20 YEARS SEMICON® Taiwan 2015

Removing the Last Road Block of Deploying ILT into 10nm Node by Model-based Mask Data Preparation and Overlapped Shots

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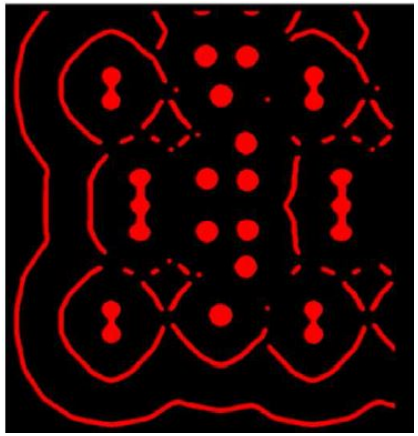
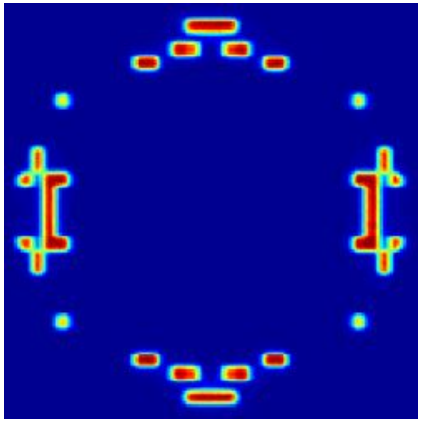
D2S, Inc.

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



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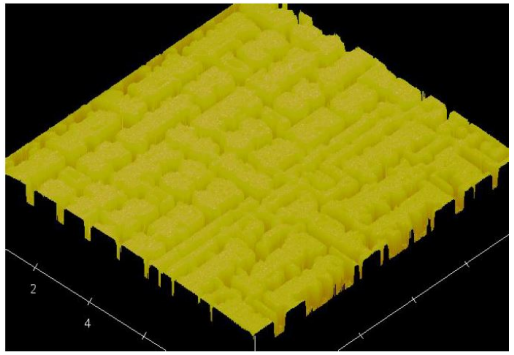
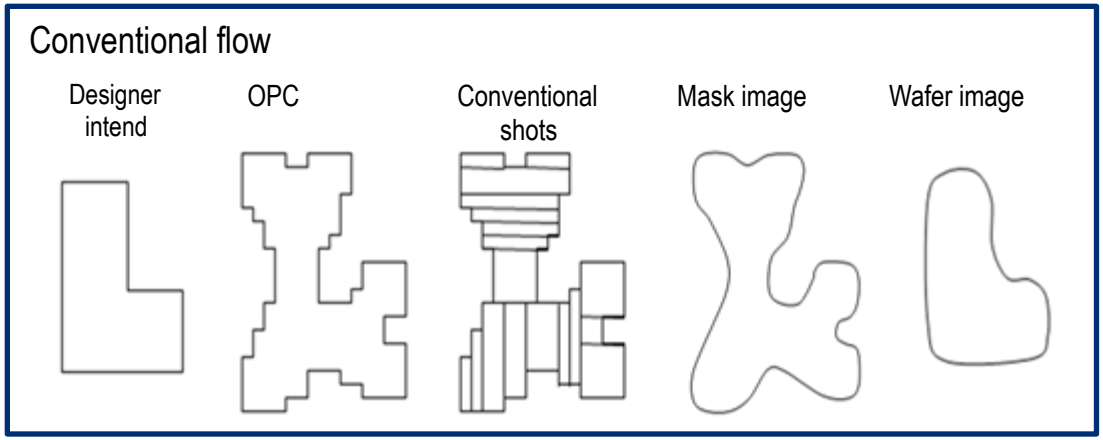


Source: SPIE6924-13

The Last Road Block: How to Write Such Complex Masks?

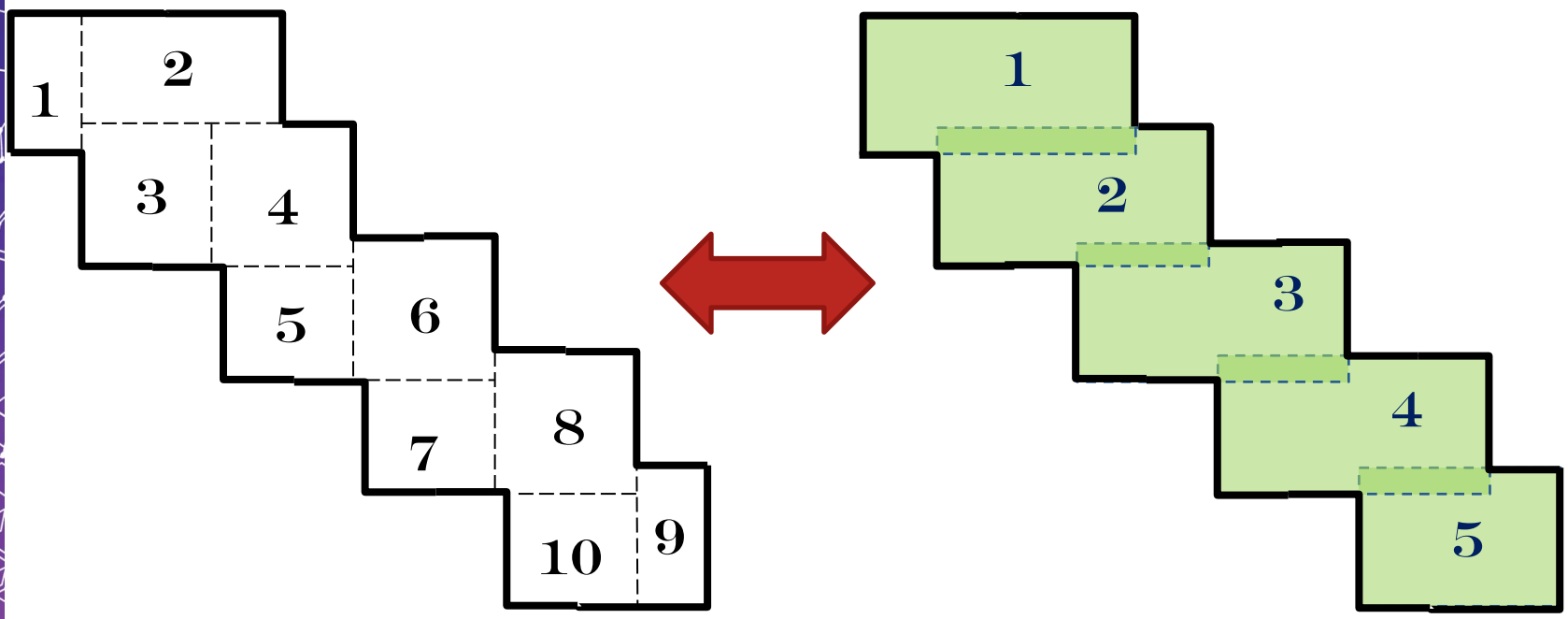
- Shot count
- Pattern fidelity



Overlapped Shots Are the Answer to Reduce Shot Count for Complex Shape

10 conventional shots to write

5 overlapping shots to write
Extra energy in overlapping areas



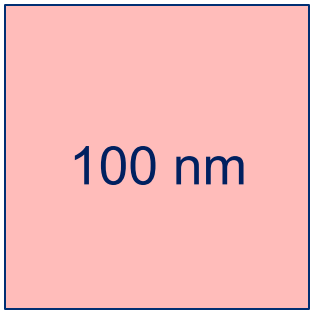
Overlapping shots cast more energy in less mask writing time:
= Better process margin
= Better CDU
= No mask writing time and mask quality compromise

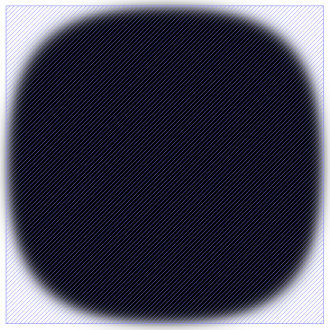
Now eBeam Also Need Proximity Correction just Like OPC at 90/65nm Node

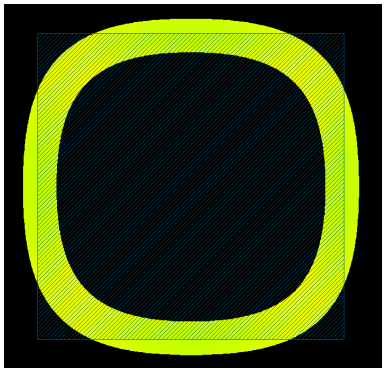
Shot Size

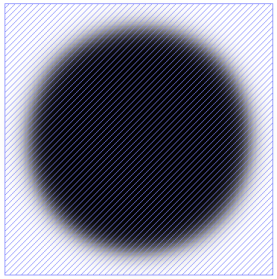
Exposed Resist

Edge Slope





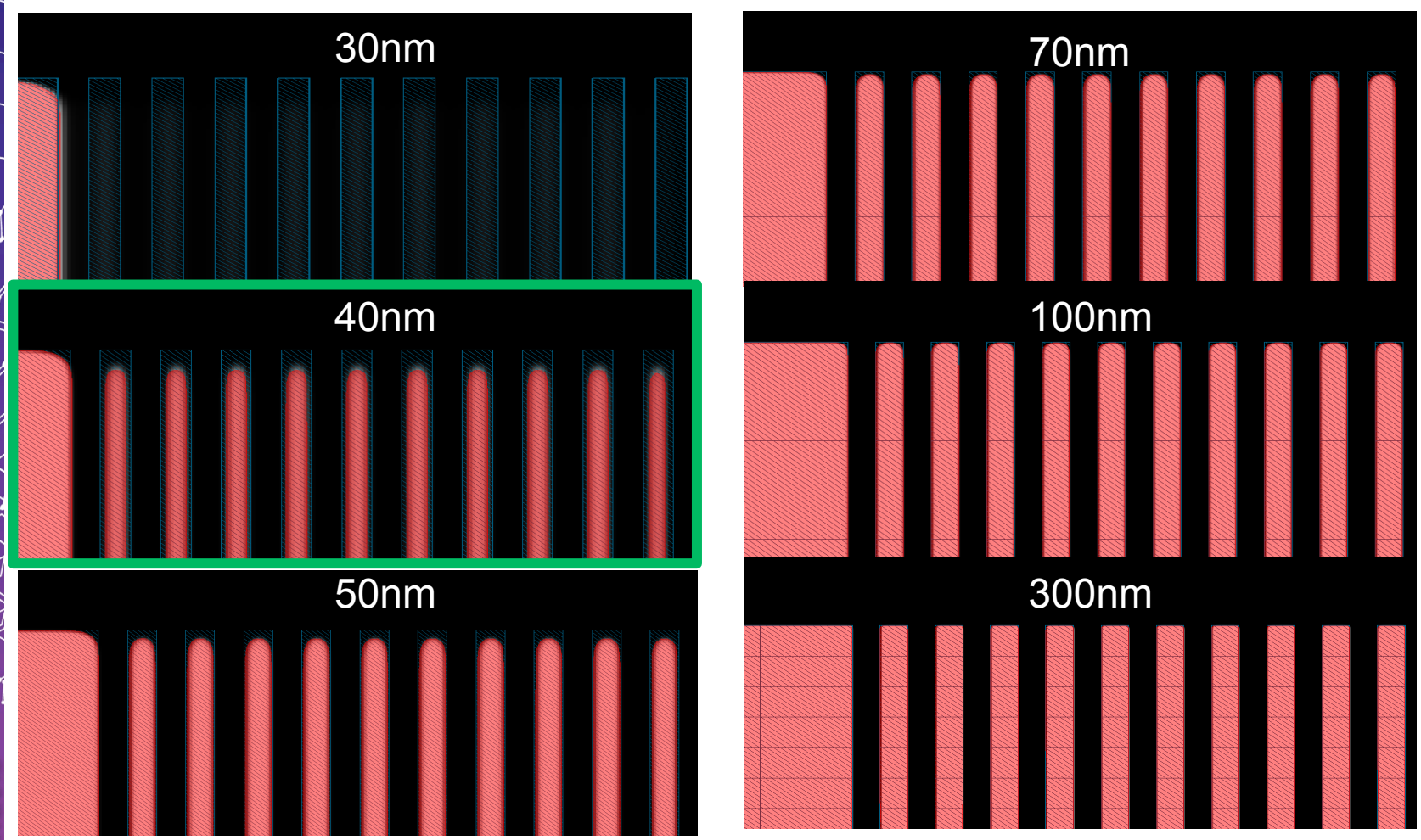




Bad Dose Margin

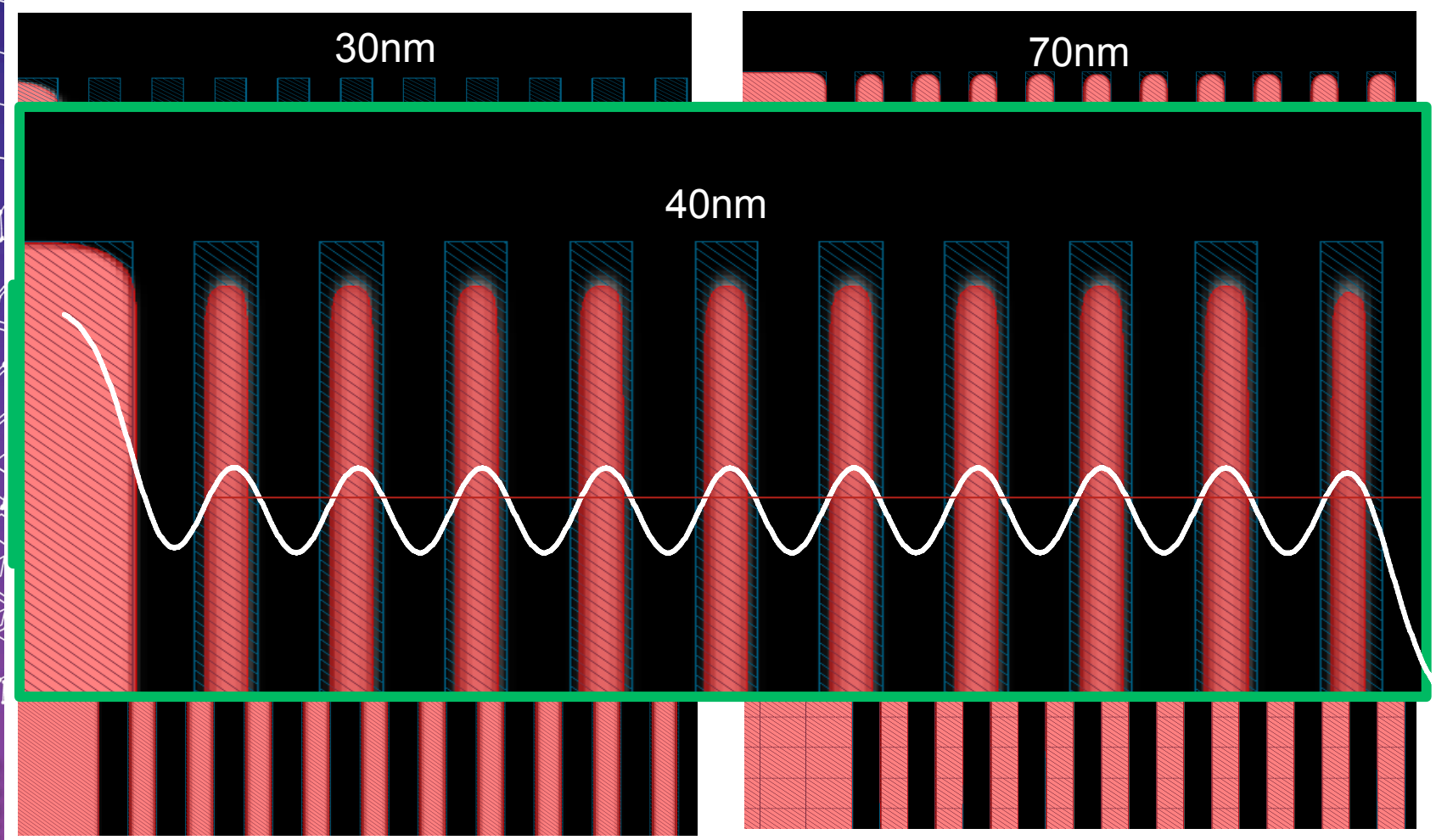
- Discontinuity at 20nm logic node
- eBeam writing is no longer “faithful”
- Mask Linearity is one issue : but the problem is bad Dose Margin
  - Lack of resiliency to manufacturing variation : LER and CDU problems

< 50nm, Context is Critical



Each picture is scaled up to show the contour

< 50nm, Context is Critical



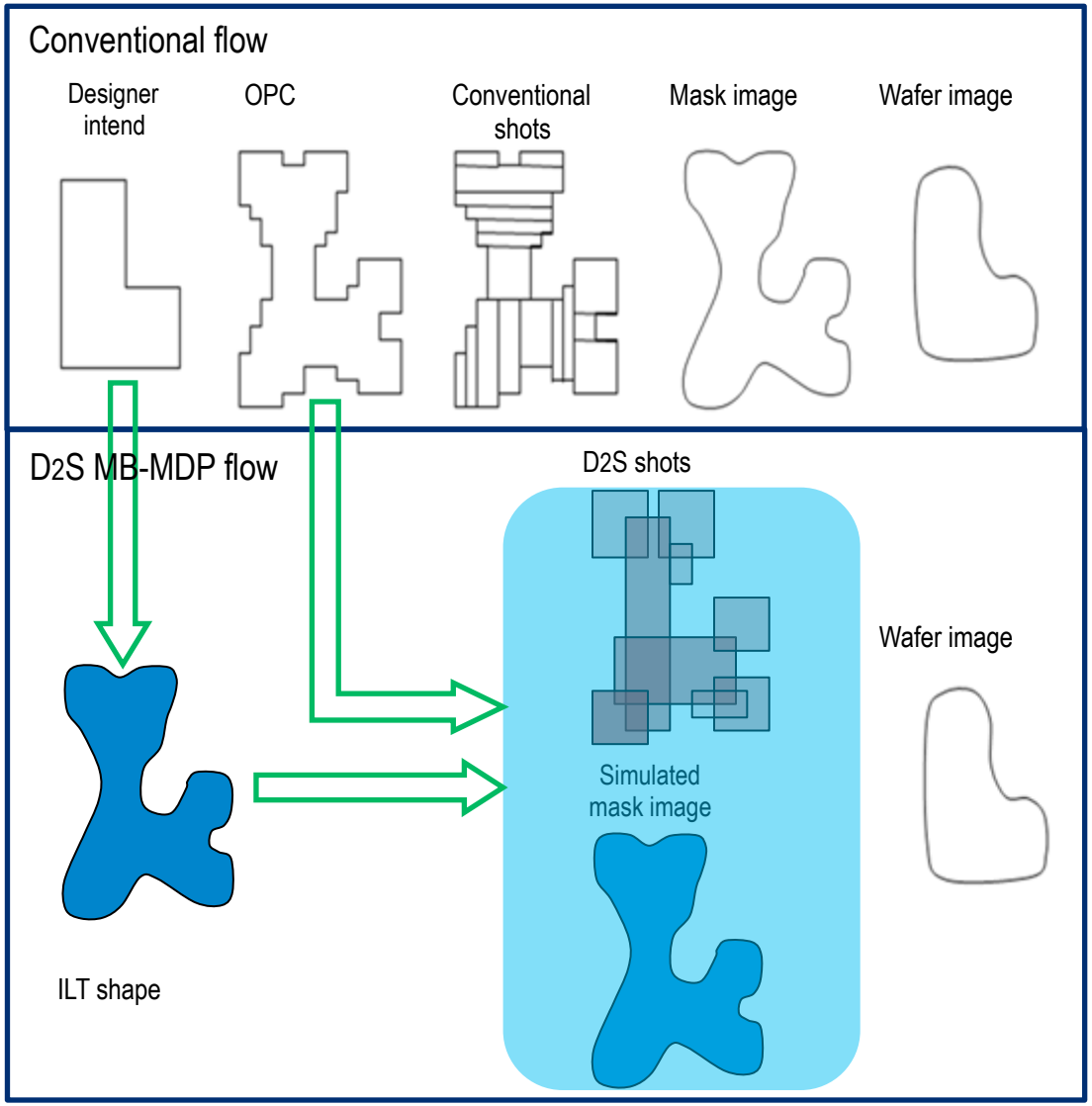
Each picture is scaled up to show the contour

Simulation-Based Mask Data Processing Is the Answer for ILT Mask Pattern Fidelity

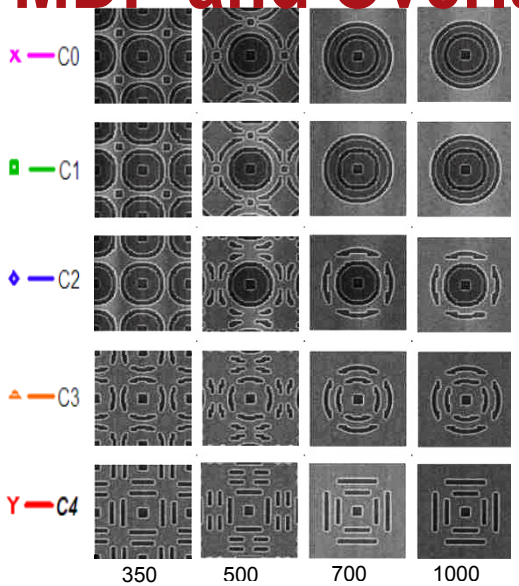
- Above 50nm, context-independent rules-based processing works well enough
- Below 50nm, context is critical
- If we can't push below 40nm, we leave the benefits of Moore's Law on the table
- Simulation-Based Mask Processing is the inevitable answer

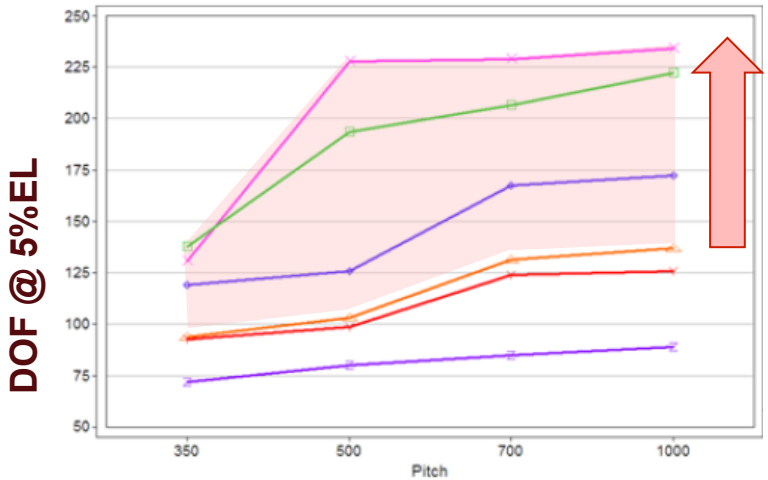
MB-MDP and Overlapped Shots are Must with VSB for Complex Masks

- Conventional solution:
  - Geometry-based
  - Shots cover CAD layout without overlapping
  - More shot count and worse mask fidelity
- D2S solution:
  - Model-based, better CDU control
  - Utilizes overlapping shots to maximize shot contribution to the final mask shapes
  - Less shot count and better mask fidelity



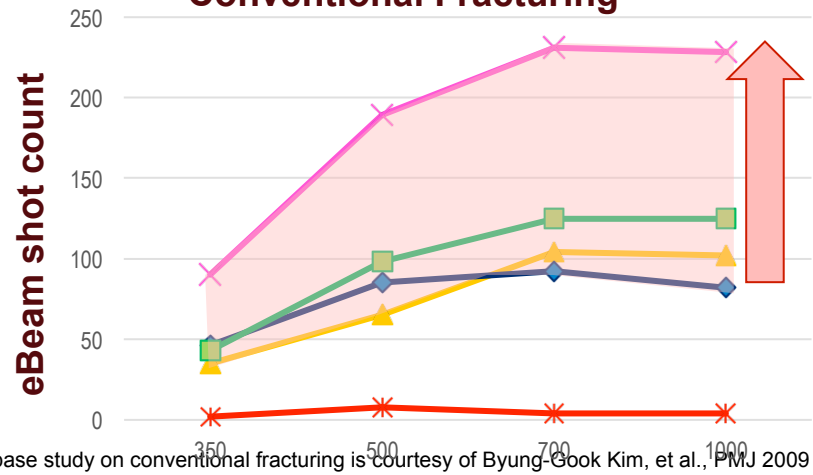
Complex Shapes are only Feasible with MB-MDP and Overlapped Shots





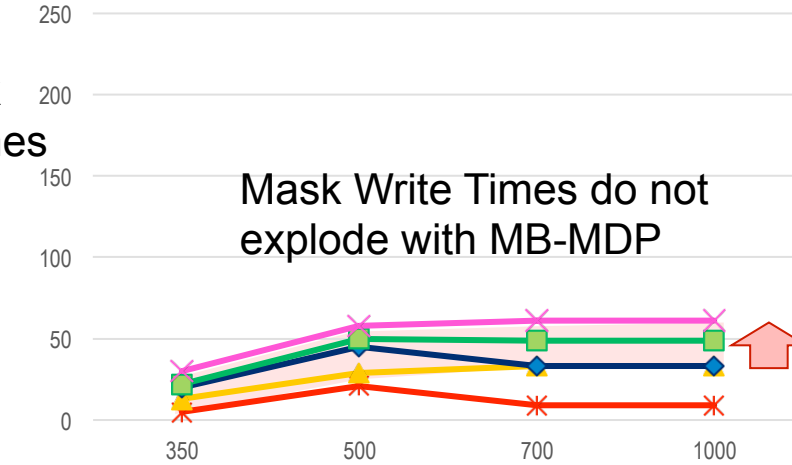
Much better DOF possible with unconstrained shapes

Conventional Fracturing



But Mask Write Times Exploded

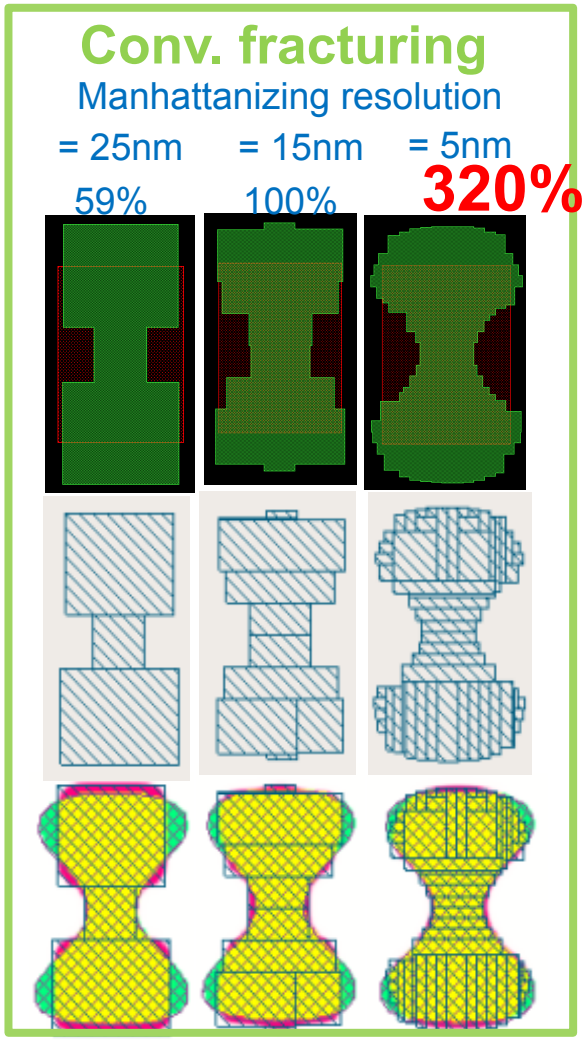
With MB-MDP

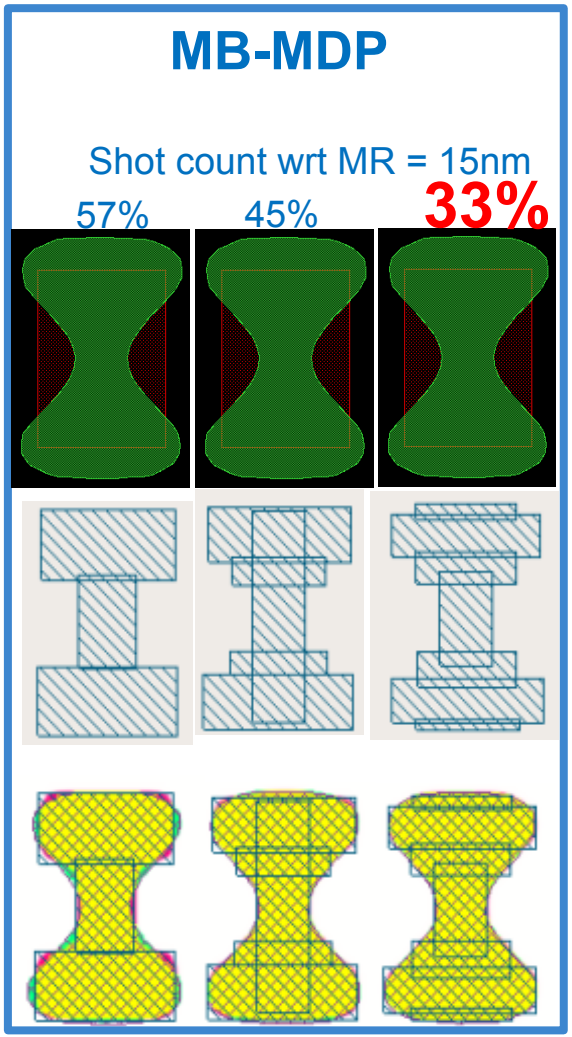


Mask Write Times do not explode with MB-MDP

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

Complex Mask Write Time: w' Conv. MDP – Impossible; w' MB-MDP – Under Control

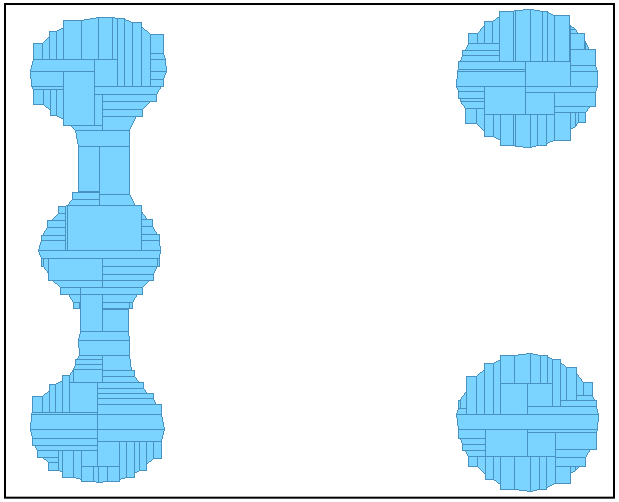




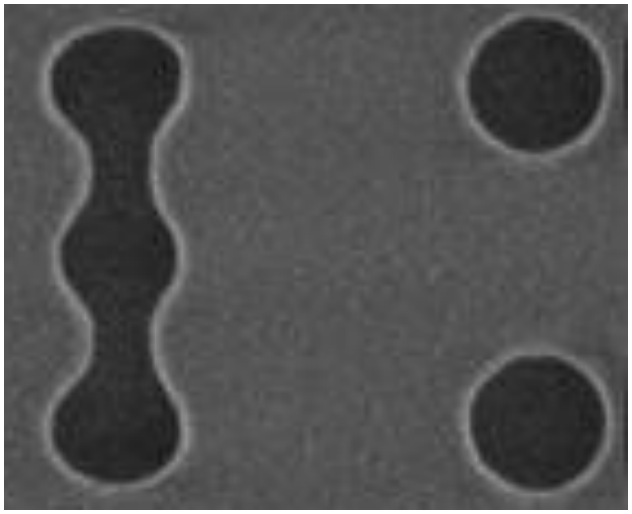
G. Chua, et. al, "Optimization of Mask Shot Count using MB-MDP and Lithography Simulation", 28th European Mask and Lithography Conference, 2012

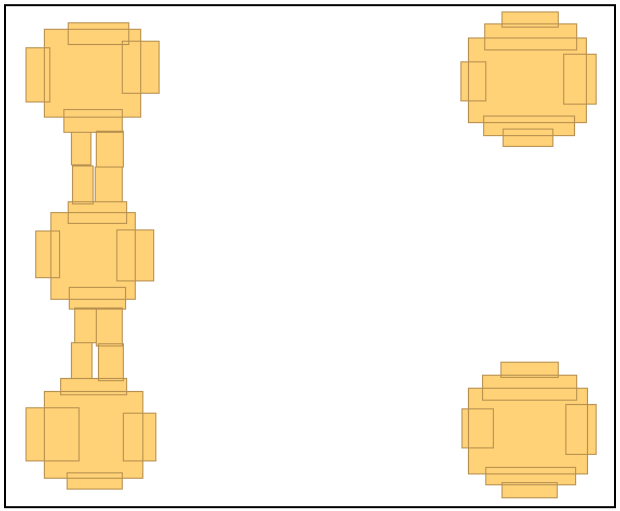
Evidence: Images Identical w' 77% Reduction in Shot Count with MB-MDP

Resist SEM MFG:75K

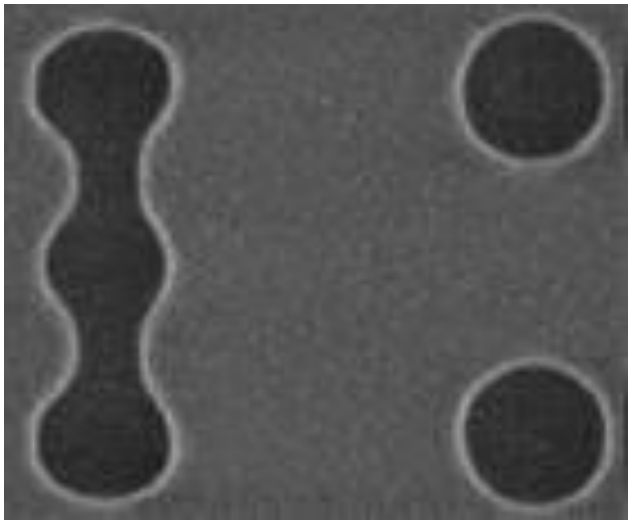


Conventional





MB-MDP



Pattern and measurement courtesy, Dai-Nippon Printing, Ltd.

Recent ILT full chip tape-out for 10nm node

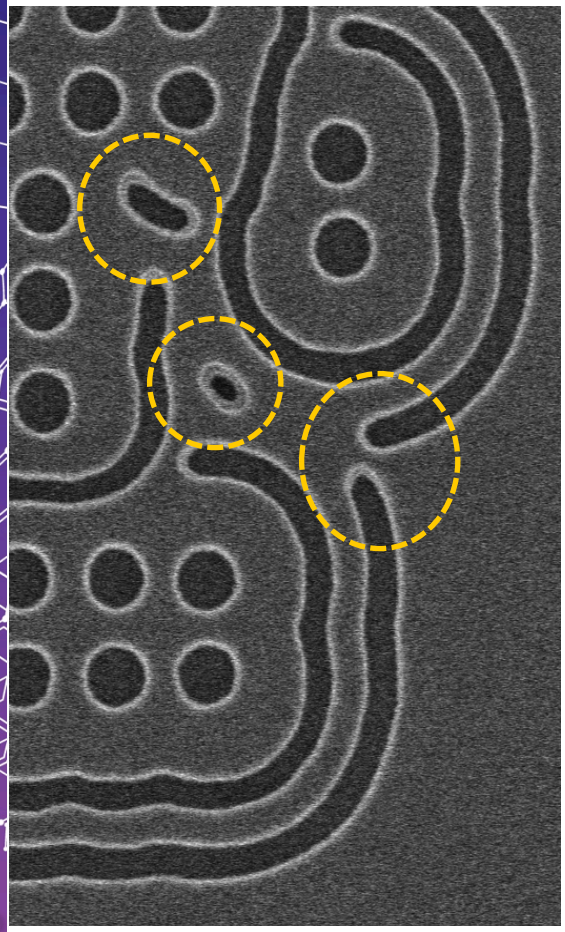
~50%

Shot Count Reduction

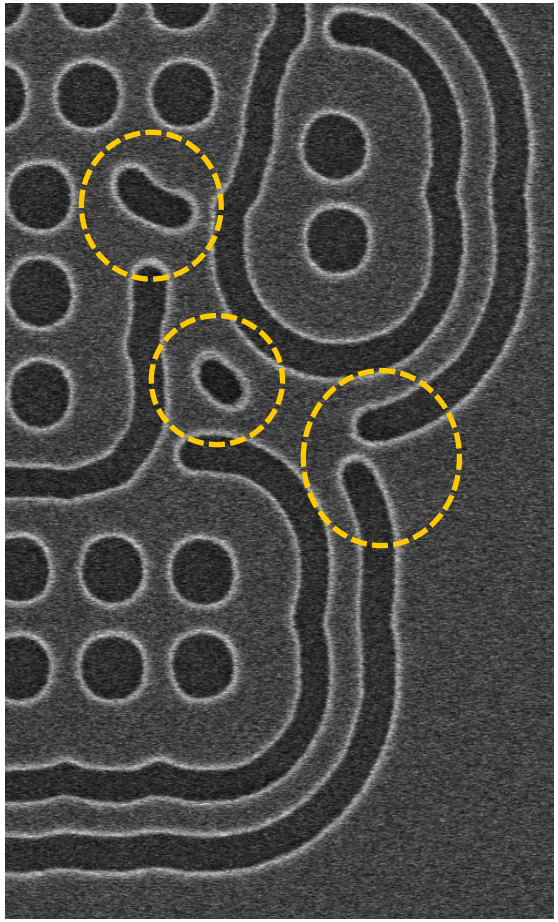
~40%

Write Time Reduction

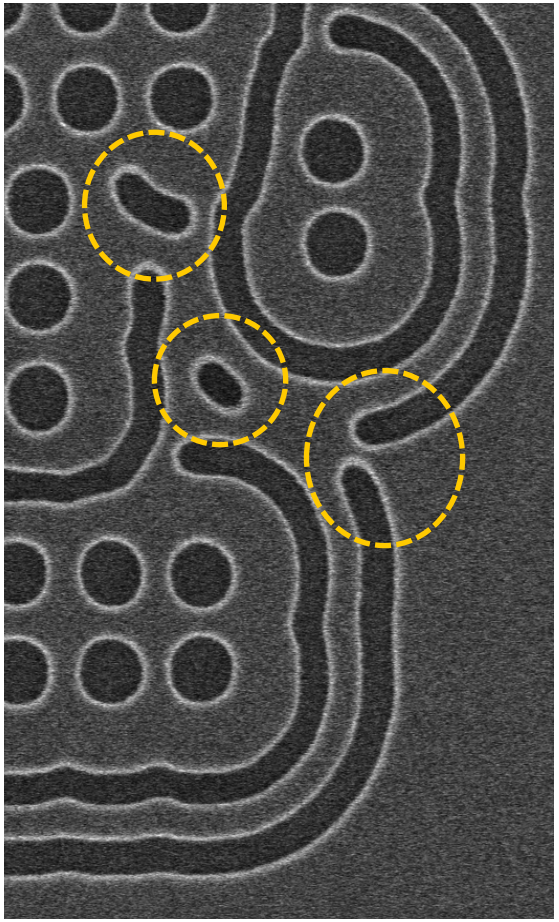
Complex Mask Pattern Fidelity: Conv. MDP – Not Acceptable, MB-MDP: Great



Conventional MDP



Shot Number driven MB-MDP

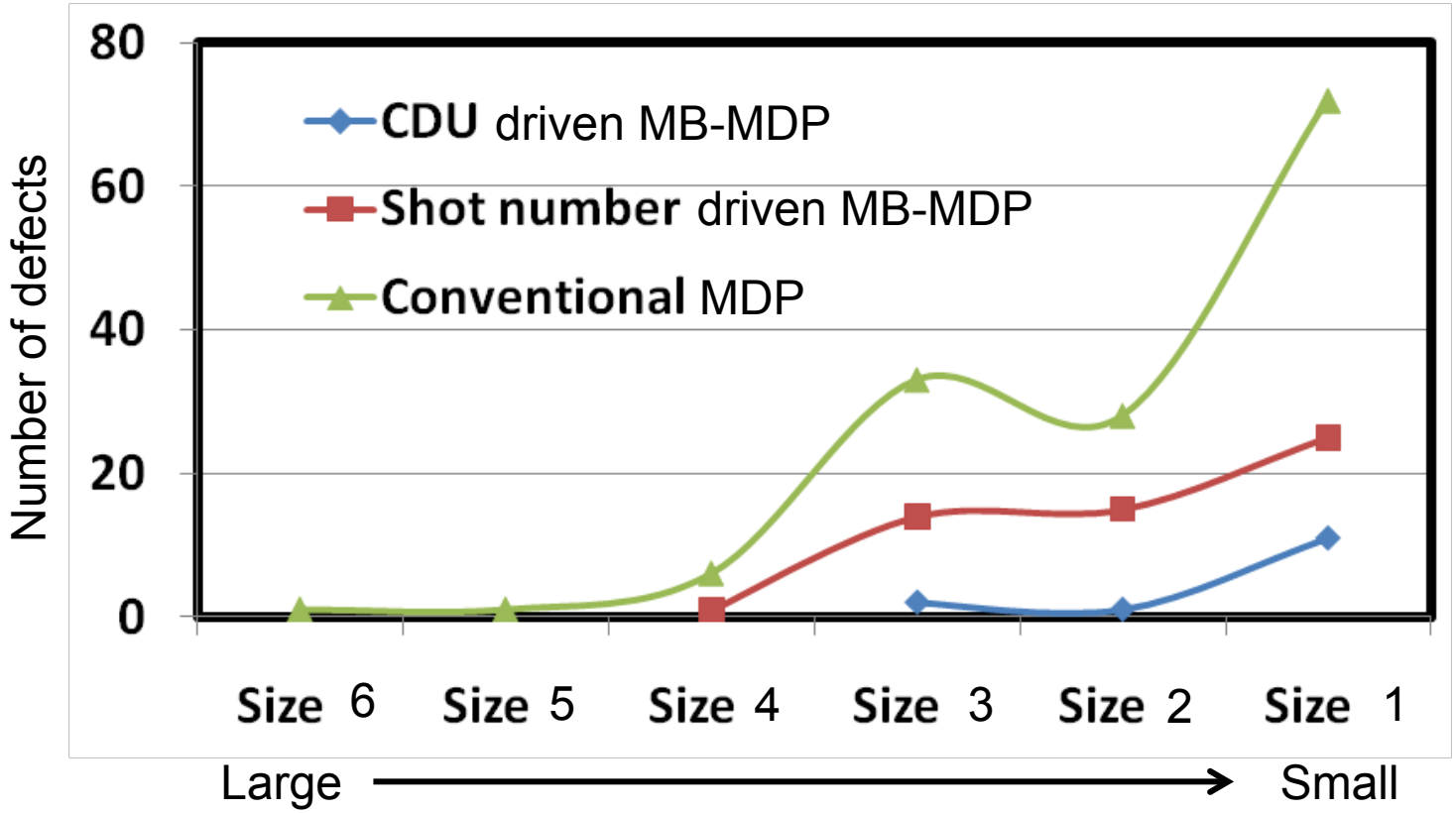


CDU driven MB-MDP

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

Complex Mask Inspectablity: Conv. MDP: Out of Control, MB-MDP: Good

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

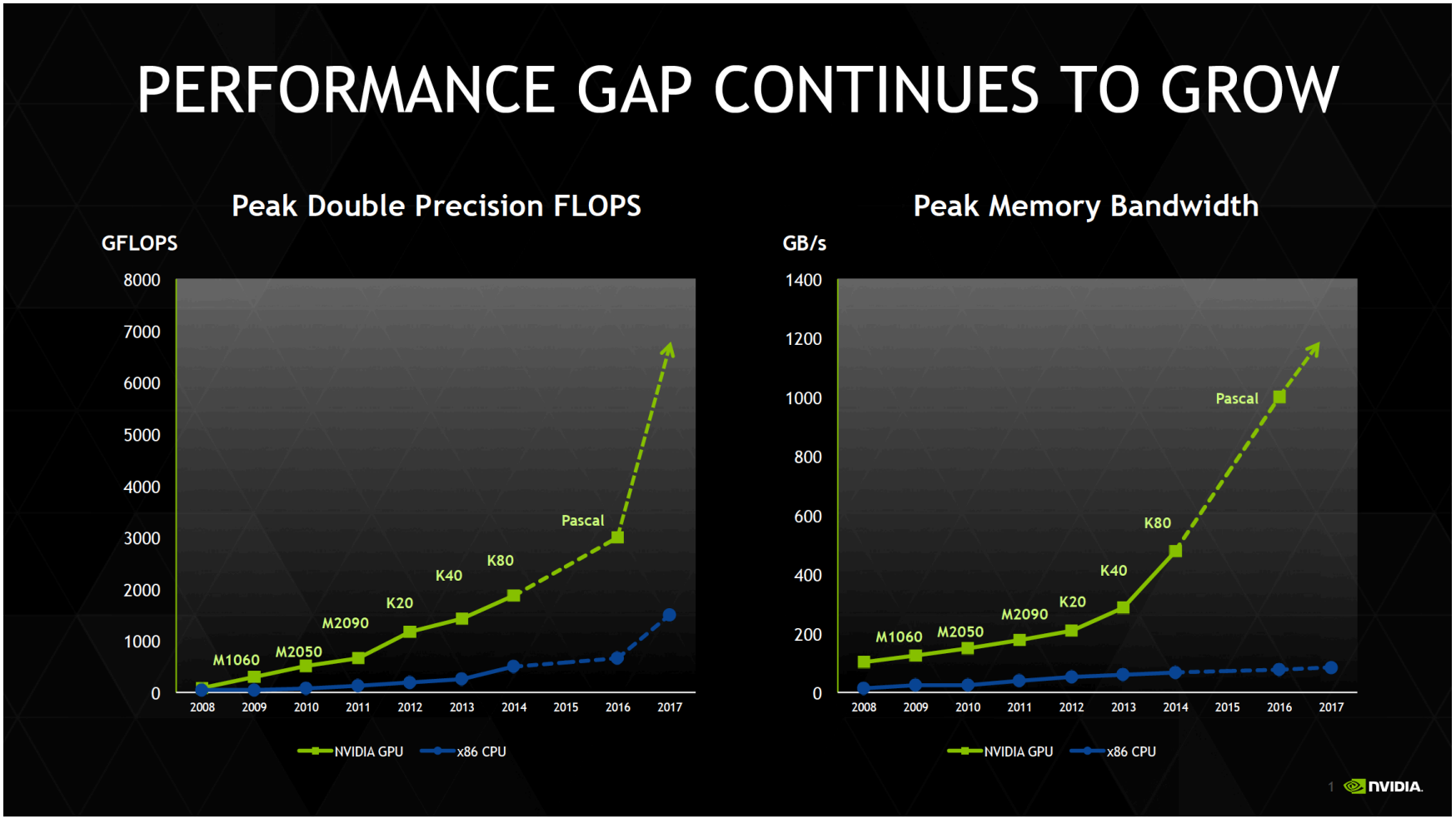


B.G. Kim, et al., "Improving CD Uniformity using MB-MDP for 14nm and beyond", BACUS, 2012

Is MB-MDP Possible?

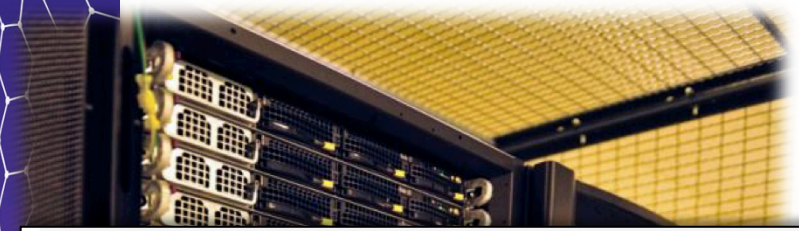
- Over 10X more computation than MB-OPC
  - Mask scale 4X than wafer scale
  - Requires optimization on fracturing
    - Break the OPC pattern into shots
  - Has to consider overlapped shots
  - eBeam proximity effect has short (nm), mid, and long range (mm)

The Answer is GPU:
-Scientific Computing Is Moving into GPU



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

D2S' Computational Design Platform (CDP)

- Could rank in the top 100 Super Computers in the Word (June, 2014)
- In production use
- Part of NuFlare EBM 9500
- Simulates the entire mask plane
- All standard parts, with built-in redundancy

TrueMask® MDP is a GPU Based General Simulation Platform

- Conventional Shot Generation
  - Compatibility
- Overlapping Shot Generation
  - Write-time reduction + CDU/LER improvement
- Dose Enhancement
  - Linearity + CDU/LER improvement of narrow features
- Shape Correction
  - Simulation-based general EPE Optimization
- Double Simulation
  - GPU-accelerate Mask-Wafer double simulation for Wafer Plane analysis
- Simulation-Based Mask Verification and Hotspot Detection
- TrueModel® mask models

Summary:
Using GPUs, ILT Mask Shapes Prevail

- ILT is being deployed at 10nm node
- Mask makers is facing ILT masks
- Overlapped shots and MB-MDP enables VSB mask writer to write complex ILT masks
- Scientific computing is moving to GPU
- GPU-accelerated MB-MDP can meet the speed requirement of mass production
- MB-MDP and Dose Modulation will also offload mask inspection and review work

D2S®