eBeam
Initiative

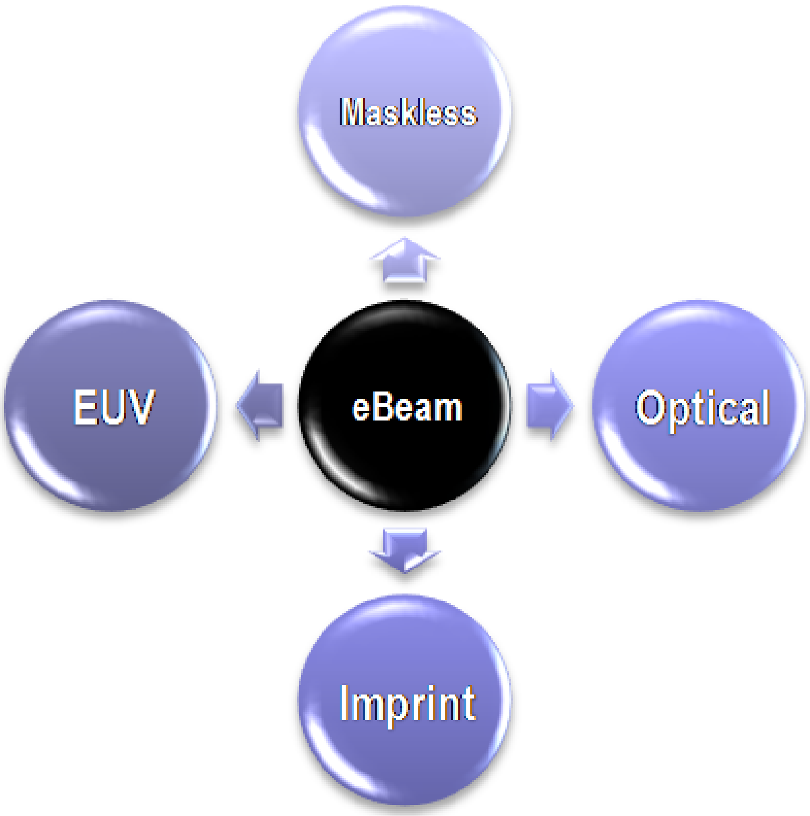
eBeam Initiative Luncheon
PMJ – April 19, 2012

Aki Fujimura
CEO – D2S, Inc.
Managing Company Sponsor – eBeam Initiative

eBeam Writes All Chips

The eBeam Initiative:

- Is an educational platform for all lithography approaches including Maskless and Imprint
- Open to any company in the semiconductor design chain with an interest in eBeam technologies



43 Member Companies & Advisors

eBeam Initiative

www.ebeam.org

aBeam technologies

ADVANTEST

ADVANCED MASK TECHNOLOGY CENTER

alchip

APPLIED MATERIALS

ARTWORK CONVERSION
CAD Translators
Postprocessors
Plotter Drivers

aselta NANOGRAPHICS

cadence

D2S

DNP
Dai Nippon Printing

EQUIcon

eShuttle

eSilicon

FASTRACK DESIGN

Fraunhofer CNT

FUJITSU

GenISys GmbH

Jack Harding
eSilicon

Grenon Consulting

GLOBALFOUNDRIES

HOYA

ims chips

Colin Harris
PMC-Sierra

IMS Nanofabrication

JEOL

KLA Tencor
Accelerating Yield

cea leti

Mentor Graphics

MULTIBEAM

NCS

NUFLARE

Riko Radojcic
Qualcomm

PETERSEN ADVANCED LITHOGRAPHY INC.

SAMSUNG

SoftJin
Enabling Electronic Design

SYNOPSYS

Jean-Pierre Geronimi
ST

tau-Metrix
Performance-based Metrology™

Tela Innovations

TOOL

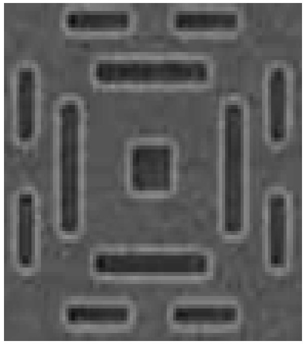
TOPPAN

Vistec

XILINX

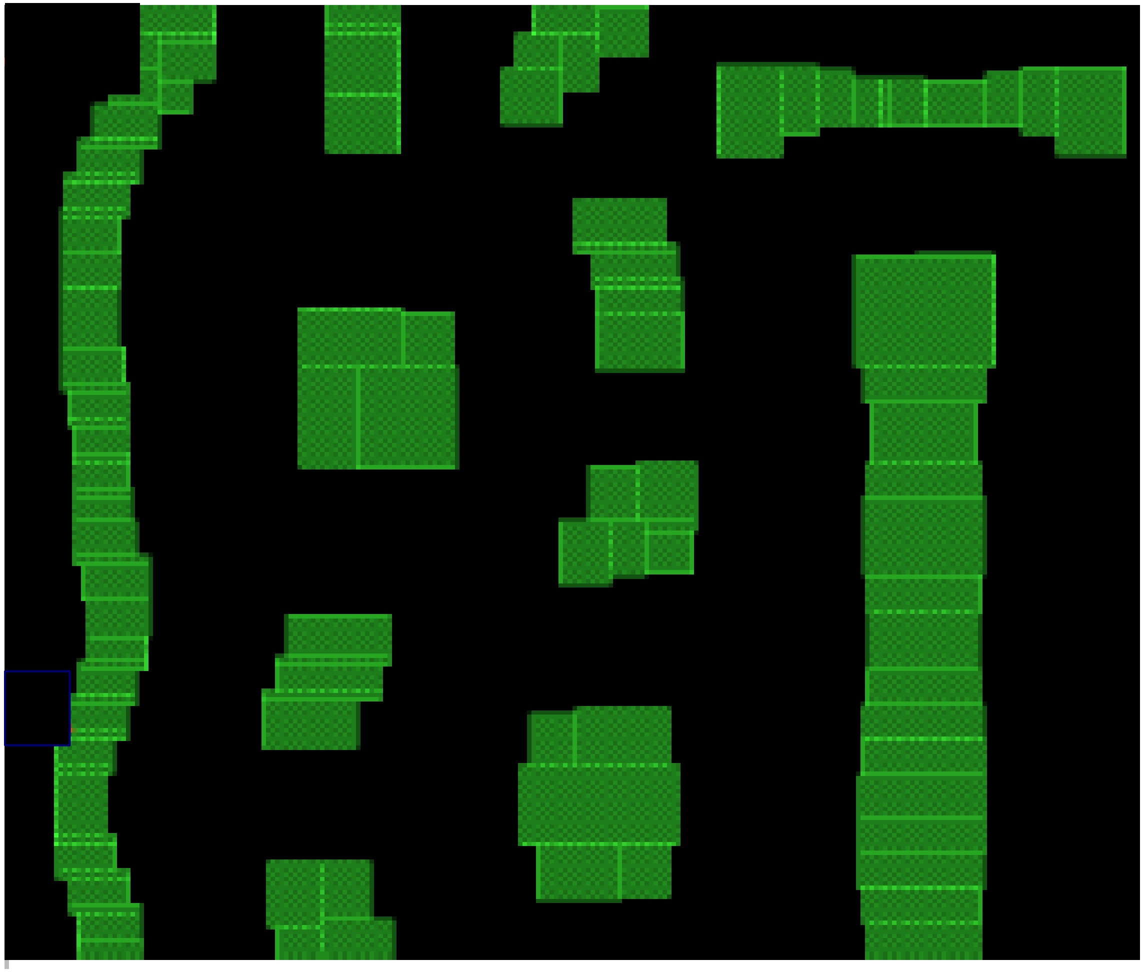
2010 Design for eBeam (DFeB) Roadmap: Complex Mask Shapes are Required at 20 nm & Beyond

28nm



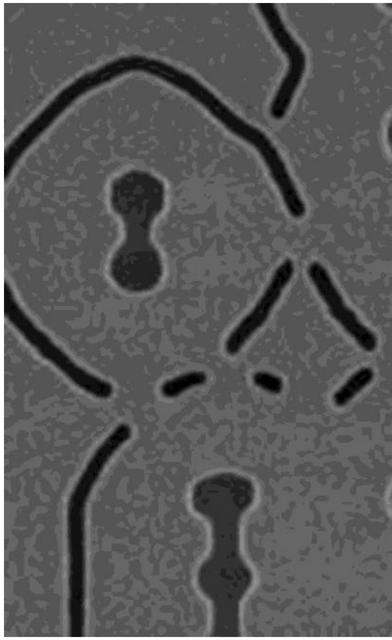
Courtesy : Samsung

20nm



Courtesy : IBM

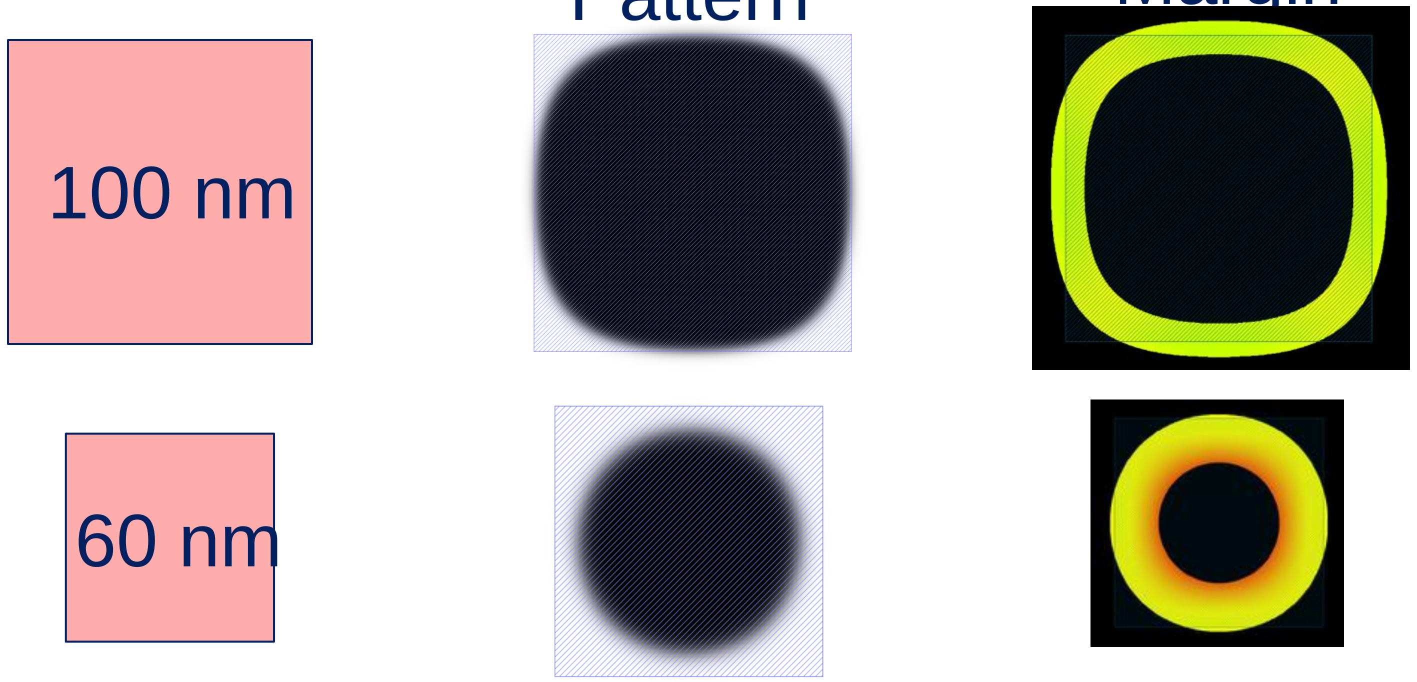
14nm



Courtesy : DNP

2011 Design for eBeam (DFeB) Roadmap: Sub-80-nm Discontinuity Has Arrived

Shot Size | Simulated Pattern | Dose Margin



The old assumption : Dose Margin is independent of shape
The new world : Dose Margin depends on shape and size

2012 Design for eBeam (DFeB) Roadmap: Importance of Mask CD Uniformity

eBeam Initiative

Roadmap Themes
- Mask write times
- Total cycle times
- Mask accuracy
- Wafer quality
- Design for eBeam Methodology

2010
- Complex masks
- Overlapping shots – circles, VSB
- Model-based mask data prep (MB-MDP)

2011
- Thermal analysis of overlapping shots
- Dose control for accuracy
- Double simulation for more accurate analysis of wafer quality

2012
- Mask CD Uniformity improvements
- Accurate measure of mask goodness
- Full chip MB-MDP

2013
- Design for eBeam (DFeB) mask methodology
- Incorporating eBeam Initiative technology roadmap

eBeam Technologies to Improve Mask CDU

- **Dose Modulation**
- **Mask Process Correction (MPC)**
- **Model Based - Mask Data Prep (MB-MDP)**
  - Enables overlapping shots, dose modulation and circular (or any shape) shots
- **Circular eBeam Shots**
  - Requires MB-MDP and machine support

Today's Speakers

- **CD Uniformity Improvements using VSB Shots**
  - Ryan Pearman, D2S, Inc.
- **MB-MDP Impact on Mask Accuracy and Write Times**
  - Yasuki Kimura, HOYA
- **Proof Point on MB-MDP and Wafer Quality Simulation**
  - Gek Soon Chua, GLOBALFOUNDRIES
- **Q&A**

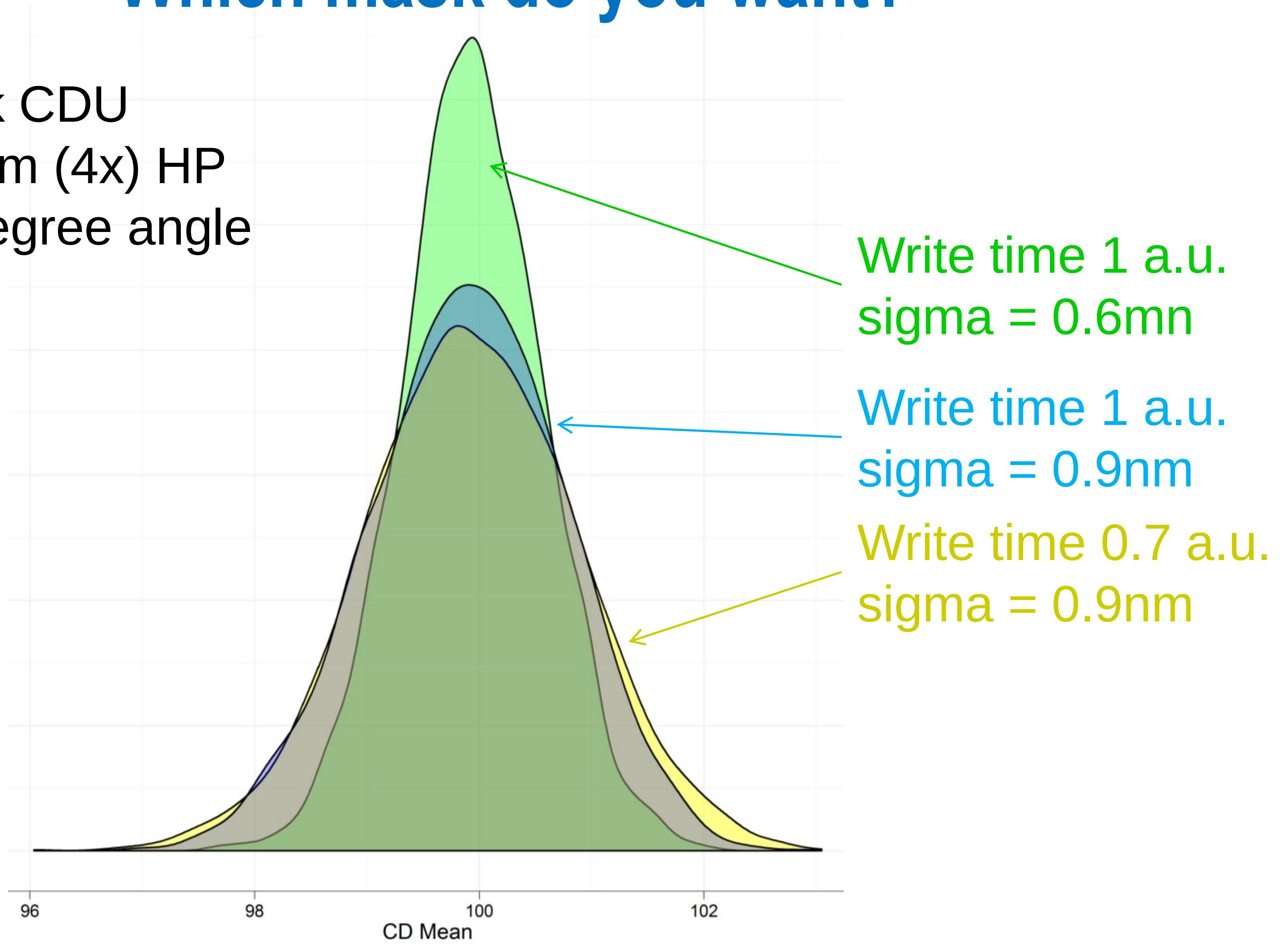
CD Uniformity Improvements Using VSB Shots

Ryan Pearman
Director of Modeling – D2S, Inc.
Bob Pack

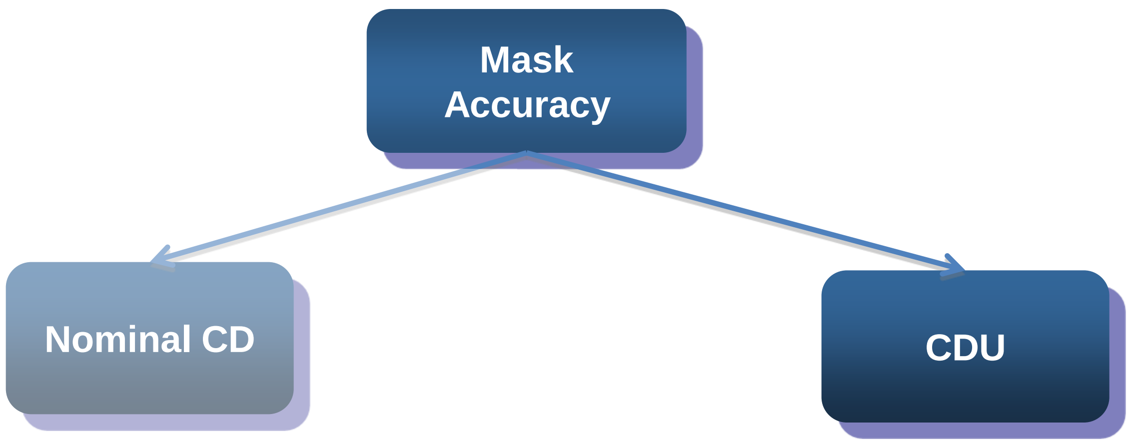
www.ebeam.org

Which mask do you want?

Mask CDU
100nm (4x) HP
30 degree angle



Critical Dimension Uniformity (CDU) on Mask



- CD Linearity
- Mask Process Modeling

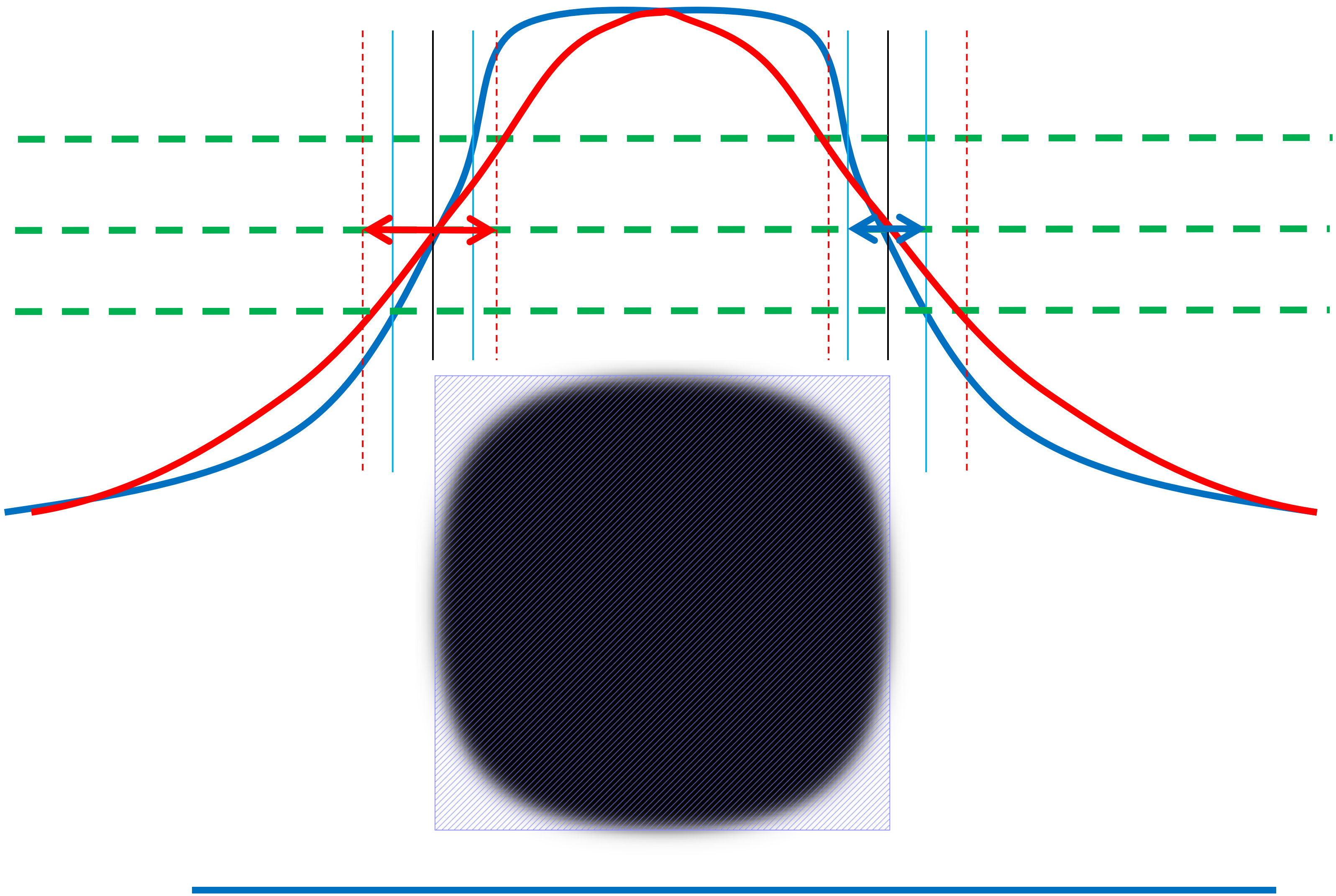
- Dose Margin
- CD Split
- Shot slivers

From a wafer fab perspective, improving CD accuracy is important.

Reducing CD variability is key

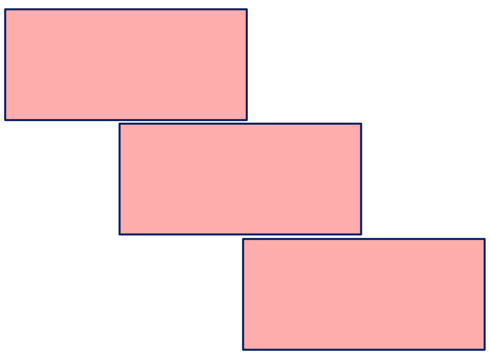
What can the Mask Shop contribute to our customer's success?

Dose Margin is a Key to CDU

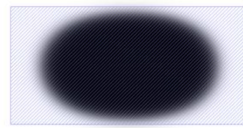


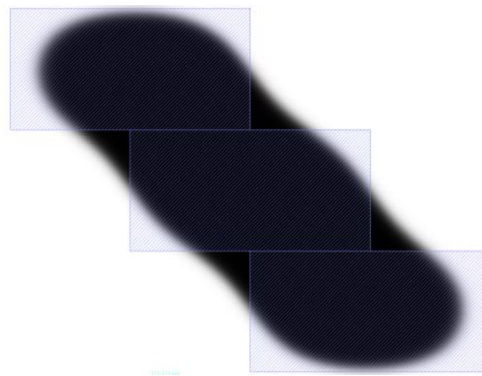
Dose Margin and VSB Shots

90 nm x 45 nm
VSB Shot

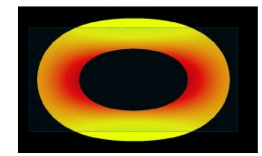


Simulated
Image

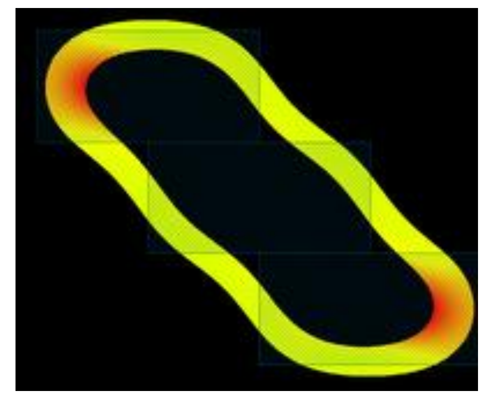




Dose Margin



Bad DM
(red -- left and right)



Worse Dose Margin when printed features deviate from drawn

- Small features
- Line-ends
- Sharp corners
- Tight pitch

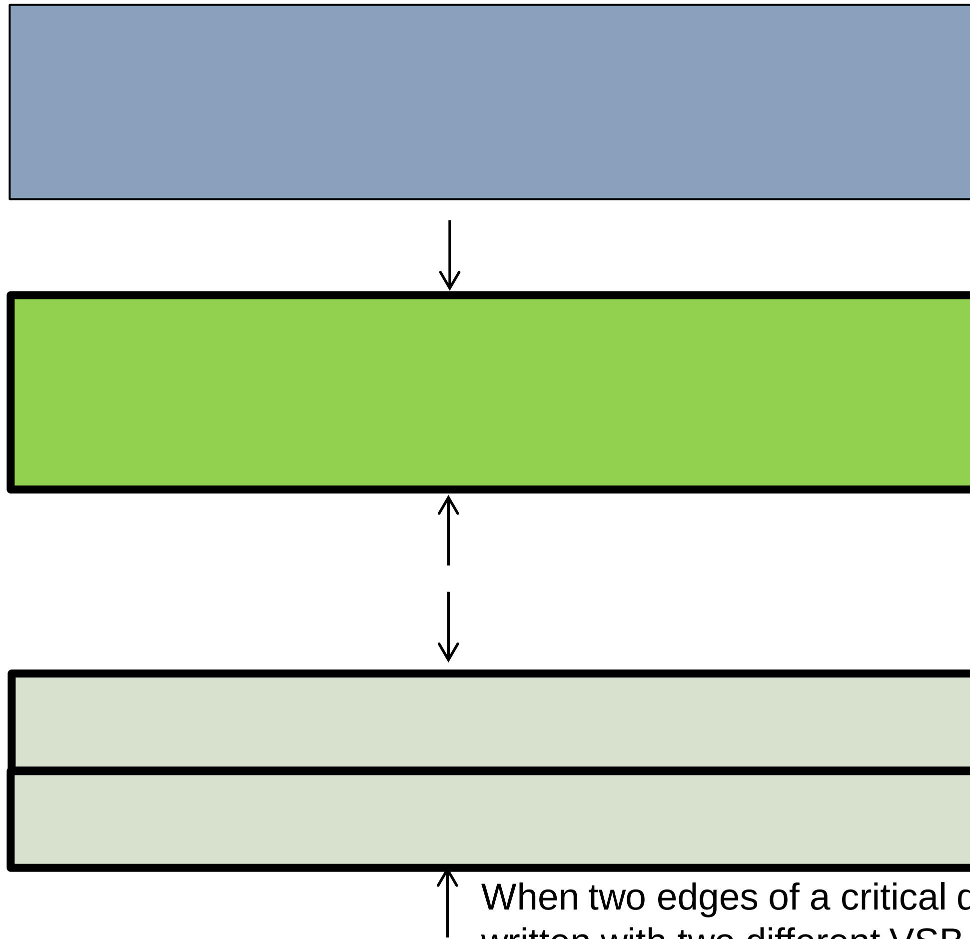
Conventional MPC cannot address problem
MB-MDP overlapping shots creates margin

CD Split is Another Key to CDU

Desired
Mask Shape

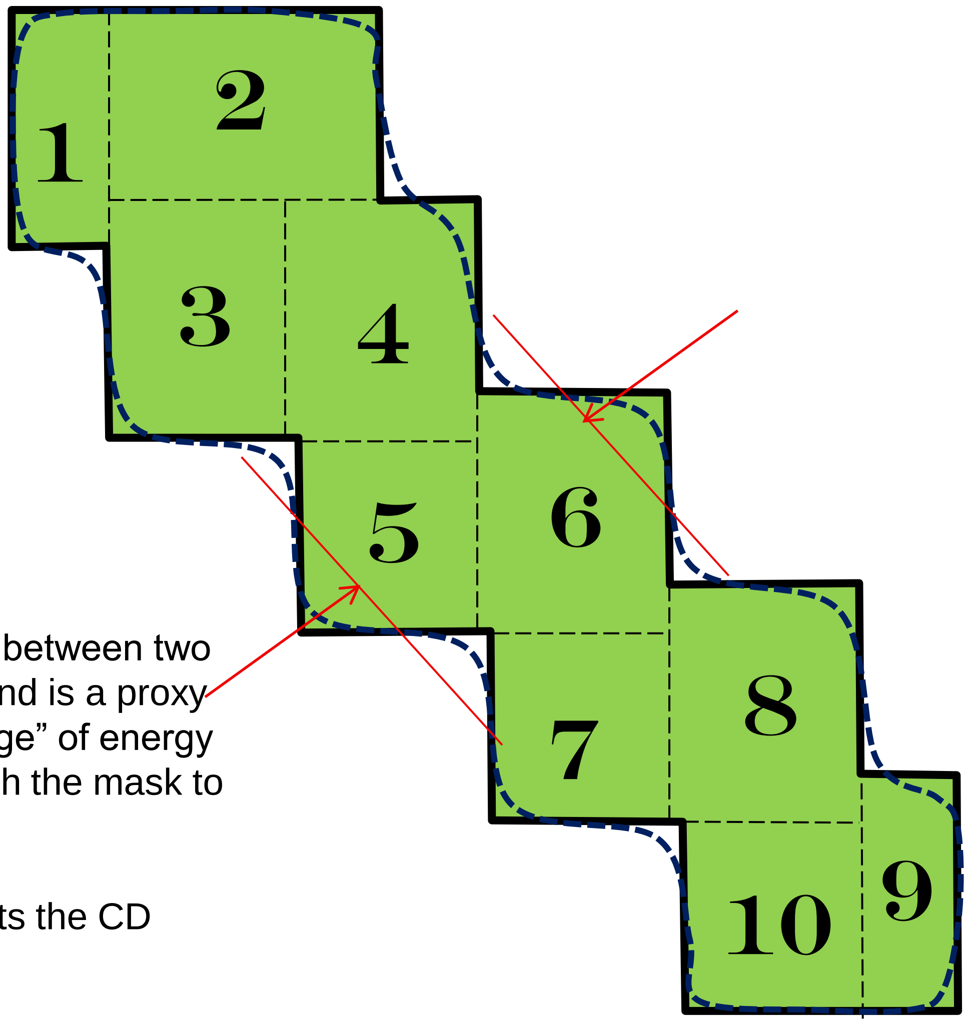
One Shot Solution
No CD Split

Two Shot Solution
With CD Split



When two edges of a critical dimension are written with two different VSB shots, positional error of the writer translates to worse CDU

Complex ILT with non-orthogonal SRAFs

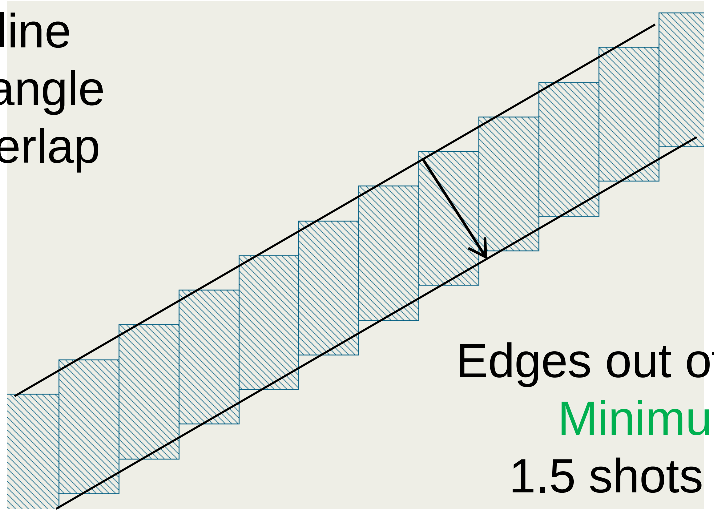


"CD" is measured between two wavy line edges and is a proxy for "running average" of energy transmitted through the mask to the wafer.

Shots 5 and 6 splits the CD

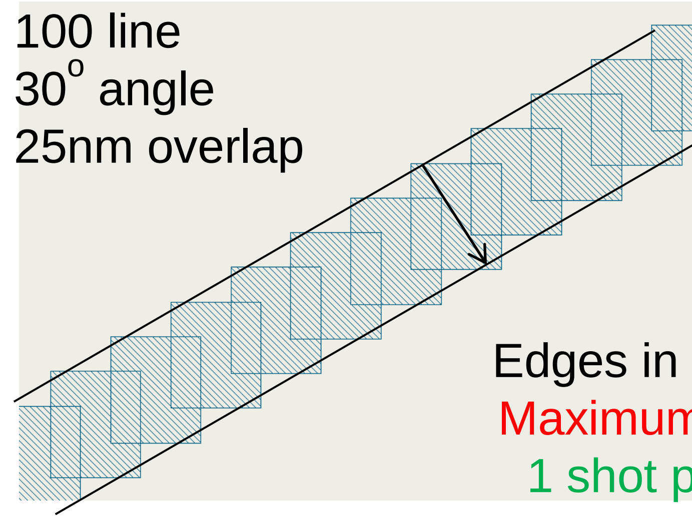
Modulating CD split with overlap

100 line
30^{o} angle
0 overlap



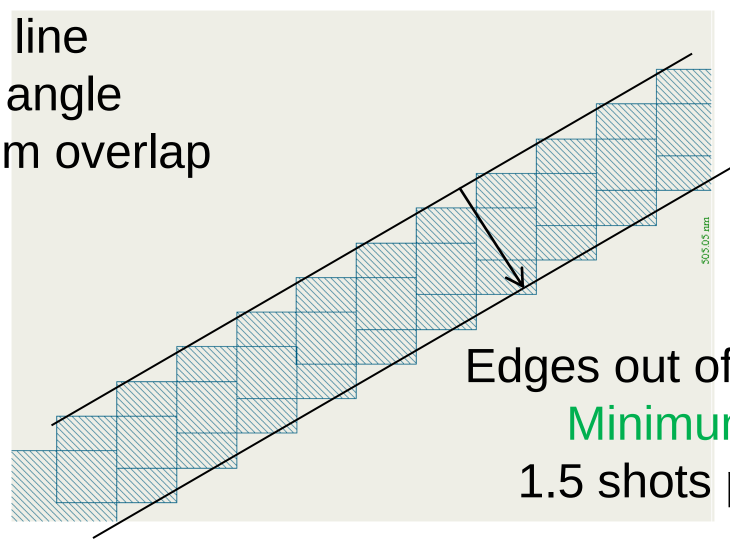
Edges out of phase
Minimum LWR
1.5 shots per CD

100 line
30^{o} angle
25nm overlap



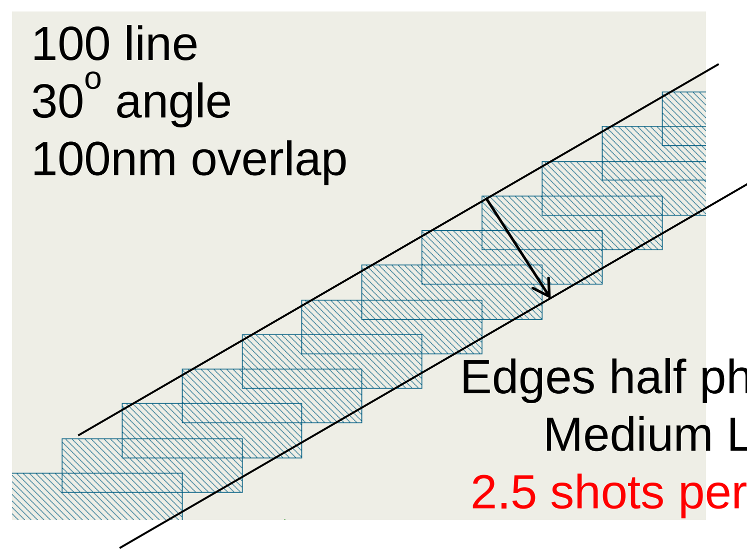
Edges in phase
Maximum LWR
1 shot per CD

100 line
30^{o} angle
50nm overlap



Edges out of phase
Minimum LWR
1.5 shots per CD

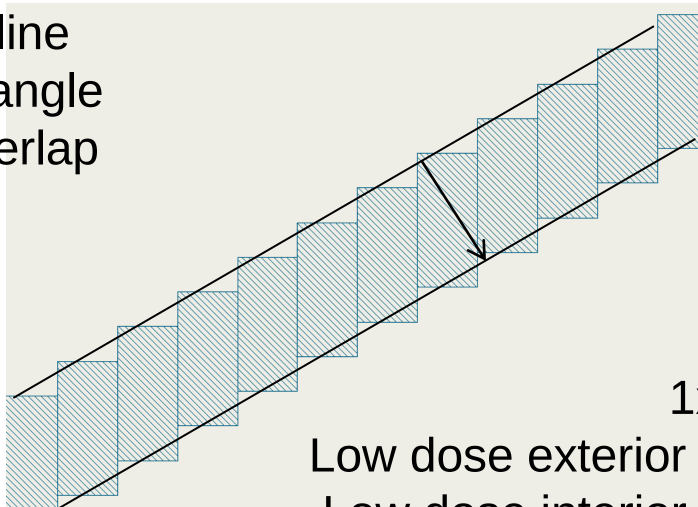
100 line
30^{o} angle
100nm overlap



Edges half phase
Medium LWR
2.5 shots per CD

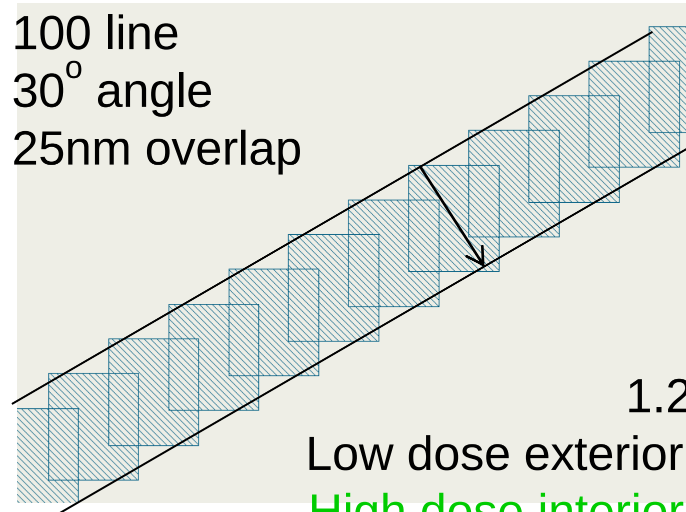
Modulating Dose Margin with Overlap

100 line
30^o angle
0 overlap



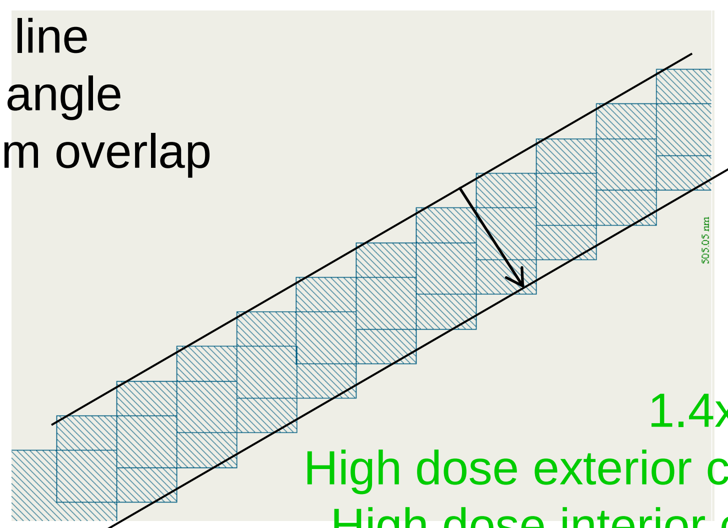
1x dose
Low dose exterior corner
Low dose interior corner

100 line
30^o angle
25nm overlap



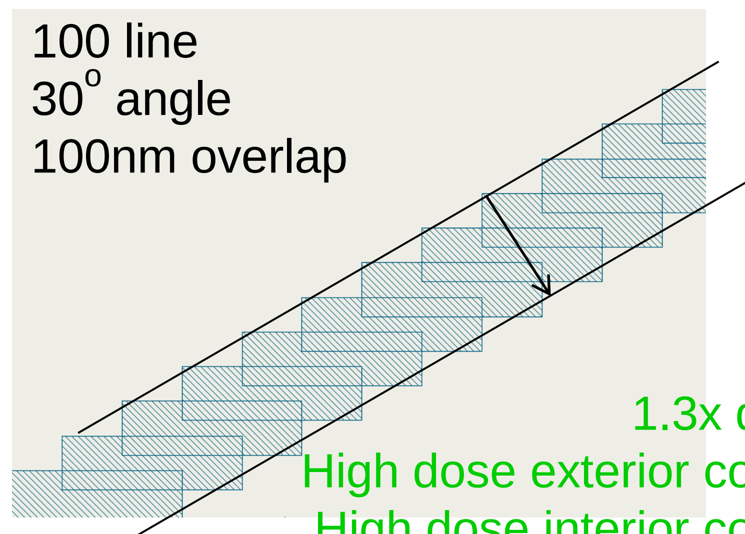
1.2x dose
Low dose exterior corner
High dose interior corner

100 line
30^o angle
50nm overlap



1.4x dose
High dose exterior corner
High dose interior corner

100 line
30^o angle
100nm overlap



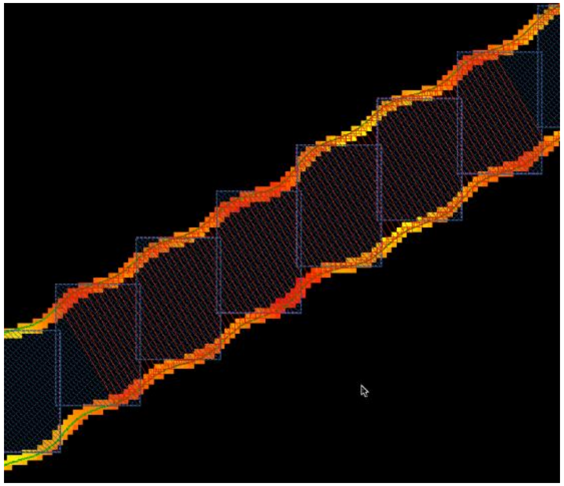
1.3x dose
High dose exterior corner
High dose interior corner

Overlapping VSB shots provide options

- **In the past, we have not had to think about shot optimization. There was really only one way to do things.**
  - Shape defines your shot placement
    - VSB restricted to manhattan (0,90,+/-45) angles
    - Arbitrary shapes at a cost of finer manhattanization
      - Costs in both write time and CDU.
  - Minimize overall number of shots (write time)
  - Co-optimize CD-split minimization with sliver avoidance (CDU)
    - Cost to write time for this
- **Introduction of overlapped VSB shots provides an extra degree of freedom**
  - Can it be possible to improve on all three elements at the same time?
    - Reduce or remove shape restrictions?
    - Simultaneously write a mask faster while improving overall CDU?

Simulation Experiment

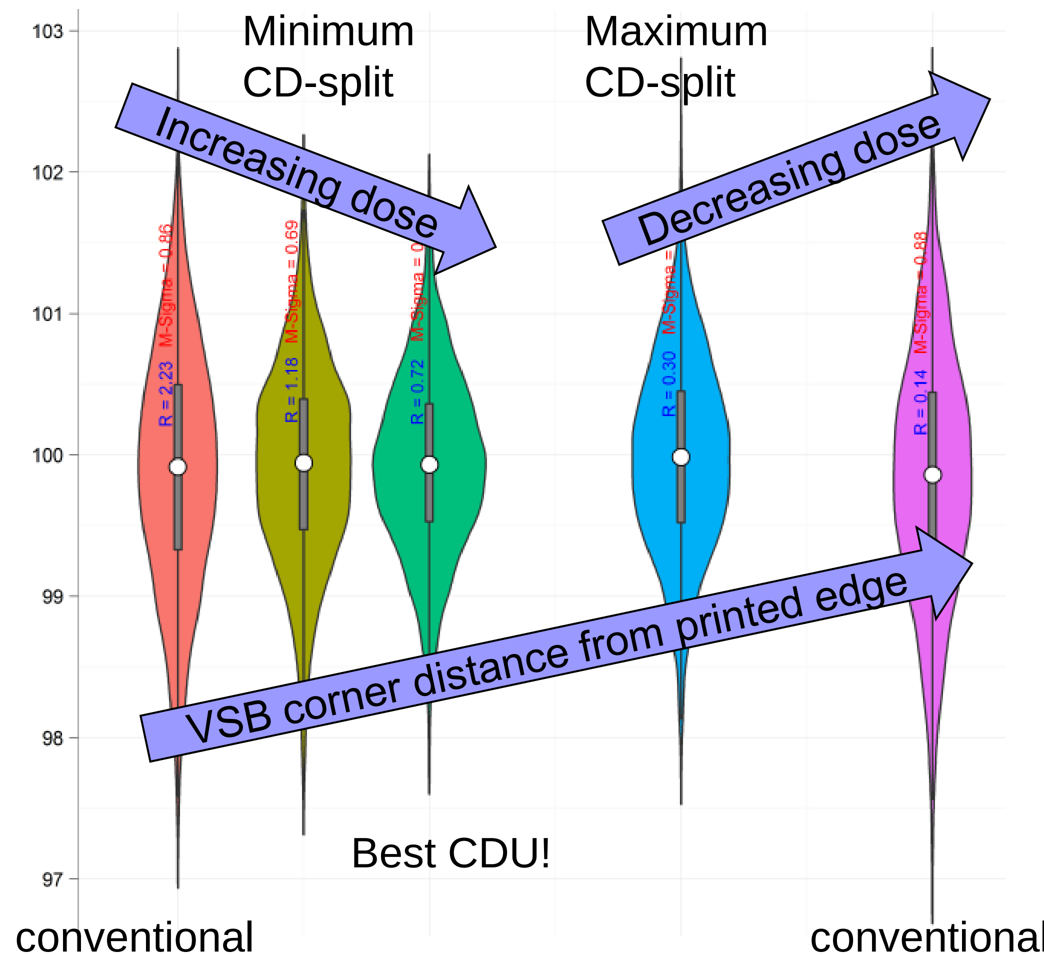
- **Monte Carlo simulation of effect of shot and dose variability on many long 30 degree ILT srafs**
  - Vary dose (σ=5%)
  - Vary position (σ=1.5nm)
  - Vary shot density (50-100% of conventional shots)
    - Affects: aspect ratio of rectangles, degree of overlap



CDU at constant pitch

		CD	
shot count	width	average	sigma
100	50	99.9	0.9
100	75	99.9	0.7
100	100	99.9	0.6
100	150	100.0	0.7
100	200	99.8	0.9

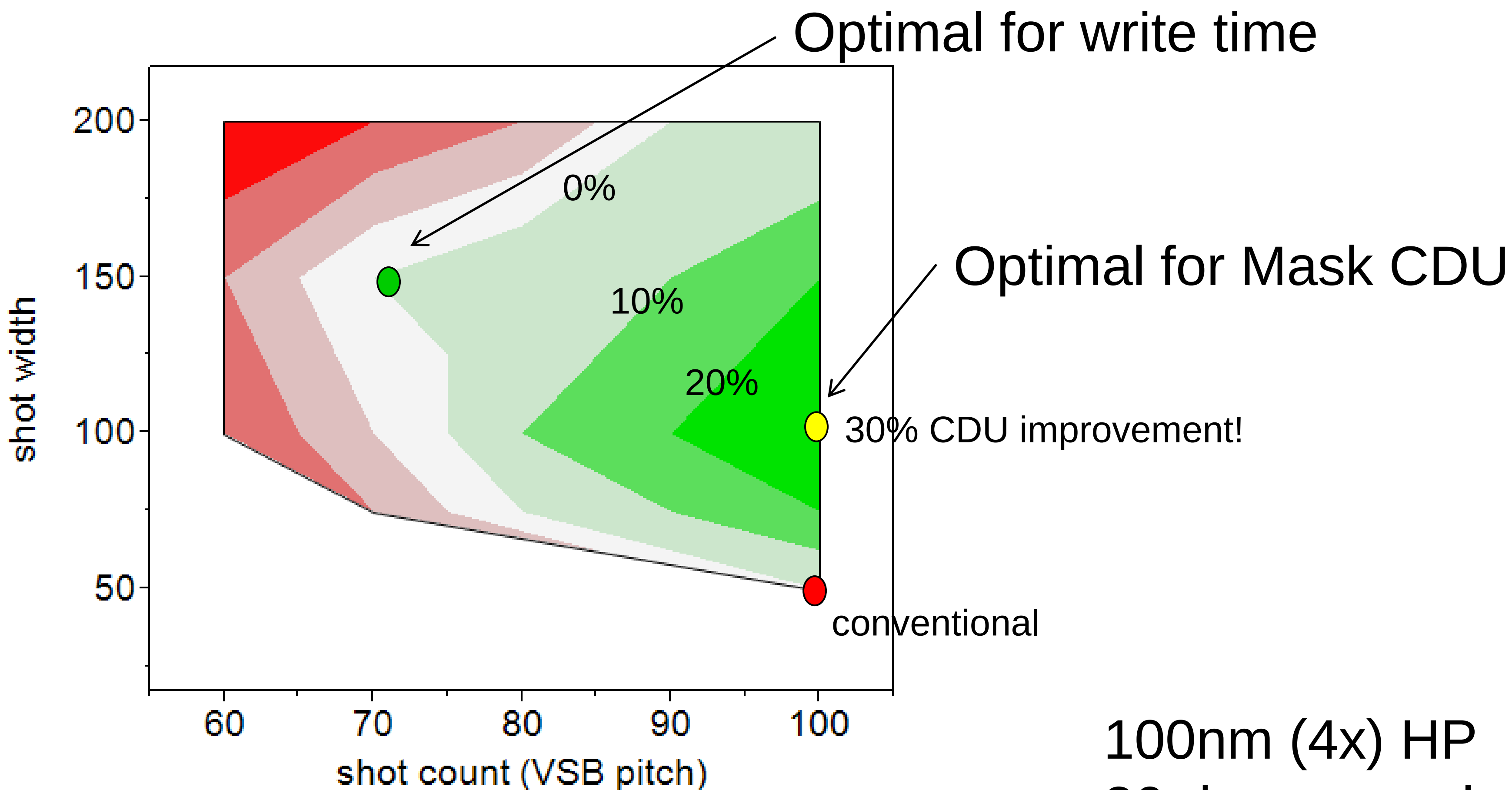
Drawn LWR



shot width 50 75 100 150 200

Optimal amount of VSB overlap which minimizes overall CDU at a given shot density.

Determining the optimal shot



100nm (4x) HP
30 degree angle

Which mask do you want?

Write a mask with 33% better wafer variability

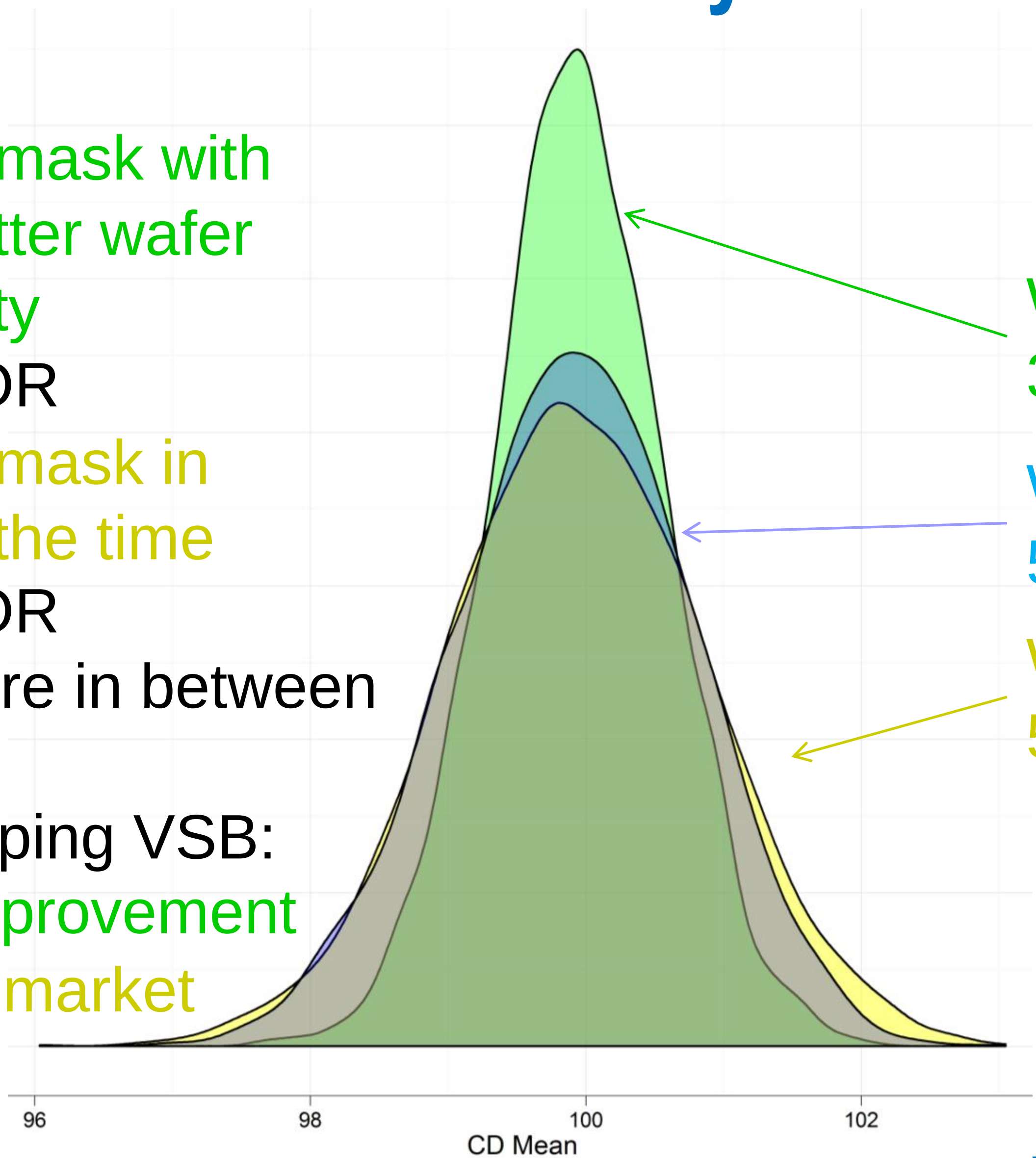
OR

Write a mask in 70% of the time

OR

Anywhere in between

Overlapping VSB:
Yield improvement
Time to market



Write time 1 a.u.
3.6nm, 6sigma

Write time 1 a.u.
5.4nm, 6sigma

Write time 0.7 a.u.
5.4nm, 6sigma

Mask CDU
100nm (4x) HP
30 degree angle

Model-Based Mask Data Preparation Impact on Mask Accuracy & Write Times

Mask Division
HOYA Corporation
19 April 2012
eBeam Initiative Lunch

Motivation

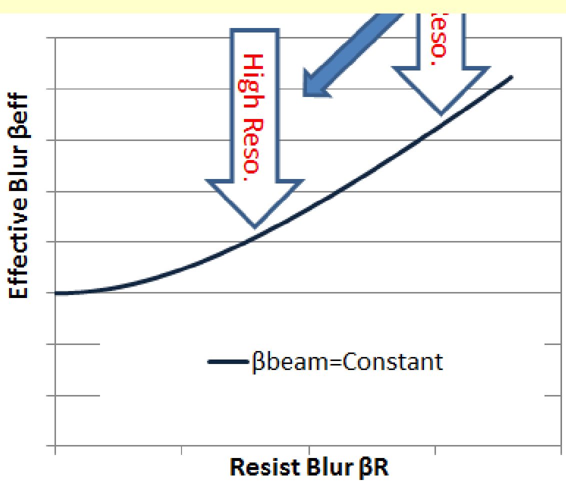
- **Fidelity Limit**
- **Too Much Writing Time for SMO mask.**
  14nm node needs 2X～8X shot counts than 22nm node @ previous eBeam Initiative Lunch Meeting
- **Limit of Rule Base Correction of SRAF.**
  CD of Main pattern is closing to CD of SRAF .
  we shall apply model base correction to main.

Limit of Fidelity

$$\beta_{eff}=(\beta_{beam}{}^2+\beta_{Resist}{}^2)^{1/2}$$

Beam Blur β_{beam} of 50kV VSB EB Writer
is Constant for More than 10years.

More smaller β_{beam} is required.
HOYA does not agree too high current !



Advanced Resist
Beam Blur β_{beam} > Resist Blur β_{Resist}

Advancement of Resist decrease to enhance Resolution.

β_{eff}: Effective Blur, β_{beam}: Beam Blur, β_{Resist} : Resist Blur

Why MB-MDP is Good for Mask Making

Requirements: Shot count reduction,
Fidelity Enhancement,
Works well with our machine

MB-MDP: Dose, Figure, Overlap 3Dimension
+ ○Aperture 4Dimension

**To achieve challenging requirements,
we need as many dimensions of correction
flexibility as possible!
MB-MDP has the most dimensional control.**

Experimental

MB-MDP condition

β_{eff}=25nm, Eth=0.5

Single Gaussian

Test Pattern

Phase 1: Qualitative analysis

- SMO

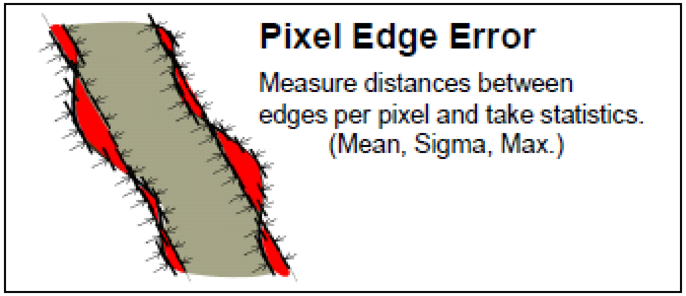
  3D: Dose, Figure, Overlap

Phase 2: Quantitative analysis

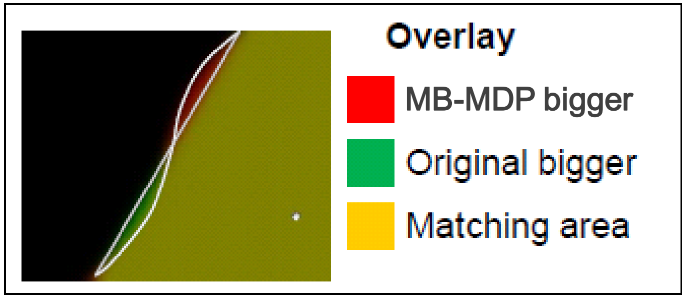
- Diagonal

  2D: Figure, Overlap

- Error Analysis
  - Per Pixel Edge Error.
    - Compare EB-simulated image by shots with target image.



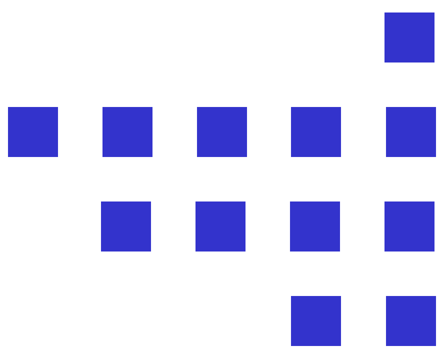
  - Overlay Image
    - Overlay to check visibly.



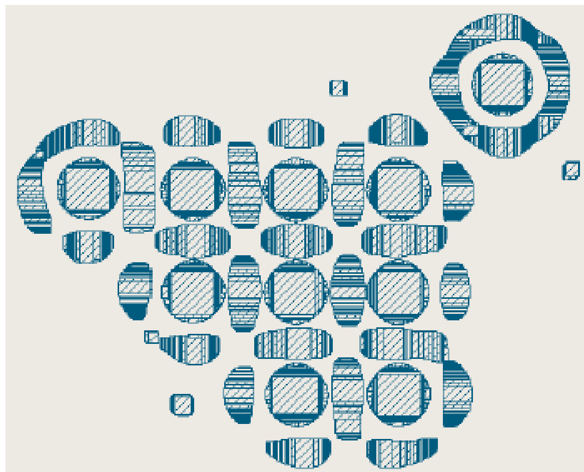
SMO（Qualitative analysis）

- Target hp64 60nm Hole 6% HT
  No Limitations of MRC & DRC. Example for 8nm Gaps on mask

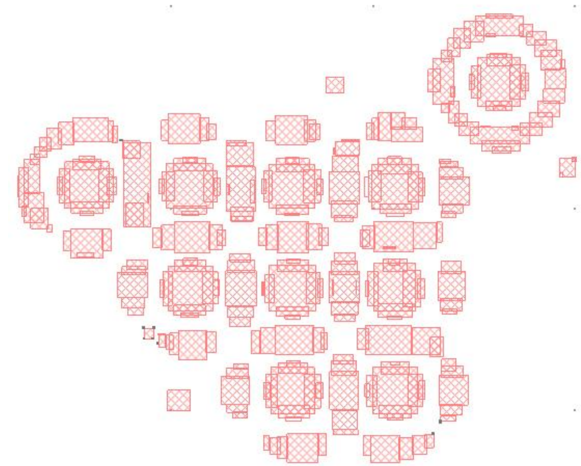
Original



Conventional



MB-MDP



10 Shots → SMO → 2266 Shots → MB-MDP → 267 Shots

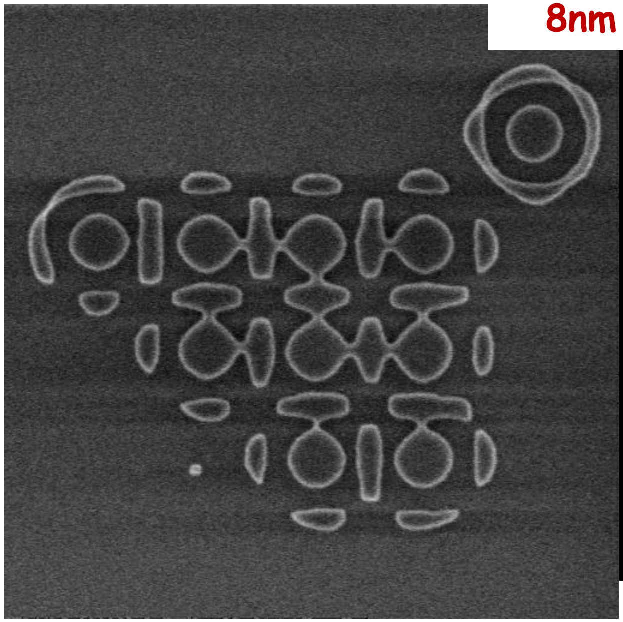
1/8 Shot Count Reduction

Less than Conventional !

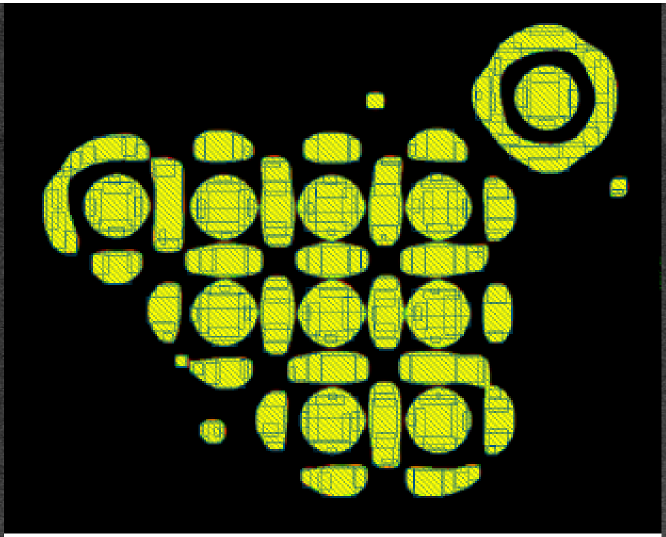
Per Pixel Edge Error (nm)		
Mean	Sigma	Max.
0.01	1.36	6.78

SMO（Qualitative analysis）

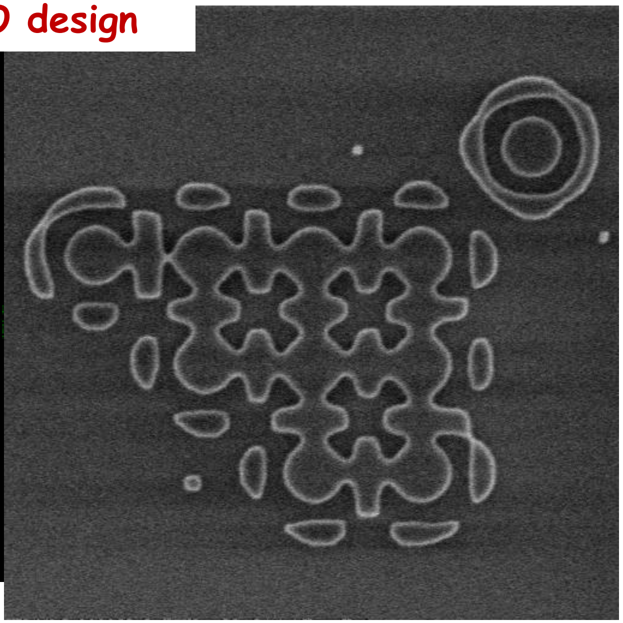
8nm Gap on Mask exists in original SMO design



Best Separation
Smaller CD



EB-simulated image
of MB-MDP



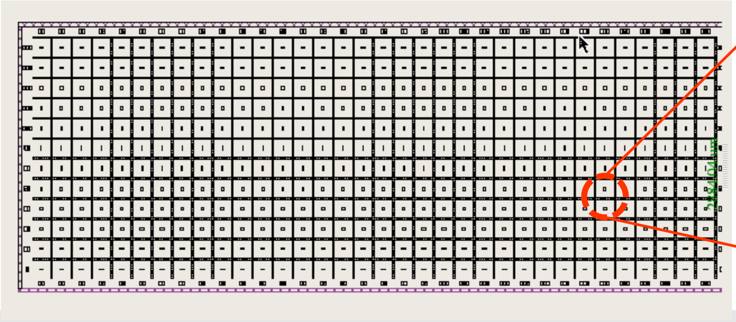
Best CD
Bad Separation

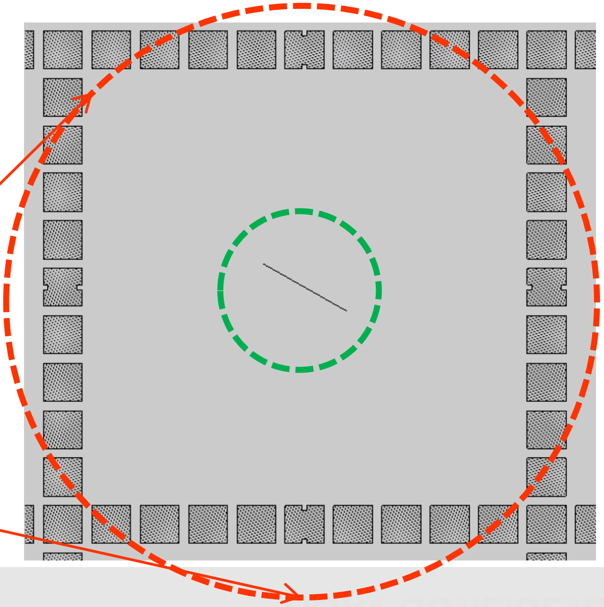
New type of DRC & MRC are necessary.
More Model calibration is progressing
to realize this pattern on Mask.

exposed with JBX-3200

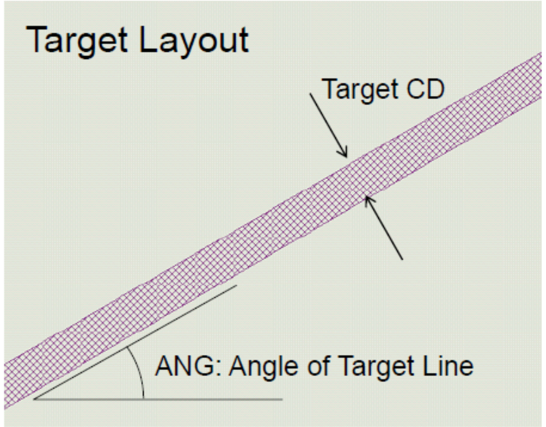
Diagonal（Qualitative analysis）

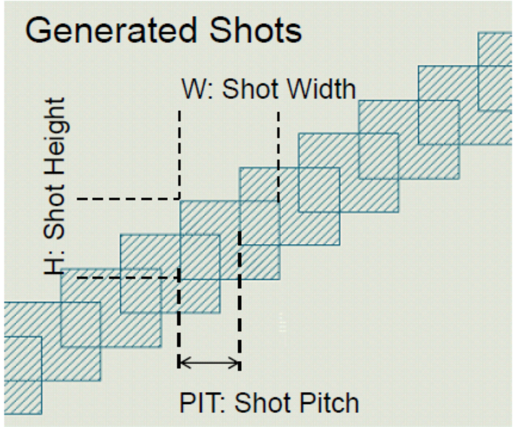
- Isolated Line for each CD & angle combination
- CD 40～200nm
- Angle 0～165° step 15°
  Too much data, So we report only 135° .
- Line Length 20um
- 2D: Figure, Overlap Same shot rank in One Line.
- JBX-3200 exposed Diagonal.
- Basic Dose of Block changes.
- CD, LWR, Dose Margin
- MB-MDP Aims Dose Margin

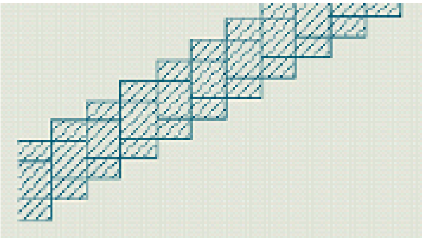




MB-MDP Fracturing Policy



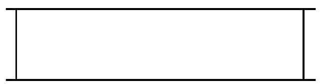
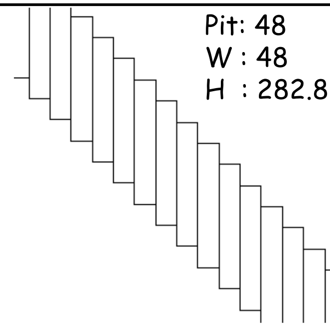
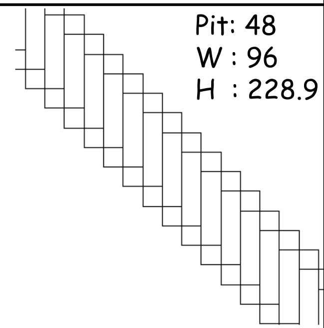
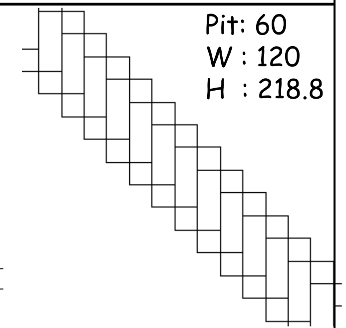
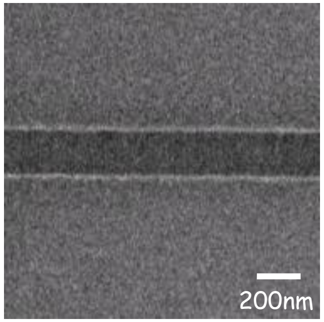
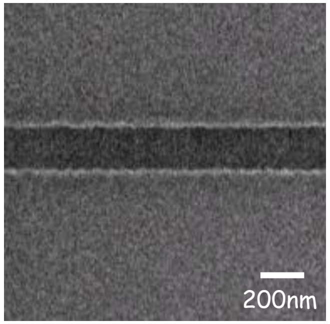
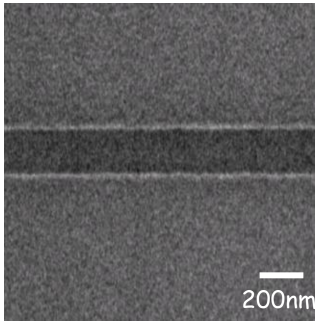
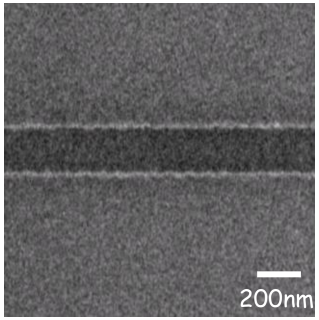
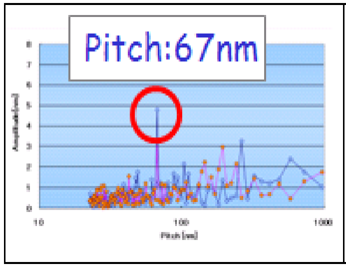
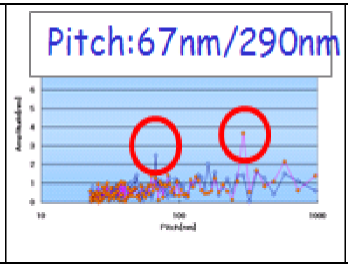
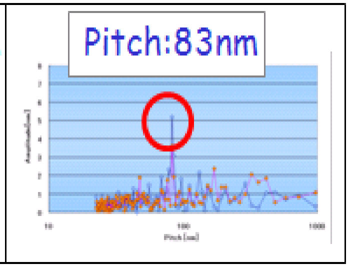




MGN Pattern
Pitch=Shot Width
=Shot Height

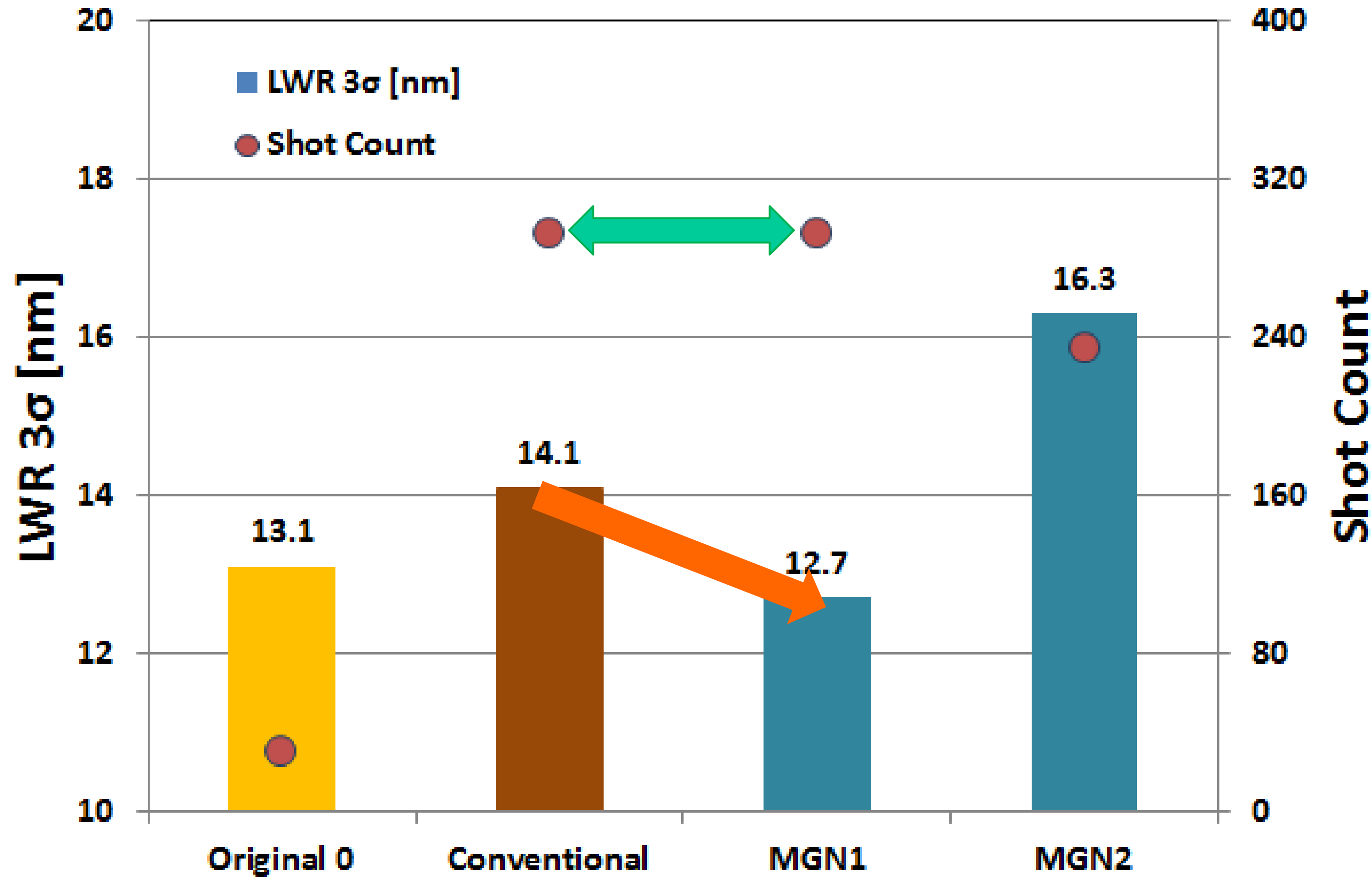
Data Set	
Conventional	Rectangle with pitch 48nm≒2*β eff
MGN1	Margin optimized width same pitch of Conventional
MGN2	Margin optimized with wider pitch (60nm) for 20% shot count reduction from Conventional.

Comparison of MGN-Pattern SEM image

	Original 0	Conventional	MGN 1	MGN 2
Design				
SEM Image				
FFT	No Peak			

- Measured CD : 200nm
- SEM images are appleid scan rotation

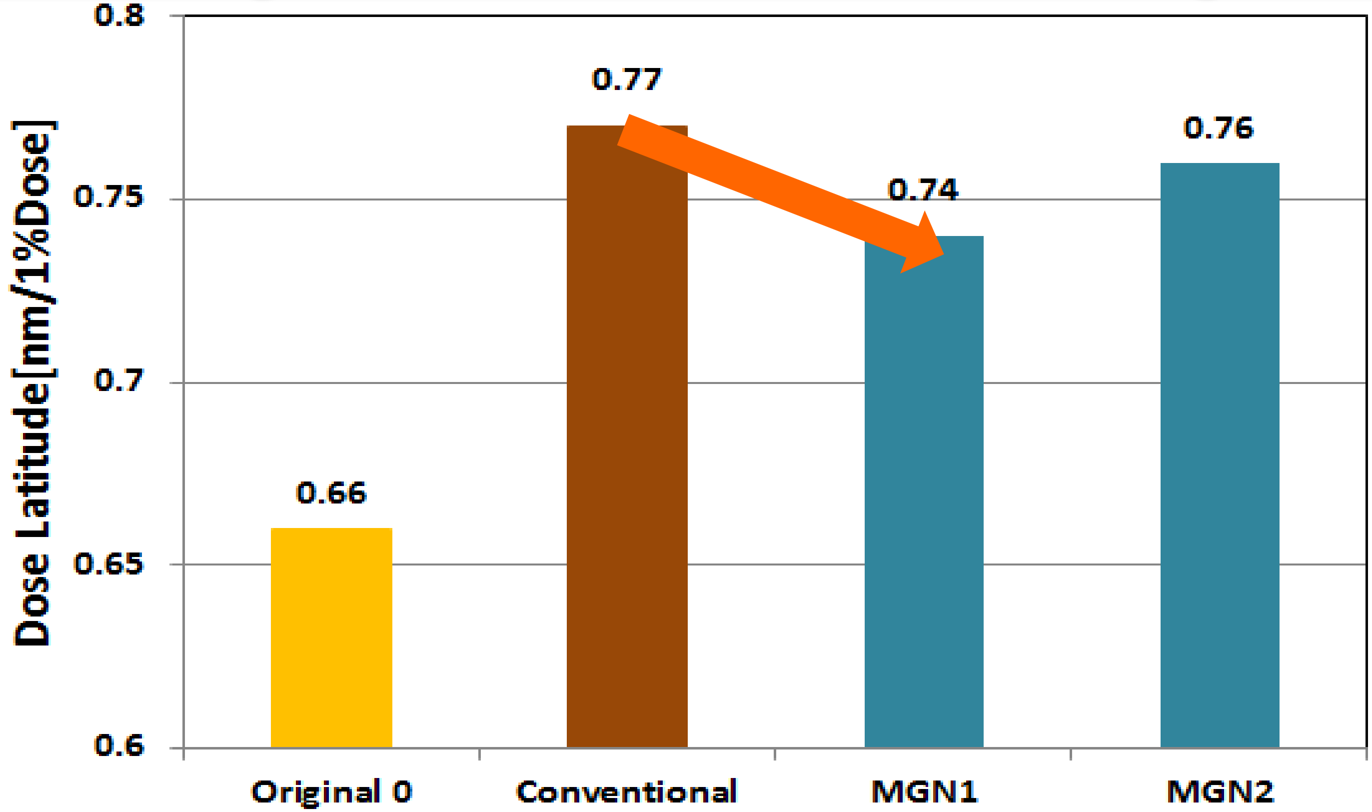
LWR & Shot Count Results of 135° Diagonal



MGN1 has the Best LWR.

Measured CD is 200nm, Box : 2900nm, 256Samples

Dose Margin Results of 135° Diagonal



MGN1 has better Dose Margin!
Now analyzing results more and will show them in detail at BACUS!

Measured CD is 200nm

Conclusion

- Model-based correction is required for Shot Count Reduction and Fidelity Enhancement.
- High Dimensional Correction is required

  to satisfy the increasingly difficult requirements.
- MB-MDP dramatically reduces shot count for complex patterns.
- HOYA found MGN1 has better Dose Margin!

  Now analyzing results more and will show them in detail at BACUS!
- More Model calibration is progressing.

Proof Point on MB-MDP & Wafer Quality Simulation

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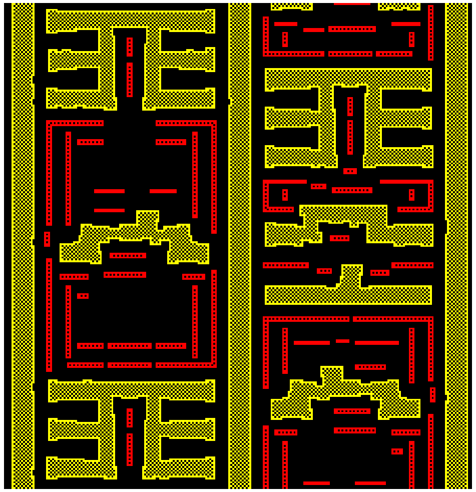
GLOBALFOUNDRIES

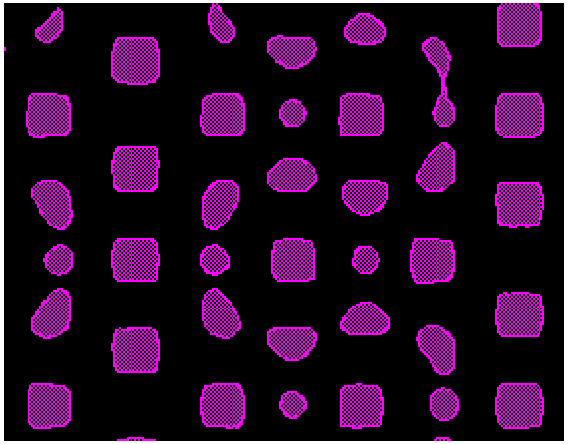
April 19, 2012

Outline

- Motivation
- Results & discussion
  - Example 1: 20nm Non-ILT Metal LOGIC
    - Lithography simulation verification results
    - CD uniformity check (new during PMJ 2012)



  - Example 2: 20nm ILT Via SRAM
    - Quality & mask shot count reduction trade-off
    - Lithography simulation verification results

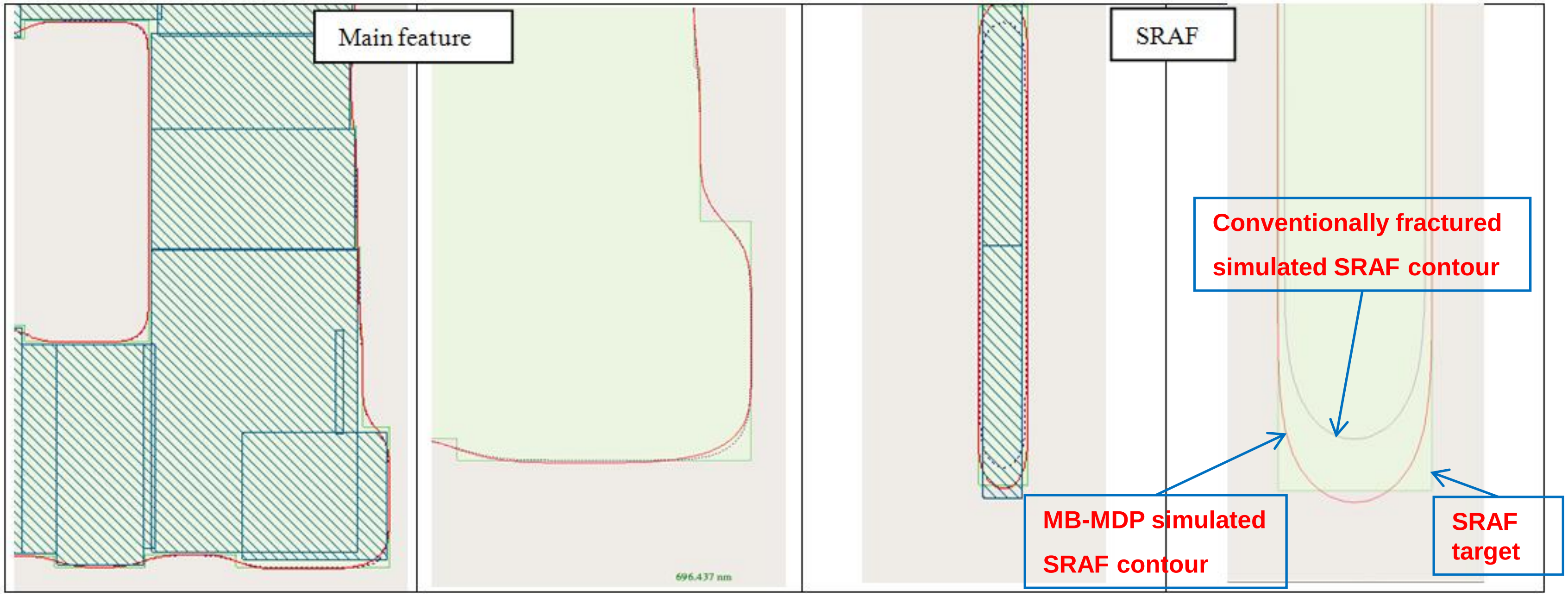


- Conclusions

Motivation

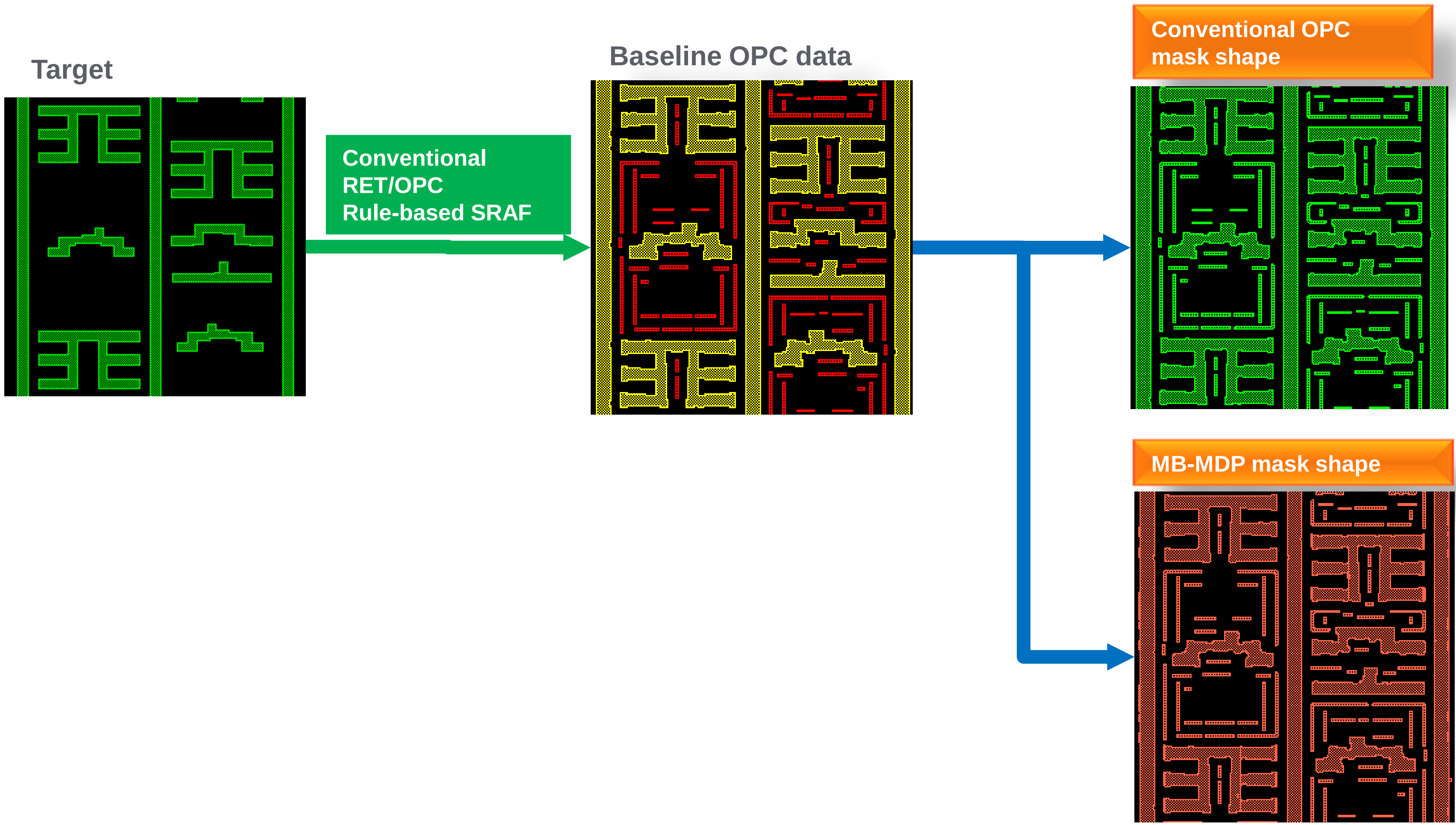
- **Current solution is a step-by-step solution, OPC → Fracturing → VSB format with MPC, which contrains each other and eventually limit in maximizing Wafer PW.**
  - MRC limits OPC flexibility
  - Mask Process (resolution limit, corner rounding) limits Free-Form OPC
  - Flat OPC signature requirement to mask limits Mask Process Optimization, such as mask resolution or CDU enhancement.
- **It is ideal if we have a solution to optimize above interactive factors at the same time.**

Example 1: Model-Based Mask Data Preparation (MB-MDP) for non-ILT metal



- Images show shot configuration and simulated mask contours for Main Features (left) and SRAFs (right)
- There are no abrupt mask contour differences for the main feature while maintaining close to 20% mask shot count reduction
- While shot count for purely rectangular SRAFs cannot be further reduced, MB-MDP can correct the CD non-linearity observed at such small dimensions and get the SRAFs back to target.
- The simulated CD loss for those 60nm SRAFs is 5nm which gets corrected during the MB-MDP step.

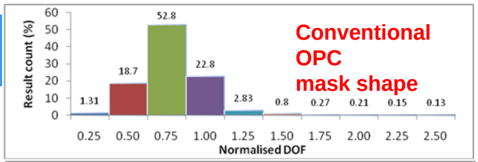
Example 1: Description of test case preparation for non-ILT layout

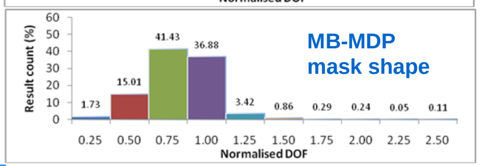


Example 1: Litho simulation verification on 20nm metal LOGIC

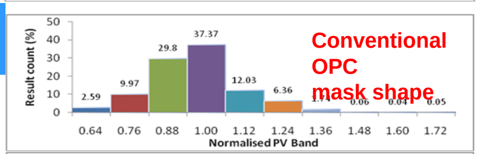
- MB-MDP improves shot count by 20%
- MB-MDP improves wafer CDU for some patterns by improving mask fidelity for small SRAFs
- PV Band, MEEF, and DOF are slightly improved with MB-MDP

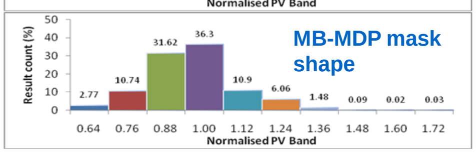
DOF



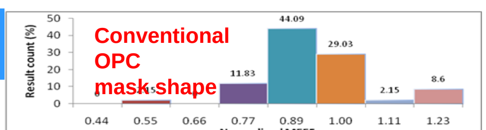


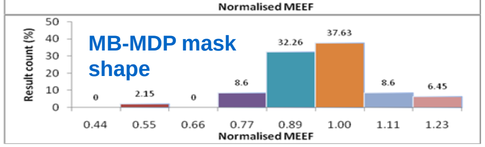
PV Band



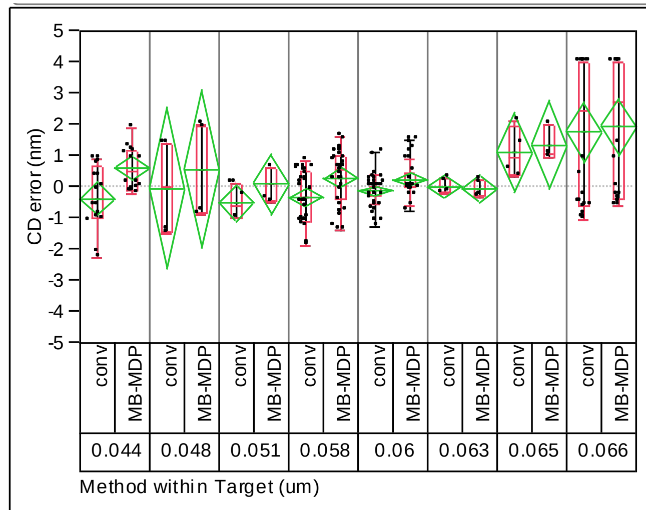


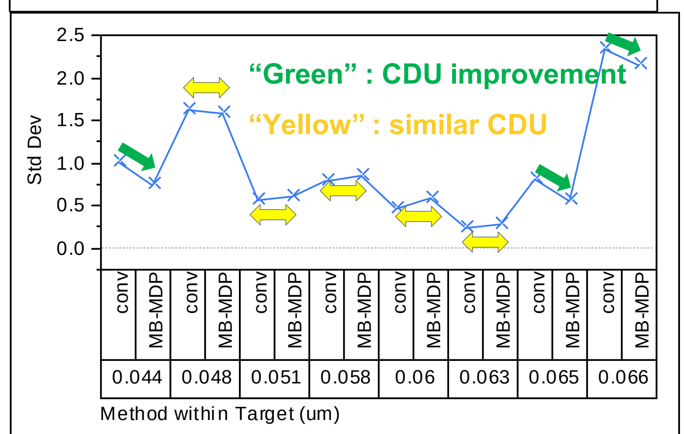
MEEF



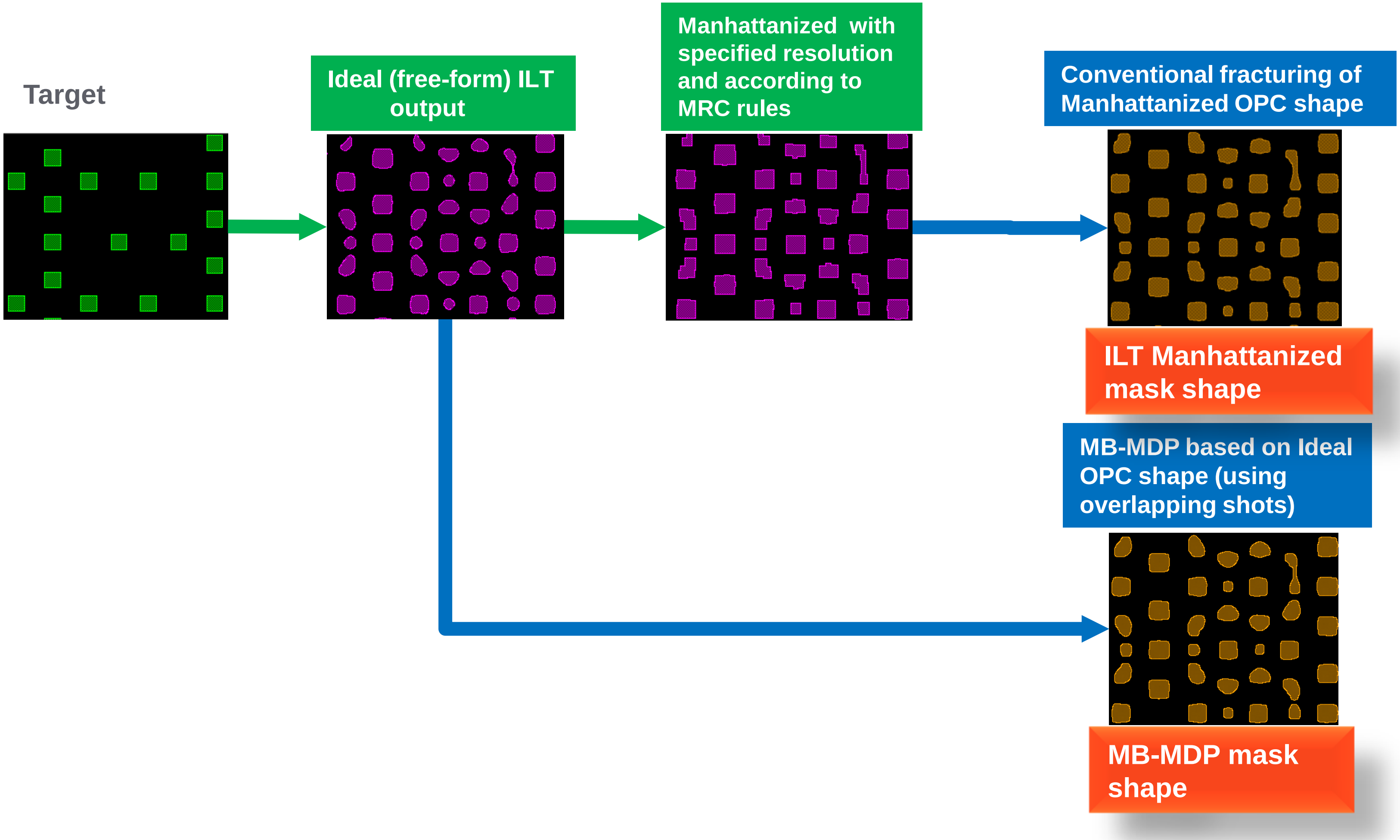


Wafer CD uniformity



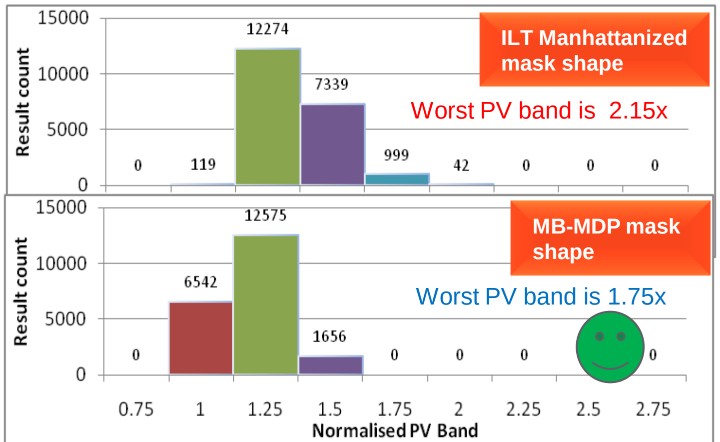


Example 2: Description of test case preparation for ILT layout

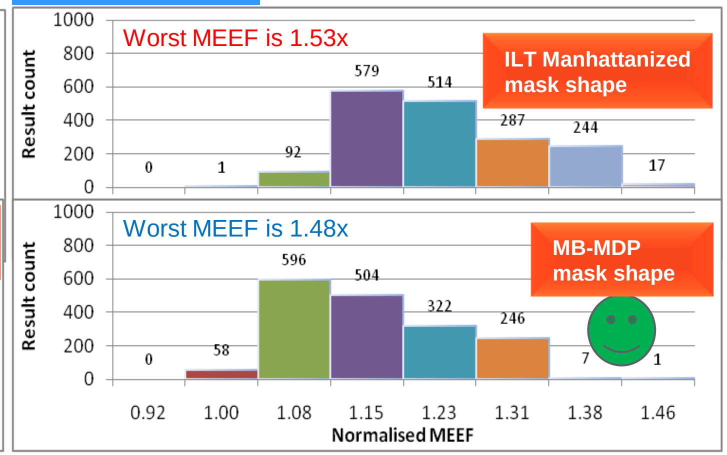


Example 2: Litho simulation verification on 20nm Via SRAM

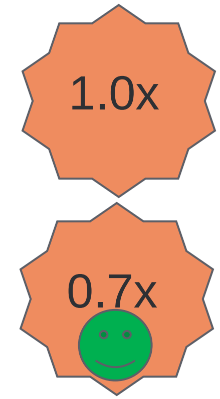
PV Band



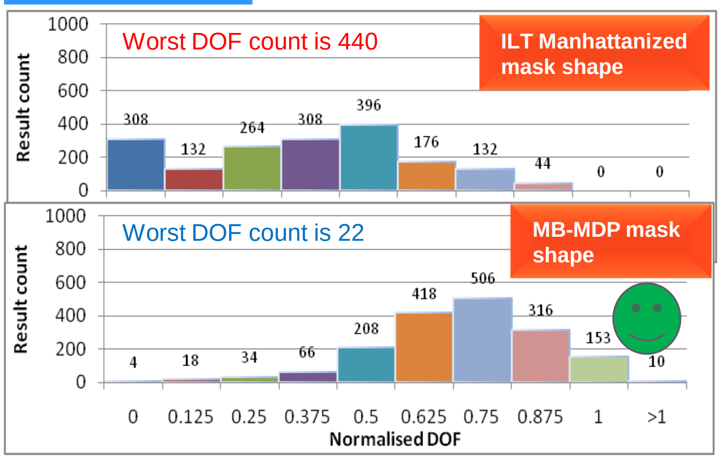
MEEF



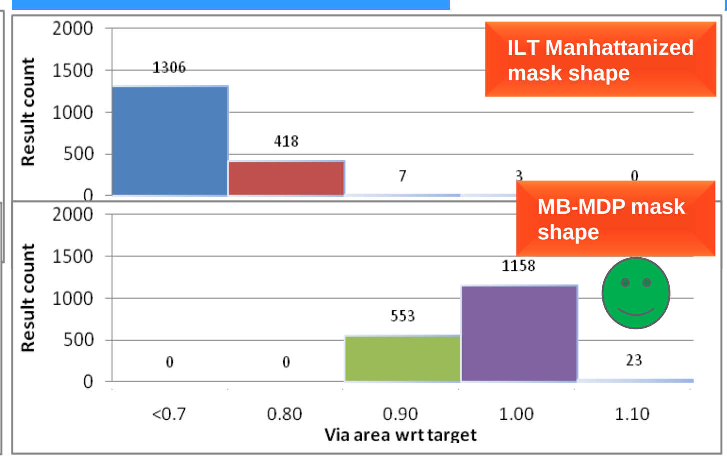
Shot count



DOF



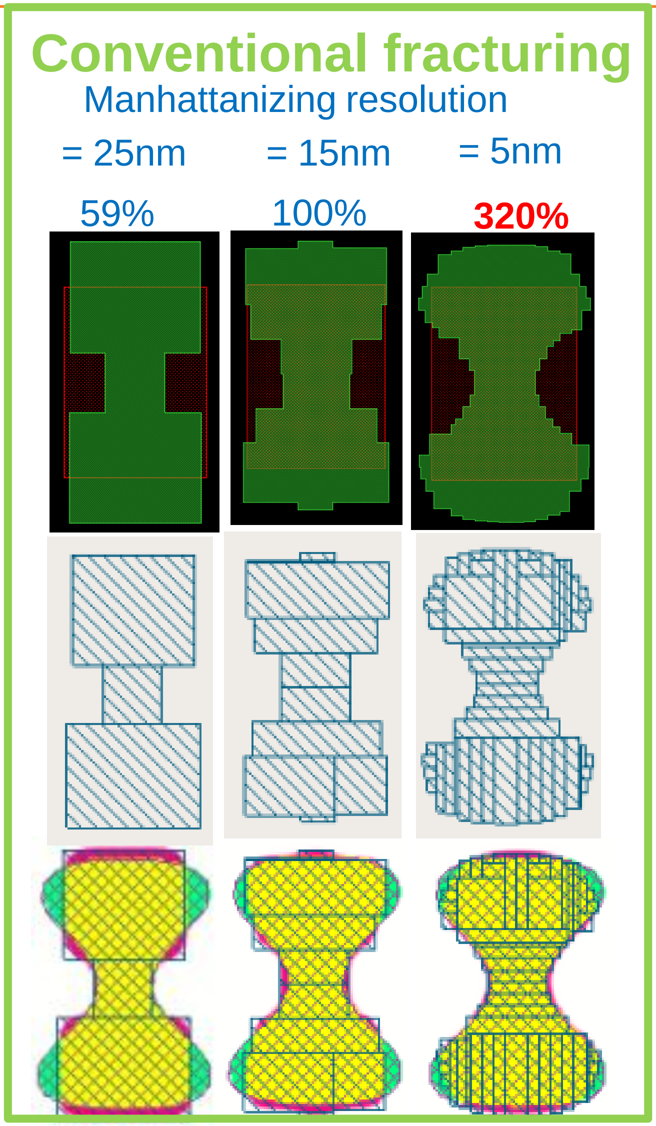
Via area wrt target

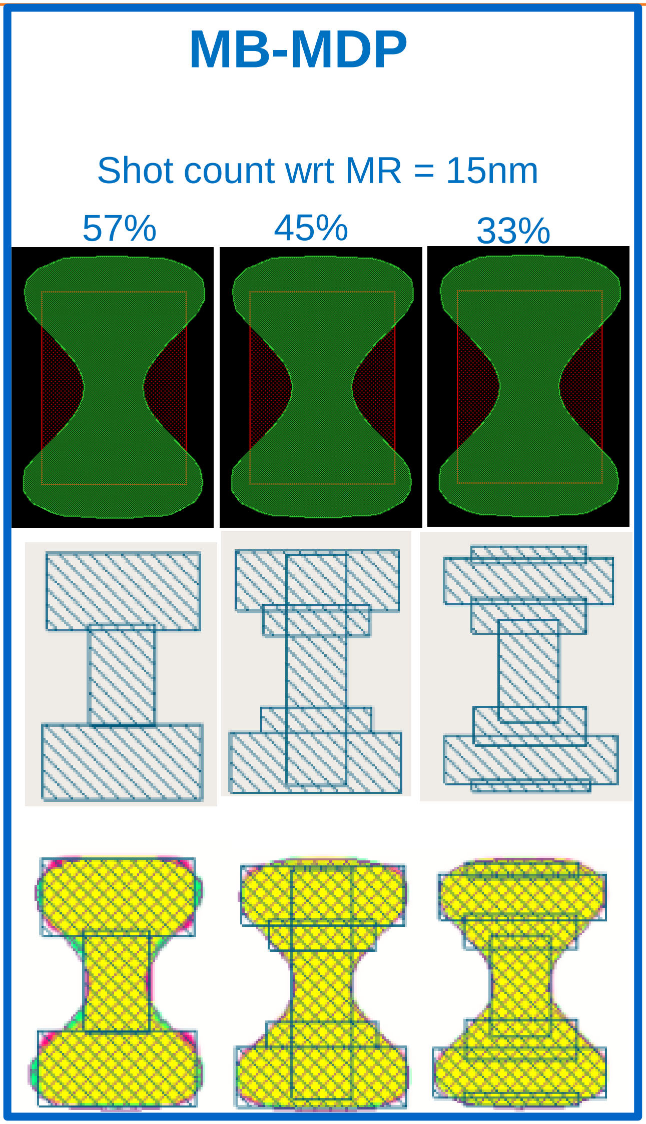


MB-MDP:

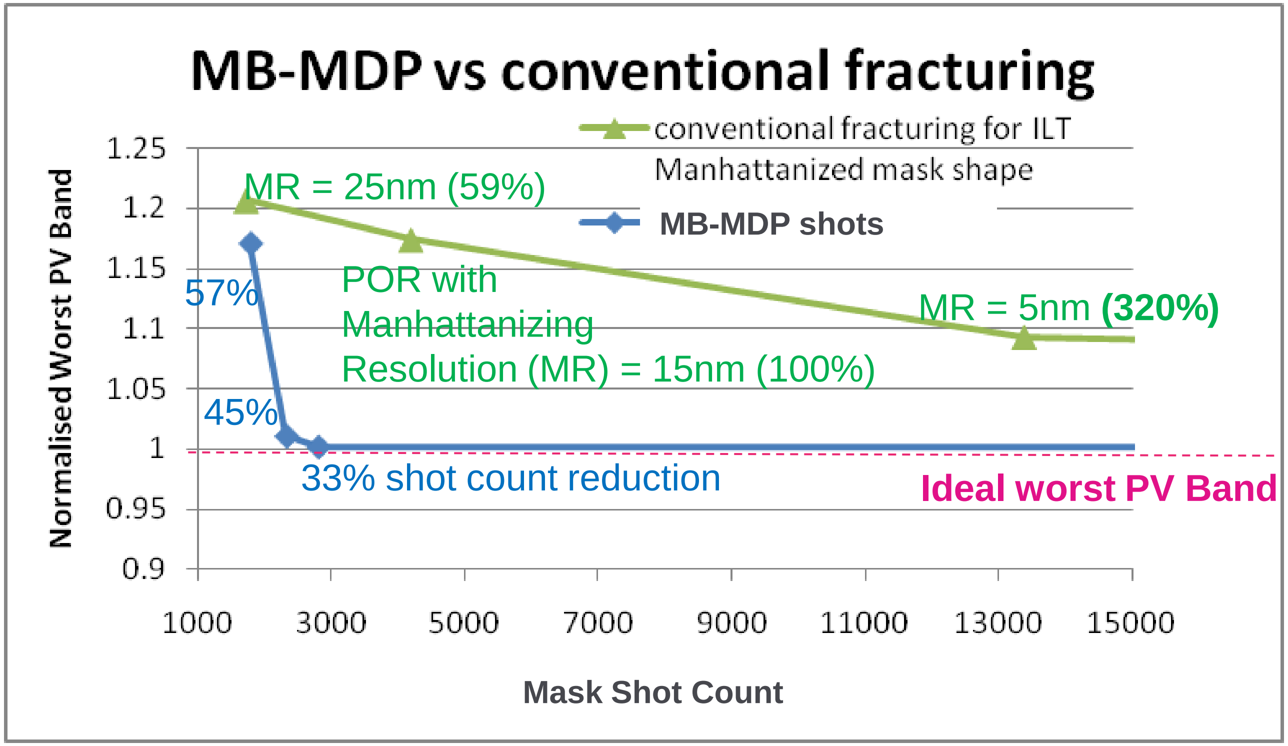
1. 33% shot count reduction
2. 30% better PV Band
3. 10% better MEEF
4. 50% better DOF
5. 30% better MTT
6. All improvements are shifting the whole curve (worst, best, and average all improve)

Example 2: 20-nm ideal ILT SRAM via patterns





Example 2: Wafer quality vs. mask shot count



- **Conventional Fracturing:** Manhattanized ILT required 13,000 shots and a 5nm resolution to get within 10% in PV Band of “ideal”
- **MB-MDP:** Using overlapping shots, the worst-case PV Band improved to the level of the “ideal” OPC for <3000 shots
- Litho performance similar to “ideal” shapes can be achieved by writing curvilinear shapes with MB-MDP
- MB-MDP improves the trade-off curve of litho performance vs. mask write times:
  - “Ideal” shapes are production worthy with this approach

Conclusion

- Overlapping shots created by MB-MDP enable lowered shot count (and therefore faster write times) while simultaneously maintaining or improving lithography process window on the wafer.
- MB-MDP simulates the effects of shots to produce the OPC-desired contour on the mask plane. This is effective to reduce shot count for complex masks generated by technologies like Source-Mask Optimization (SMO)/ Full Chip Mask Optimization (FCMO), or Inverse Lithography Technology (ILT).
- The effectiveness of MB-MDP is verified on 20nm Non-ILT Metal LOGIC. As main features & SRAF are corrected by MB-MDP, 20% shot count savings and wafer CDU improvement are achievable.
- The effectiveness of MB-MDP is verified on 20nm ILT Via SRAM. The result shows that MB-MDP can reduce variation in a 20nm SRAM contact level layout based on “ideal” inverse lithography patterns. The DOF, CDU, PV-band and MEEF are all dramatically improved while at the same time reducing the shot count by 33%.

Thank you

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