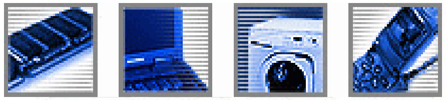
BACUS – Sep. 11, 2012

Improving CD Uniformity using MB-MDP for 14nm node beyond



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Contents

- **Background**
- **Revisit of the basic concept**
- **Extension from simple to complex**
- **Verification of the method**
- **Summary**

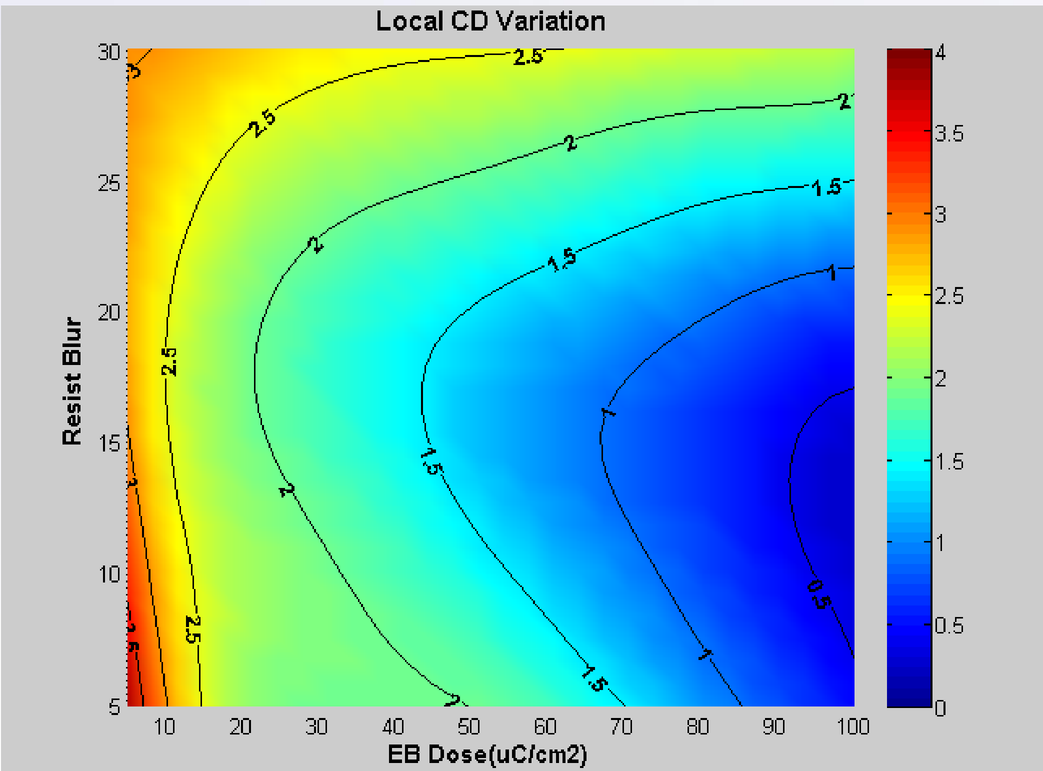
ITRS Roadmap for CD Uniformity

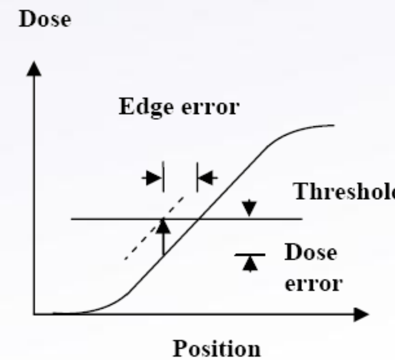
- **0.9 ~ 1.7nm CD uniformity is required in 2016**

Year of Production	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*
DRAM/ MPU/ ASIC (M1) ½ pitch (nm) (contacted)	*52*	*45*	*40*	*36*	*32*	*28*	*25*	*23*
DRAM CD control (3 sigma) (nm)	*5.4*	*4.7*	*4.2*	*3.7*	*3.3*	*2.9*	*2.6*	*2.3*
Flash ½ pitch (nm) (un-contacted poly)	*38*	*32*	*28*	*25*	*23*	*20*	*18*	*16*
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*54*	*45*	*38*	*32*	*27*	*24*	*21*	*19*
MPU gate in resist (nm)	*47*	*41*	*35*	*31*	*28*	*25*	*22*	*20*
MPU physical gate length (nm)	*29*	*27*	*24*	*22*	*20*	*18*	*17*	*15*
Gate CD control (3 sigma) (nm) [A]	*3.0*	*2.8*	*2.5*	*2.3*	*2.1*	*1.9*	*1.7*	*1.6*
Overlay (3 sigma) (nm)	*10.3*	*9.0*	*8.0*	*7.1*	*6.4*	*5.7*	*5.1*	*4.5*
Contact in resist (nm)	*66*	*56*	*47*	*39*	*33*	*29*	*26*	*23*
Generic Mask Requirements								
Mask magnification [B]	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Mask nominal image size (nm) [C]	**186**	**162**	**141**	**126**	**112**	**100**	**89**	**79**
Mask minimum primary feature size [D]	**130**	**114**	**99**	**88**	**78**	**70**	**62**	**55**
Mask sub-resolution feature size (nm) opaque [E]	**93**	**81**	**71**	**63**	**56**	**50**	**44**	**40**
Image placement (nm, multipoint) [F]	**6.2**	**5.4**	**4.8**	**4.3**	**3.8**	**3.4**	**3.0**	**2.7**
CD uniformity allocation to mask (assumption)	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
MEEF isolated lines, binary or attenuated phase shift mask [G]	**2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**
CD uniformity (nm, 3 sigma) isolated lines (MPU gates), binary or attenuated phase shift mask [H] *	**2.4**	**2.0**	**1.8**	**1.7**	**1.5**	**1.4**	**1.3**	**1.2**
MEEF dense lines, binary or attenuated phase shift mask [G]	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**
CD uniformity (nm, 3 sigma) dense lines (DRAM half pitch), binary or attenuated phase shift mask [J]	**3.9**	**3.4**	**3.0**	**2.7**	**2.4**	**2.1**	**1.9**	**1.7**
MEEF contacts [G]	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
CD uniformity (nm, 3 sigma), contact/vias [K] *	**2.1**	**1.9**	**1.7**	**1.5**	**1.3**	**1.2**	**1.0**	**0.9**
Linearity (nm) [L]	**8.3**	**7.2**	**6.4**	**5.7**	**5.1**	**4.5**	**4.0**	**3.6**
CD mean to target (nm) [M]	**4.1**	**3.6**	**3.2**	**2.9**	**2.5**	**2.3**	**2.0**	**1.8**
Defect size (nm) [N] *	**41**	**36**	**32**	**29**	**25**	**23**	**20**	**18**
Blank flatness (nm, peak-valley) [O]	**190**	**165**	**147**	**131**	**117**	**104**	**93**	**83**

CD Uniformity improvement by dose increase

- **To achieve ~ 1nm CD variation, increase of dose is inevitable to compensate shot noise effect**





Edge deviation @ x= 0 and D(x)=D_{th}

$$\Delta x\Big|_{x=0} = \frac{1+2\eta U}{2}\sqrt{\frac{e\pi}{D_{th}\cdot W}\cdot\frac{r_b{}^2+r_d{}^2}{r_d}}$$

D_{th} : Threshold

W : metrology window

r_b : beam blur inc. fwd scattering & e-beam column

r_d : blurring by resist process

η : backscattering ratio

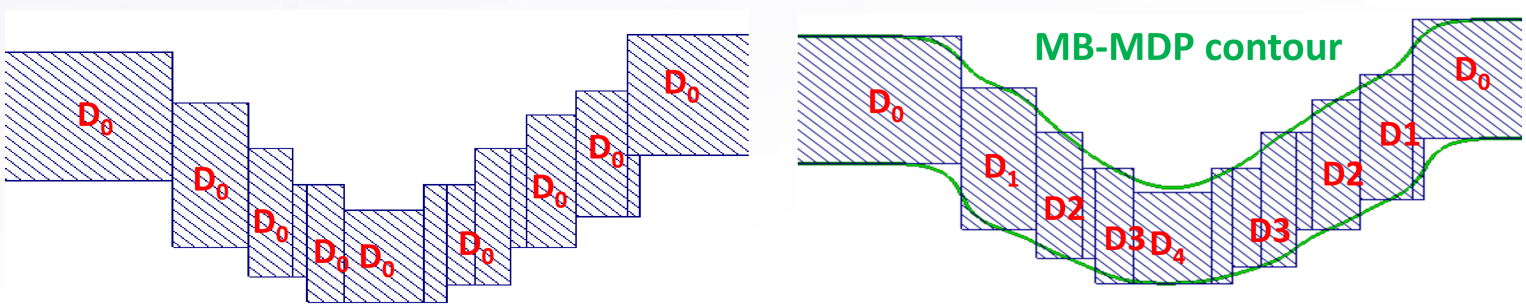
Barriers to dose increase

- Current VSB e-beam throughput cannot support such a high dose
  - Extremely high number of shot is expected in 14nm beyond
  - Heating effect must be solved for high dose assignment
  - Outgassing of resist can affect the EB hardware

- How can we do that now?
  - Increasing dose means reducing shot noise of the pattern edge

Using MB-MDP

- **Model-Based Mask Data Prep(MB-MDP) which uses overlapping shots enables more manufacturing-robust mask writing compared to Conventional MDP.**
- **Robust in:**
  - **Dose-variation (due to steeper and customizable dose margin)**
  - **Shot size variation (greater split effect immunity)**
  - **Shot placement variation (greater split effect immunity)**

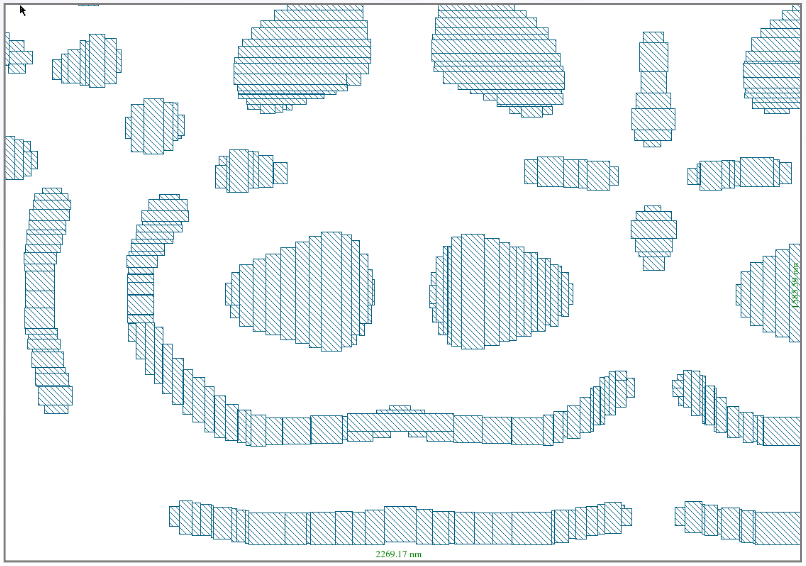


MB-MDP is physics- and simulation-based modeling for every shape
The more complex or smaller the shapes, the more this matters

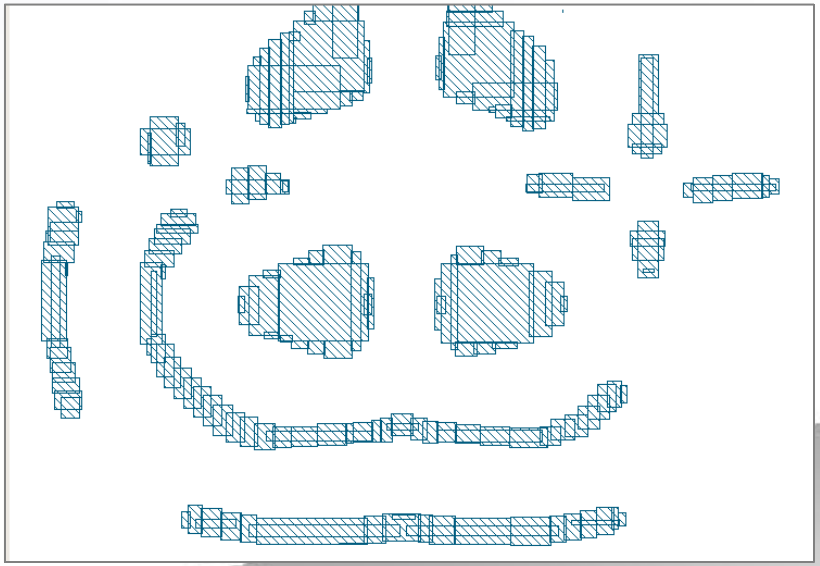
ILT pattern

- **In conventional fracturing, dose margin has not been considered in each pattern shape**
  - **Conventional MDP assumes that all shots deliver same dose margin**
  - **MB-MDP can improve regions w/ poor dose margin by optimizing shapes and doses while using over-lapping shots**

Conventional



MB-MDP



Conventional vs. MB-MDP - Image

- **MB-MDP shots enable significantly steeper dose gradient.**
- **Visually different in terms of image contrast**

Conventional

MB-MDP

D2S

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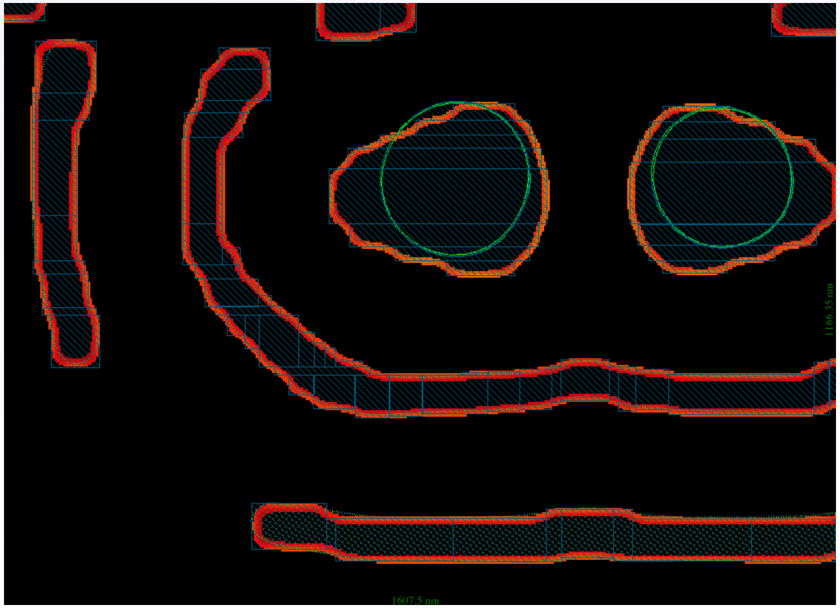
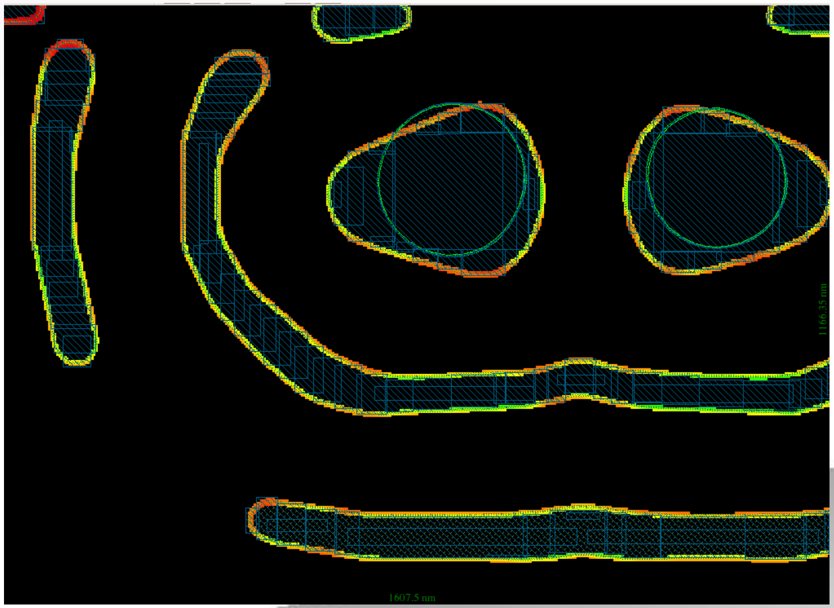
Conventional vs. MB-MDP - Dose slope

- **Patterns composed by MD-MDP method show a significantly better dose margin**
- **Green represents better dose slope (> 2% / nm) than red (< 1%/nm)**

Conventional

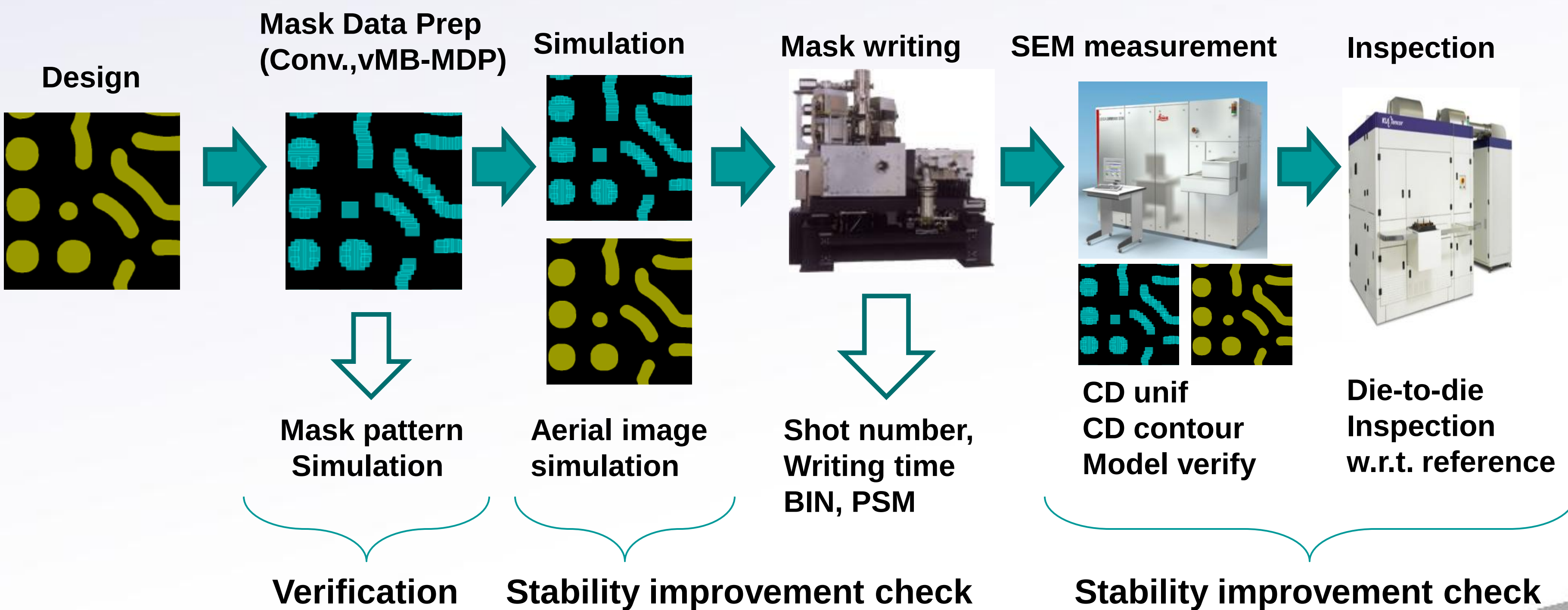


MB-MDP



Verification for CDU improvement by MB-MDP

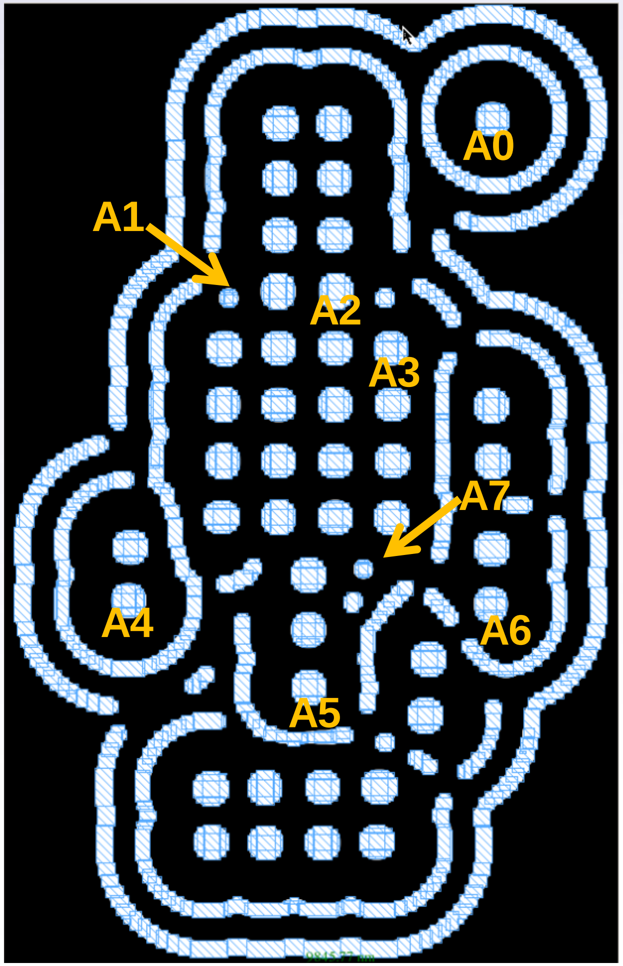
- **Inspection, SEM & AIMS measurements are planned to verify MB-MDP contribution for CD uniformity**



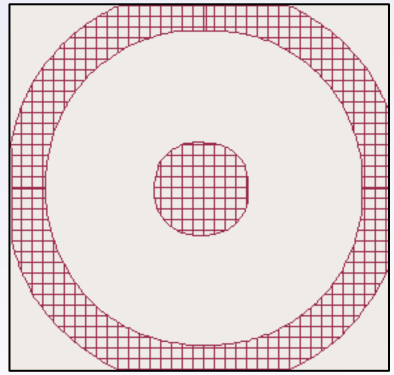
Test design – Random Logic (A)

Two settings used for MB-MDP
1. CD-MB-MDP: CDU Optimized
2. SN-MB-MDP: Shot Number Optimized

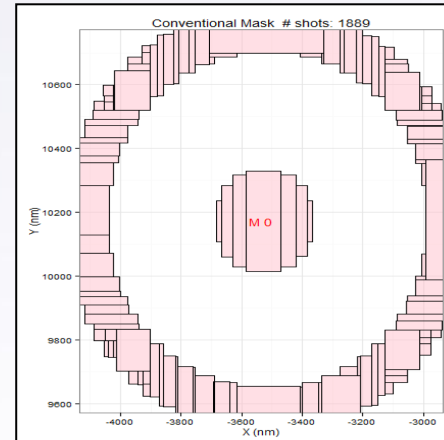
Pattern A –Random Logic



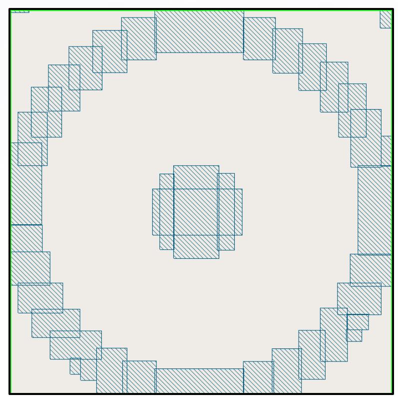
Pattern Markers



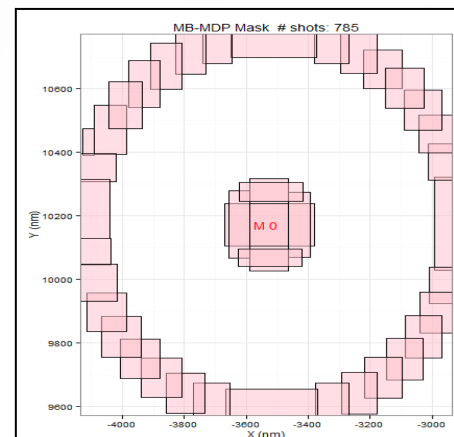
ILT TARGET



Conventional



SN-MB-MDP



CD-MB-MDP

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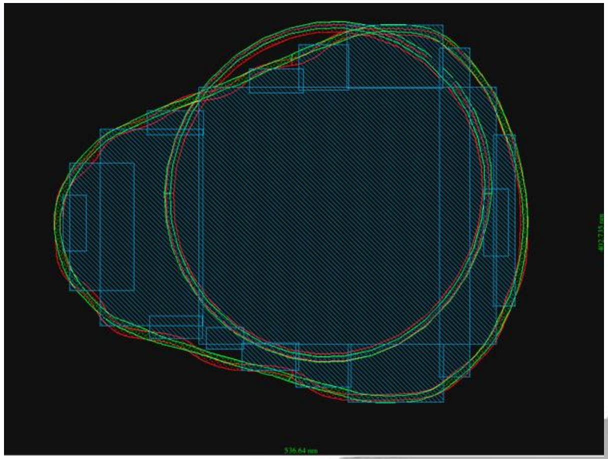
Pattern Conversion Results – Priority Choice

- Number of shot depends on which priority is important
  - Shot Number Priority or CDU Priority
- Pattern Conversion are prepared in different ways depending on the purpose of the layer

Design	Condition	Shot #
Pattern A	CD-Priority	22,544,000
	Shot # -Priority	14,240,000
	Conventional	30,288,000
Pattern B	CD-Priority	5,124,000
	Shot # -Priority	1,820,000
	Conventional	2,716,000

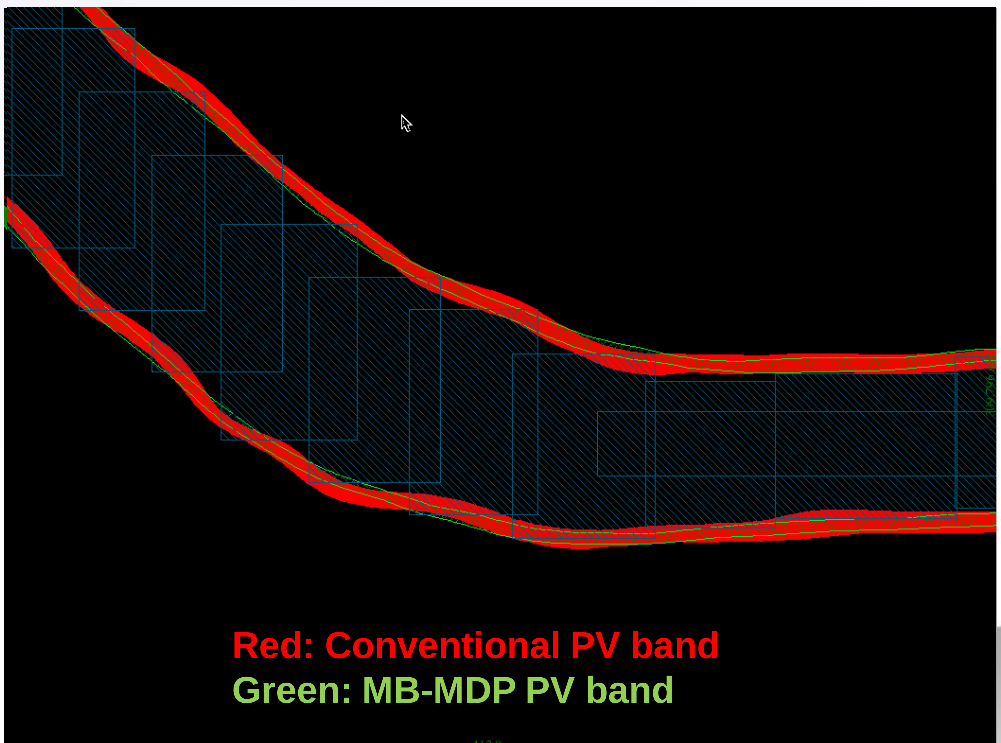
Verification by Monte Carlo simulation

- For Conventional & MB-MDP Shot Configurations, 300 Monte Carlo runs. Shots are dithered in;
  - Dose: 2% sigma
  - Shot size: 1nm sigma
  - Shot placement: 1nm sigma
- D2S TrueMask™ DS is a very effective tool for Monte Carlo analysis due to its speed and flexibility – easily customizable.
- Lithography simulation of dithered shots is also available in the Monte Carlo analysis to explore the impact of mask variations on lithographic fidelity.



Stability improvement against dithered condition

- **MB-MDP method shows better CDU stability based on MC simulation**
  - **Measure PV (Process Variation) Band**
  - **Green: MB-MDP PV band of worst observed shape**
  - **Red: Conventional-MDP PV band of worst observed shape**
- **Note that MB-MDP is clearly superior over the variation space explored as observed with narrower PV band**

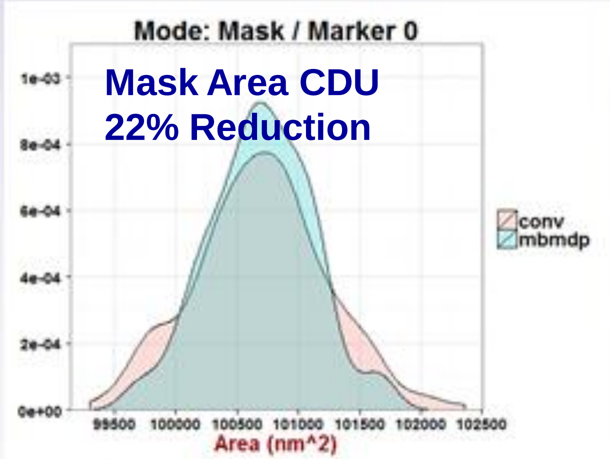


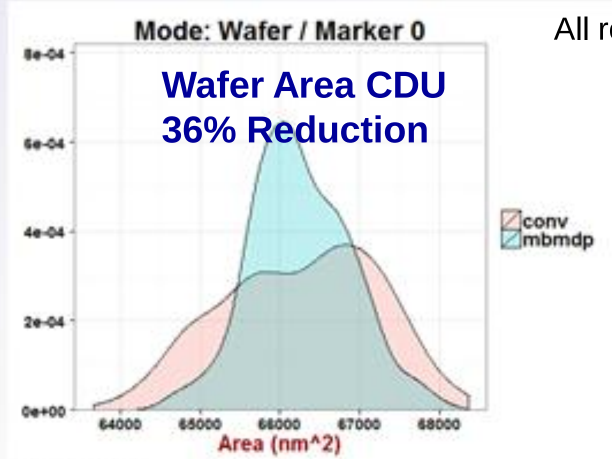
300 Monte-Carlo runs
2% Dose Variation,
1 nm size variation,
1 nm position variation
(1 sigma)

Simulation Results

- **MB-MDP method shows improved CDU of area and line-width compared to conventional MDP.   Impact at wafer level increased by MEEF.**

Marker (Pattern B)	Conventional MDP CDU (1 σ)		MB-MDP CDU (1 σ)		Reduction	
	Mask	Wafer	Mask	Wafer	Mask	Wafer
Area 1 (nm^2)	538	969	420	625	22%	36%
Area 2 (nm^2)	554	1175	418	557	25%	53%
Area 3 (nm^2)	531	1178	415	568	22%	52%
Area 4 (nm^2)	493	742	380	495	23%	33%
Line 1 (nm)	0.96	N.A.	0.62	N.A.	35%	N.A.
Line 2 (nm)	0.78	N.A.	0.55	N.A.	29%	N.A.
Line 3 (nm)	1.73	N.A.	1.47	N.A.	15%	N.A.
Line 4 (nm)	1.26	N.A.	0.89	N.A.	29%	N.A.

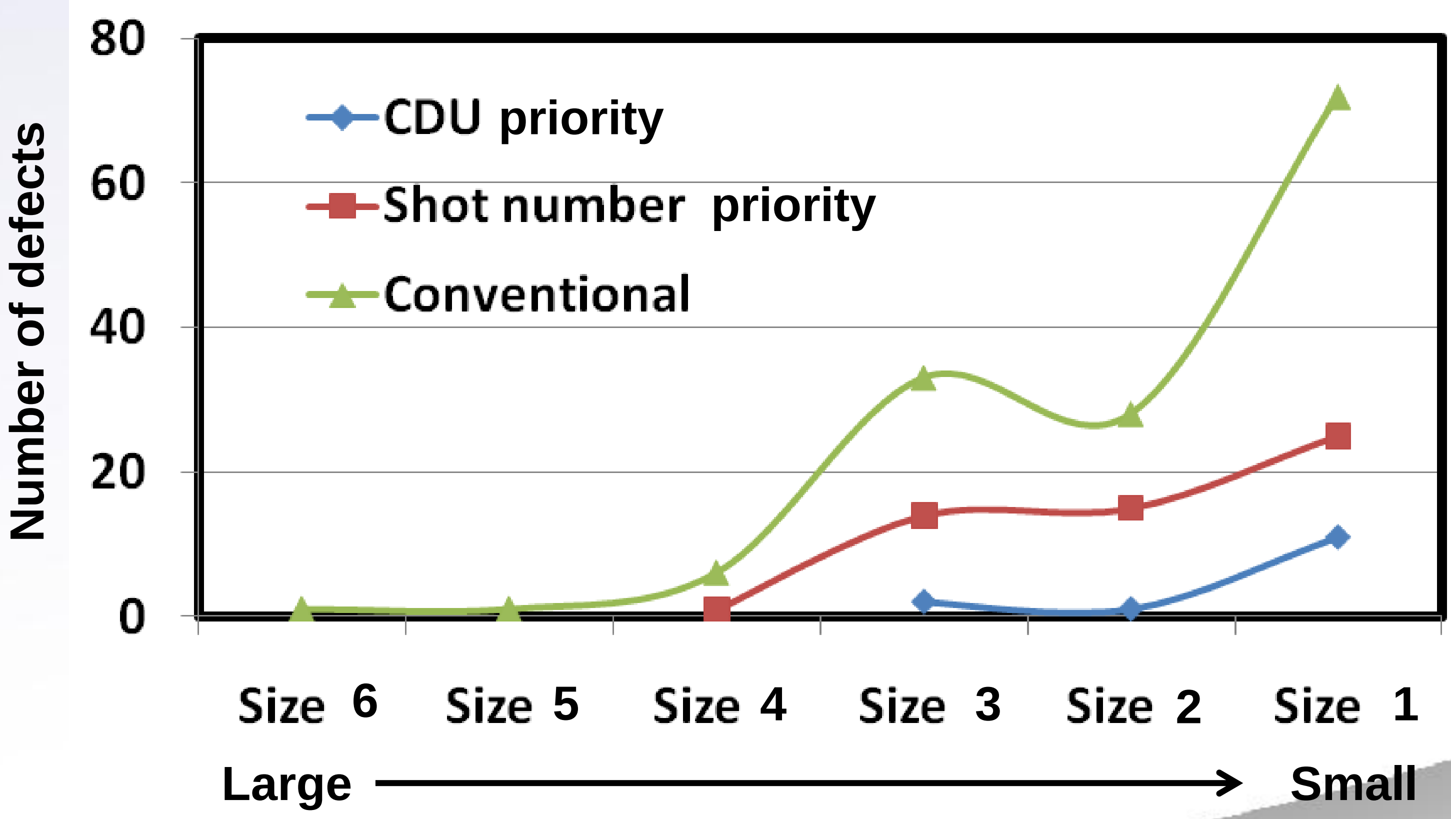




All results are in Mask Units

Inspection Results

- **Both Shot Number-Priority and CDU-Priority MB-MDP methods show clear effectiveness in reducing defects caused by size variation (i.e. CDU)**



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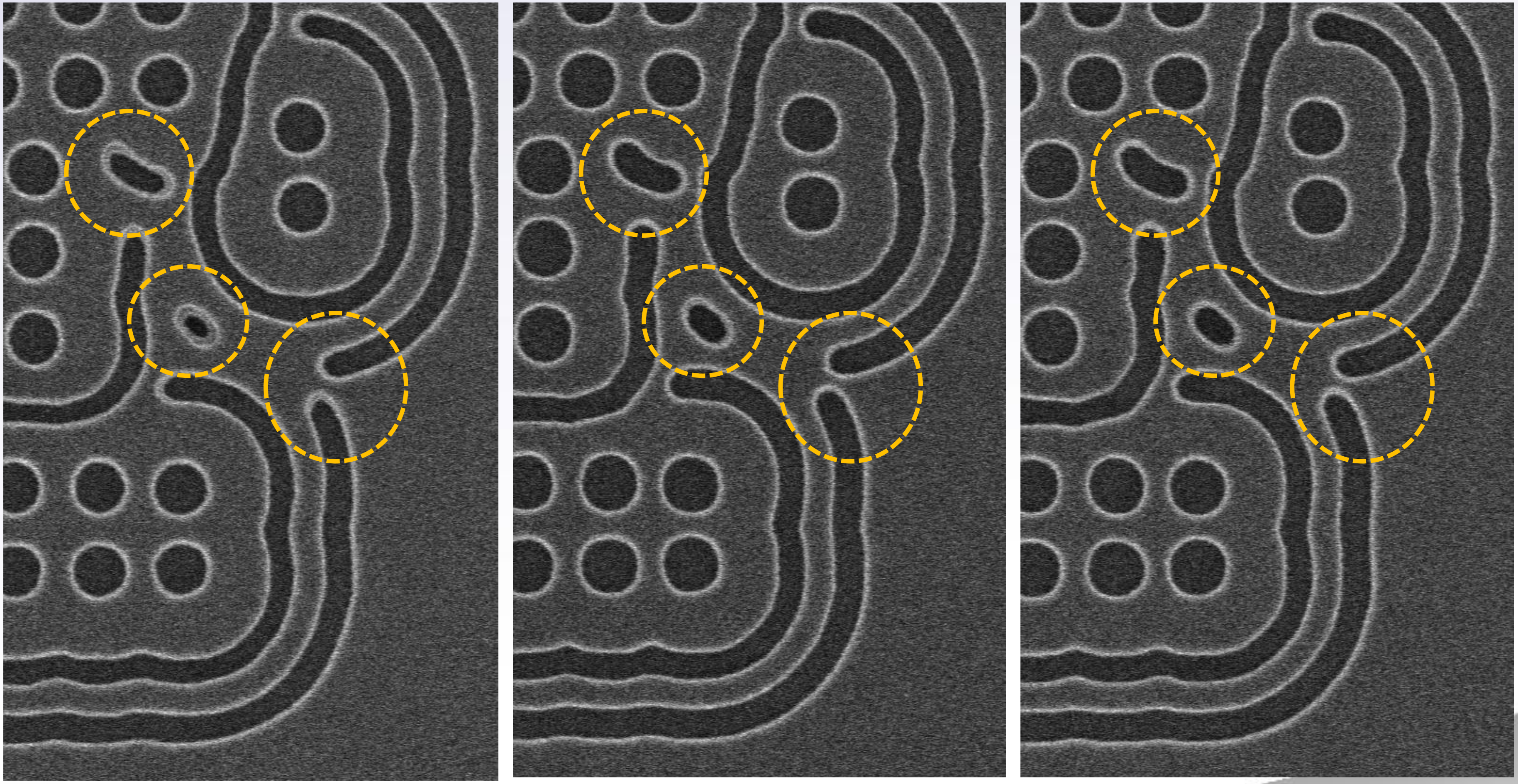
SEM Image



Conventional SN-MB-MDP CD-MB-MDP

Full SoC Chip Conversion Operational

- **Logic contact layer replicated and flattened to 40mm x 40mm (4X) area**
  - **Hierarchy and pattern matching disabled**

D2S TrueMask™ MDP

Shot Synthesis	18.5 hours*
Mean Error	<0.03 nm
2D Sigma Error**	<1.0 nm
Shot Reduction***	52%
Shot Count	80 Billion Shots

* Processing Time extrapolated from a 100 TFLOPS platform to the standard CDP (400 TFLOPS)
** Per-Pixel Edge Error (EPE) of all contour edges
*** Shot count of ideal ILT with MB-MDP compared to shot count of Manhattanized ILT with conventional fracturing

Summary

- To achieve CD variation below 1nm, an increase of dose is needed to compensate for eBeam shot noise effect.
- In conventional fracturing, dose margin has not been considered.
- Selective dose assignment with over-lapping shots could be a solution. MB-MDP can synthesize the pattern with priority to improve CDU and shot count.
- Both Simulation and Inspection results show that MB-MDP methods can improve dose margin and CDU. Improved CDU is possible with reduced dose and writing time compared to conventional MDP