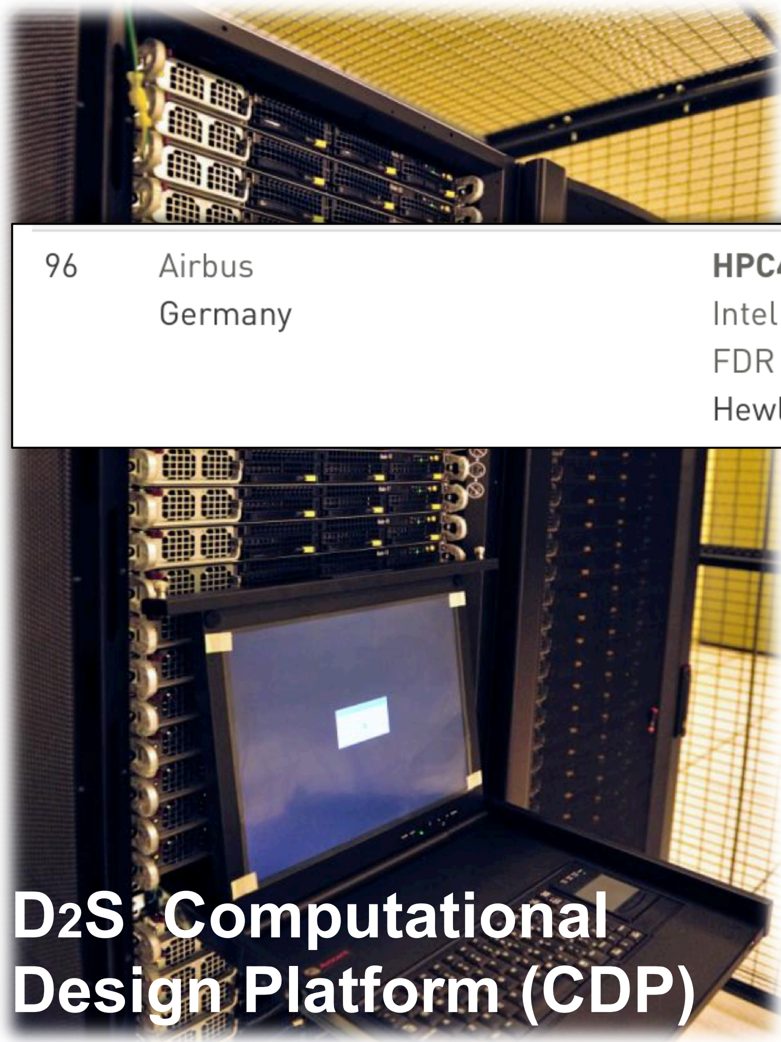
Scientific Computing Is Moving into GPU: Ride the Wave or …



Jen-Hsun Huang, CEO of NVIDIA, GPU Technology Conference, 2015

D2S Has Built 400TFLOPS Computational Design Platform Using GPUs

96	Airbus Germany	**HPC4** - HP POD - Cluster Platform BL460c, Intel Xeon E5-2697v2 12C 2.7GHz, Infiniband FDR Hewlett-Packard	21,120	400.4	456.2



- Could rank in the top 100 Super Computers in the Word (June, 2014)

- In production use
- Simulates the entire mask plane
- All standard parts, with built-in redundancy

Simulation-Based Solutions with GPU

Provides

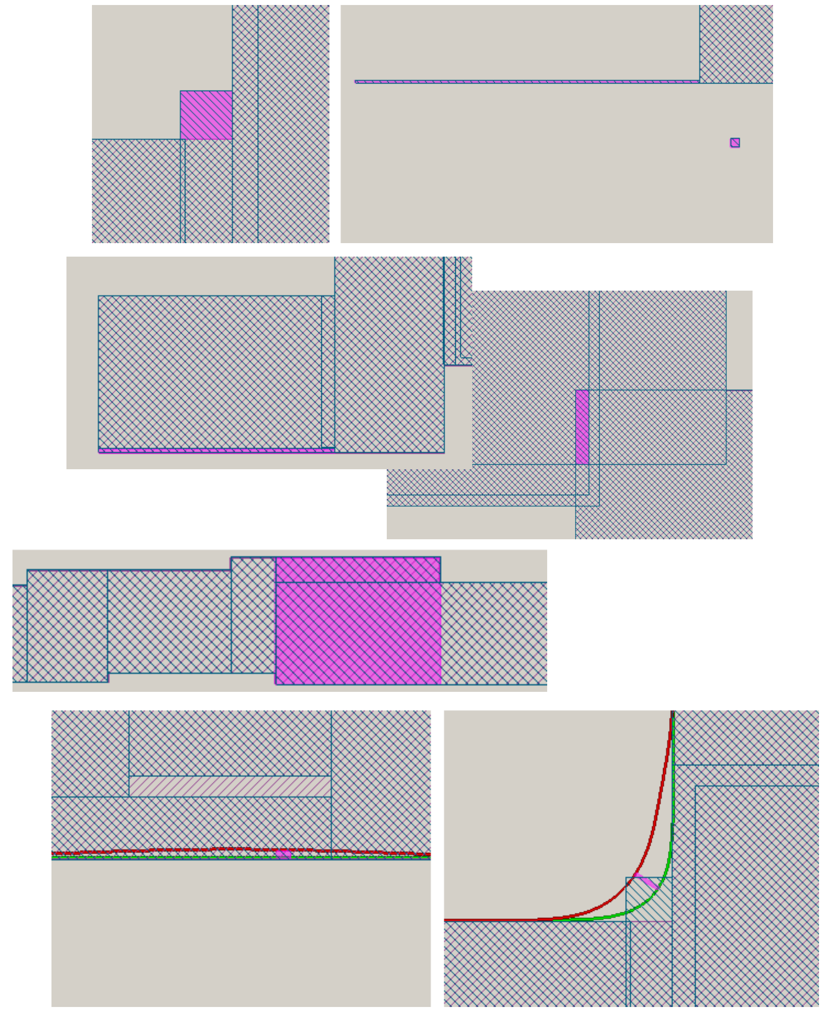
Mask pattern reconstruction	Higher resolution
Litho simulation using reconstructed mask	Wafer printability Free form source
3D mask model	Auto, fast, accurate dispositioning

With GPU, the Simulation-based Mask Review Applications are Endless

With GPU, Mask Hotspots Can Feed to Mask Inspection and Review

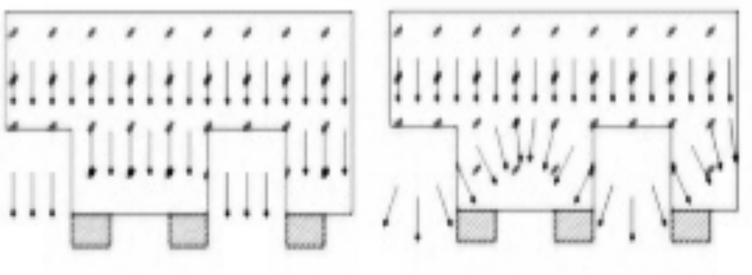
Using Full Chip Model-Based Mask Verification

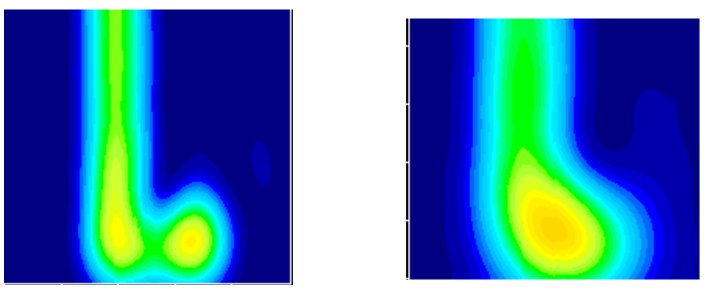
- Hotspots due to Fracture:
  - Sliver
  - Extensive overlap shots
  - CD split
- Mask Hotspots
  - Line-end shorting
  - Necking, bridging
  - EPE error
  - Bad dose margin



With GPU, Rigorous M3D Simulation Becomes Real Time

Mask

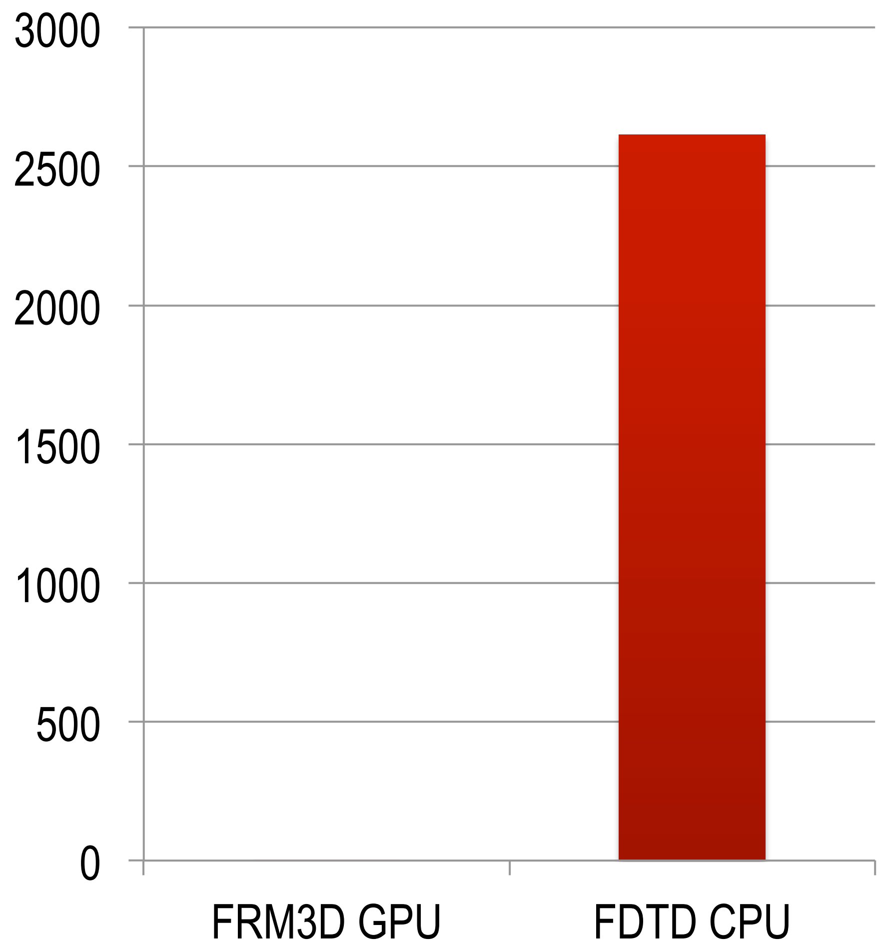




Aerial image

2D 3D

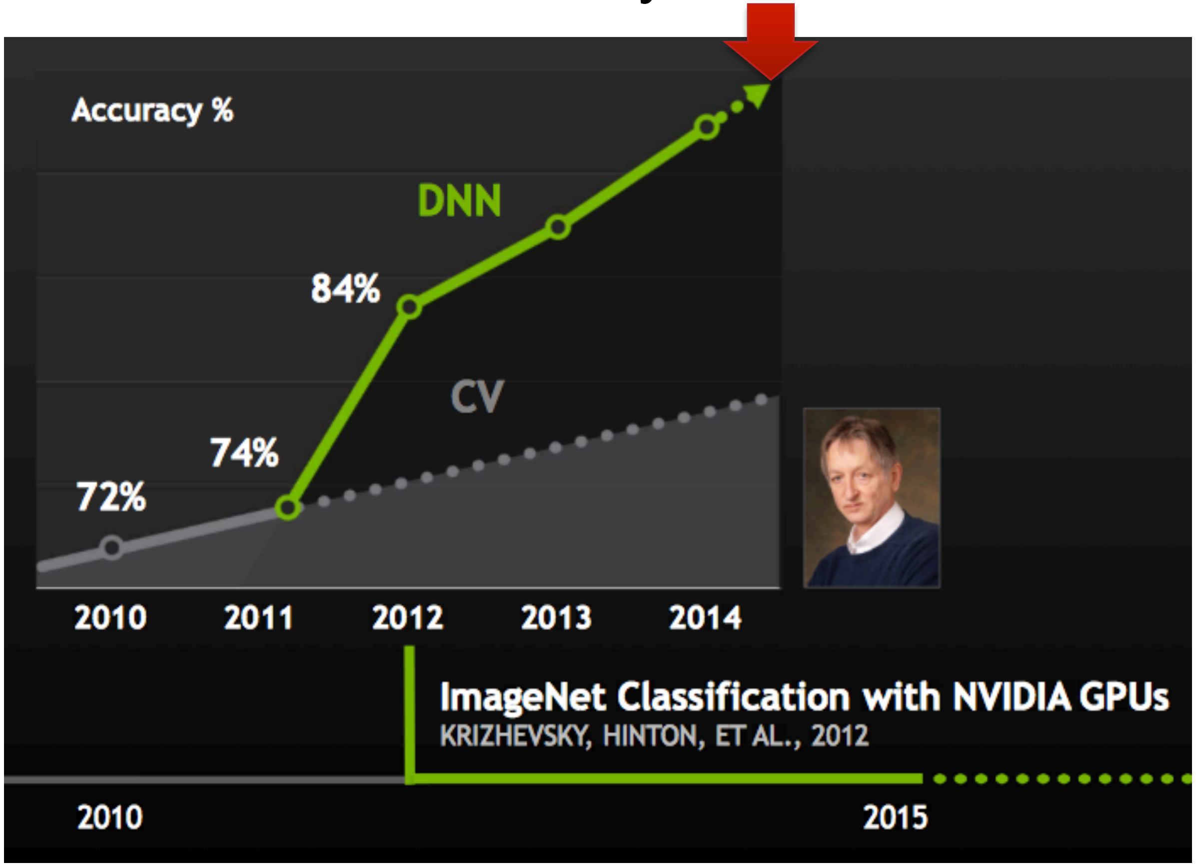
Runtime (seconds)



D2S Mask 3D >1000 times faster

With GPU, Deep Learning Can be Applied to Mask Defect Classification

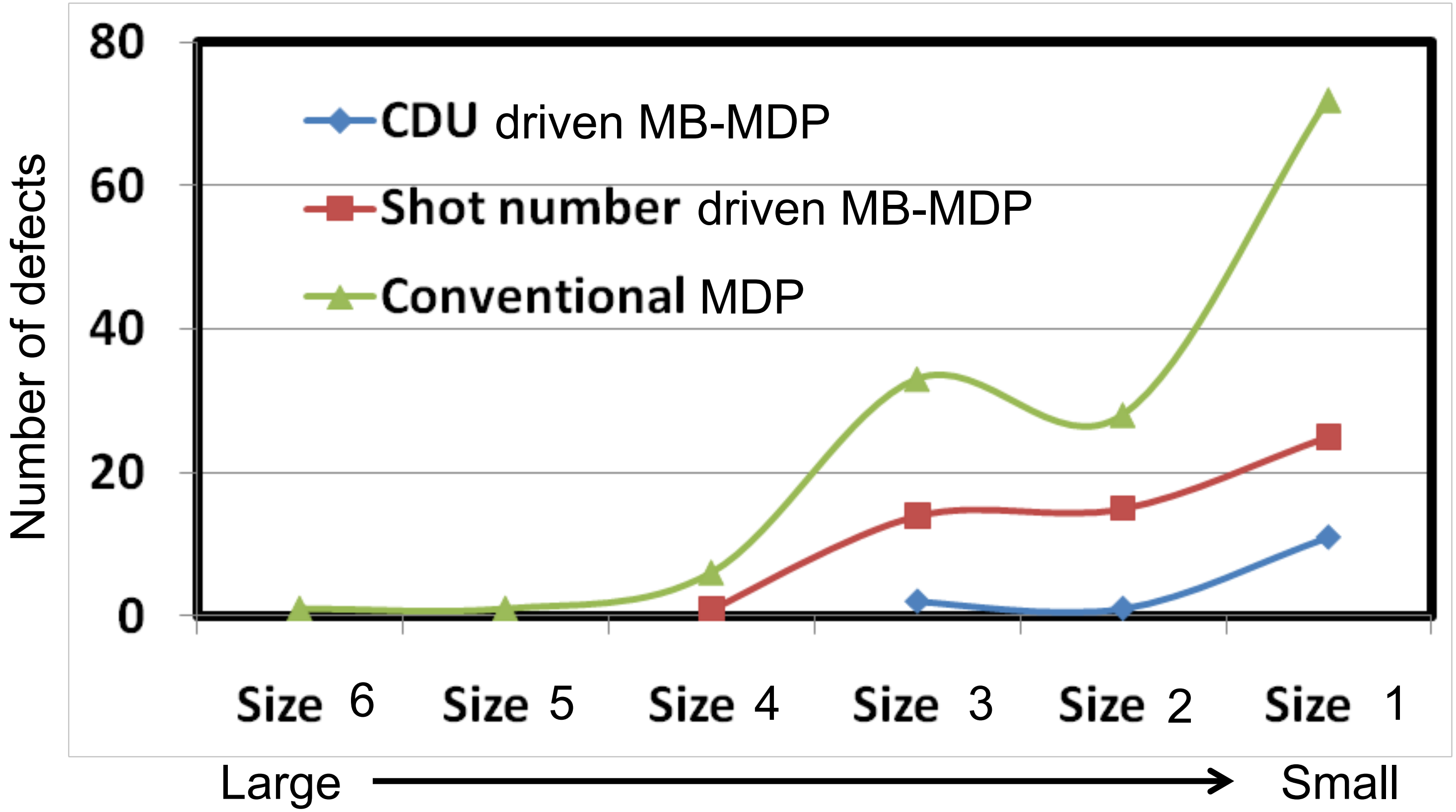
With GPU accelerated deep leaning, the image classification accuracy is better than human now



Jen-Hsun Huang, CEO of NVIDIA, GPU Technology Conference, 2015

Isn't it Better to not Have so Many Mask Defects From the Beginning?

- Both *Shot Number* and *CDU*-driven MB-MDP are clearly more effective in reducing size variations.



B.G. Kim, et al., "Improving CD Uniformity using MB-MDP for 14nm and beyond", BACUS, 2012

Summary: Using GPUs, Complex Mask Shapes Prevail

- Mask makers will be facing complex masks soon
- Simulation-based mask inspection and review helps to solve challenges in mask defect dispositioning
- Scientific computing is moving to GPU
- GPU-accelerated simulation-based mask inspection and review is your best friend
- MB-MDP and Dose Modulation will offload mask inspection and review work