Sept. 30, 2021| AKI FUJIMURA, CEO, D2S, Inc.

Curvilinear masks: an overview

Yohan Choi, Abhishek Shendre, Aki Fujimura

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Why Bother with Curvilinear Masks?

Don't we have enough to deal with already?

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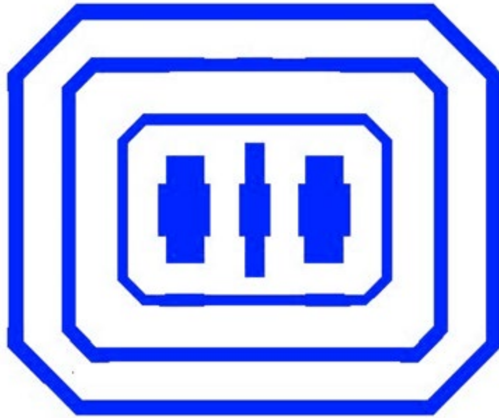
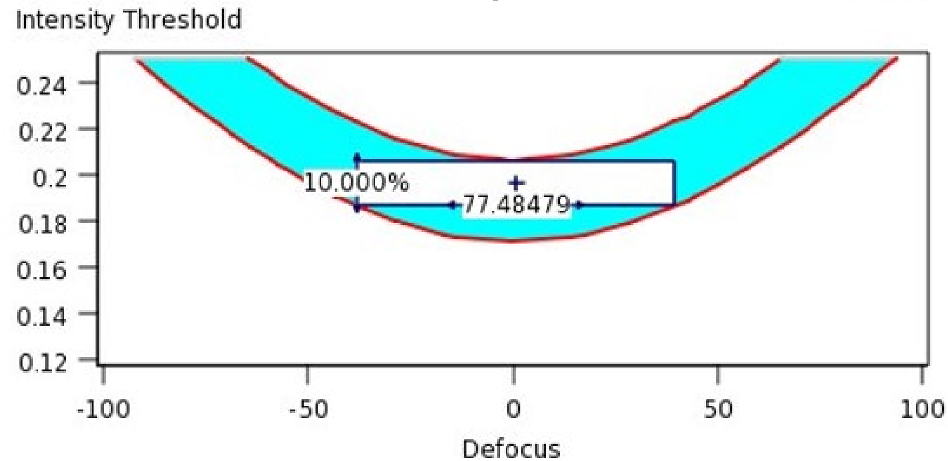
Curvy is Better

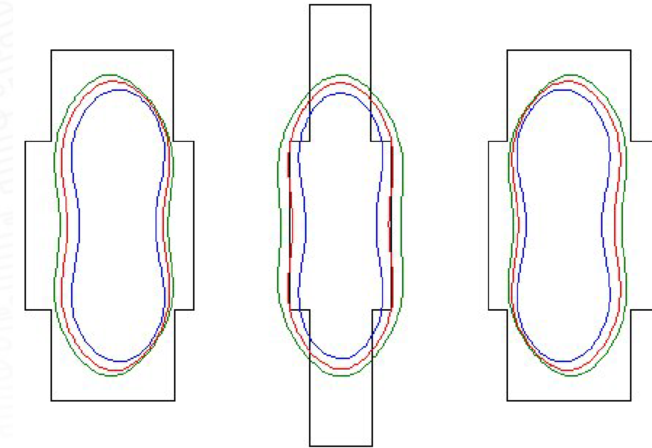
Curvilinear ILT vs. Standard OPC: *First to fail site*

Standard OPC



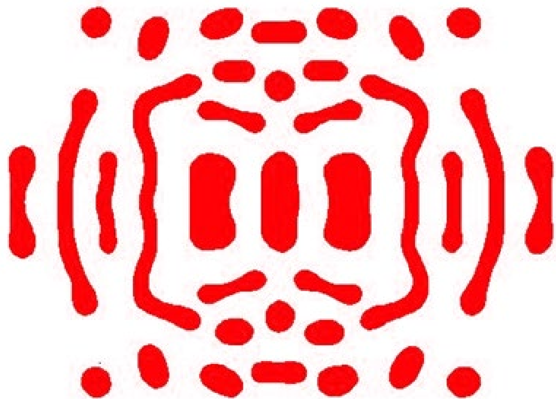


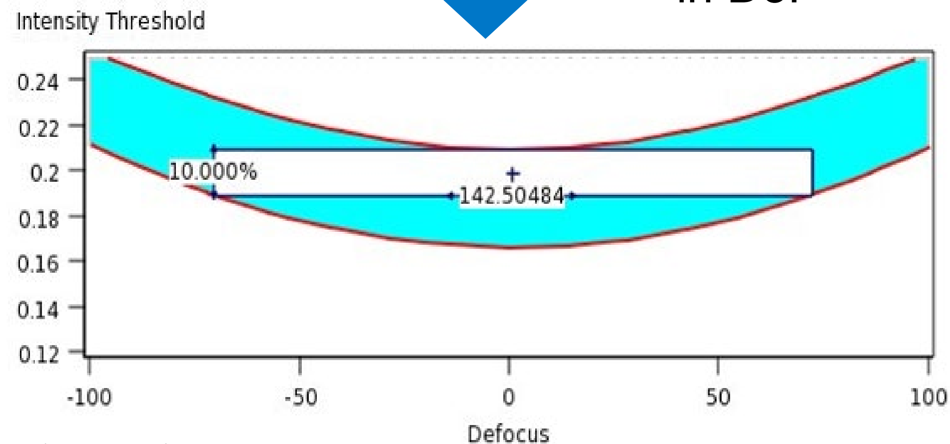
PV Band
0, 60, 90nm defocus

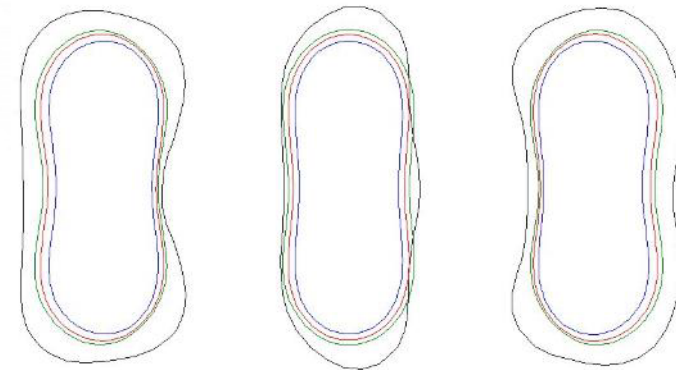


~85% increase in DoF

Curvilinear ILT







Source: Micron, ILT Curvilinear Mask Designs for Advanced Memory (ebeam.org)

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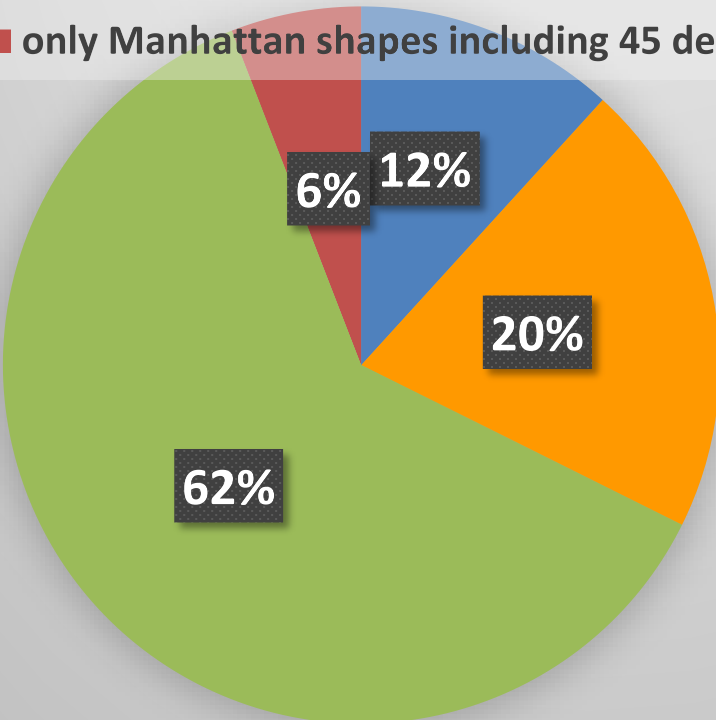
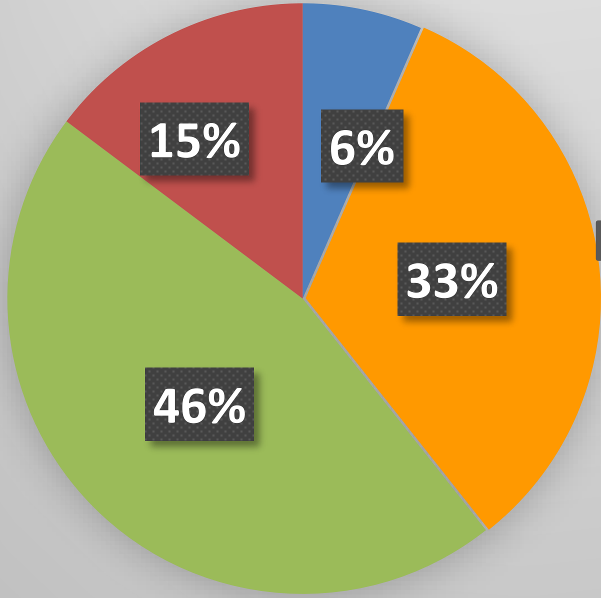
85% say EUV masks with Some Curvilinear Shapes by 2023 According to 2020 Luminaries Survey Predictions

Manufacturing of curvilinear masks is enabled by multi-beam mask writers. How extensively will curvilinear shapes be used for leading-edge (EUV, 193i) masks intended for high volume manufacturing (HVM) by 2023?

- entire reticles of curvilinear shapes
- a hybrid of mostly curvilinear shapes and some Manhattan shapes
- a hybrid of mostly Manhattan shapes with some curvilinear shapes
- only Manhattan shapes including 45 degree shapes



193i Masks n=68



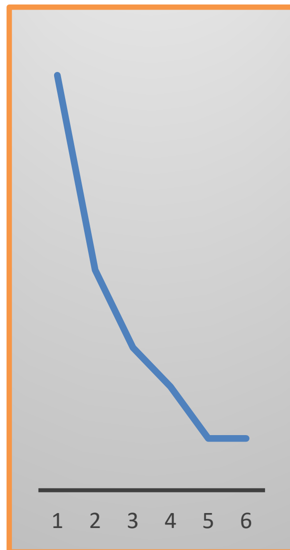
EUV Masks n=61

EUV Remains Top Reason to Buy Multi-Beam Writers

EUV precision ranked #1 reason in 2021 Luminaries Survey

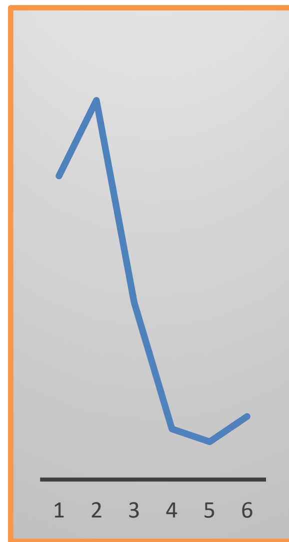
Please rank the primary reasons for purchasing multi-beam mask writers. Note in the answers below, precision refers to CD uniformity as well as placement accuracy. n=81

#1: More precision required for EUV masks



N/A=6%

#2: More throughput for EUV masks

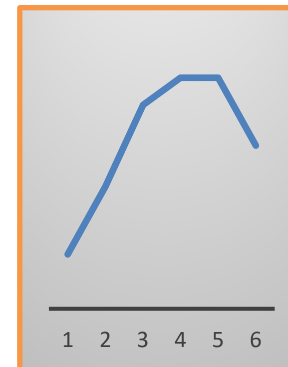


N/A=1%

#3: Curvilinear ILT for EUV masks

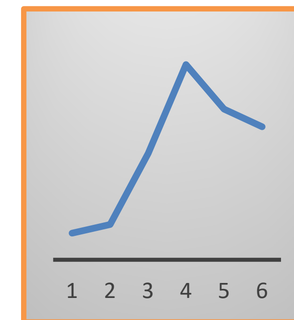
N/A=9%

#4: Curvilinear ILT for 193i masks



N/A=9%

#5: More precision required for 193i masks



N/A=10%

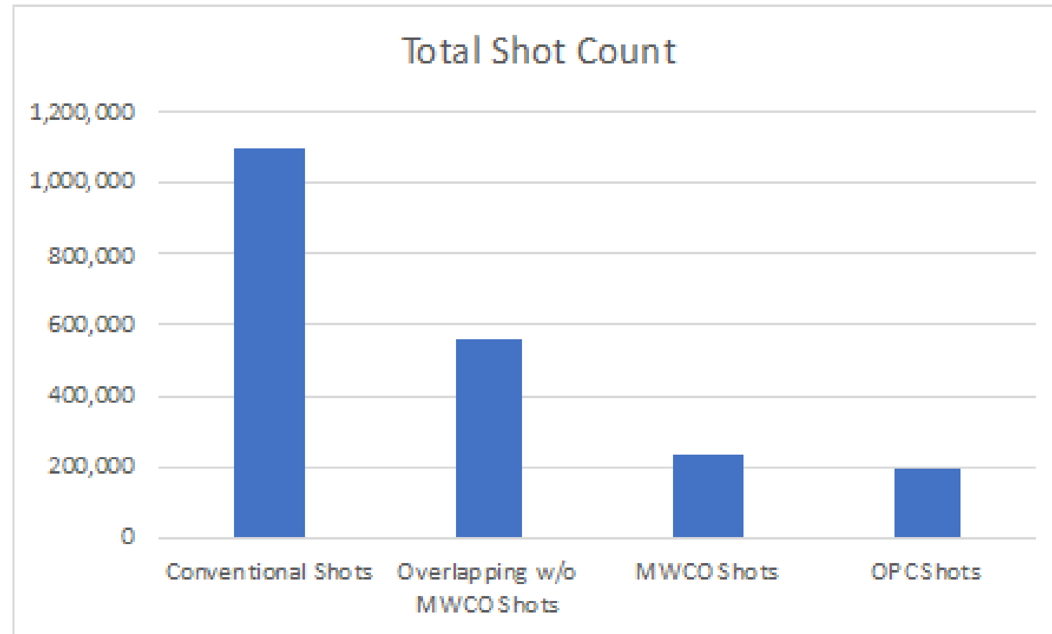
#6: More throughput for 193i masks

N/A=10%

Note: 1-6 on X-axis indicate # of respondents that ranked that question as that ordinal number with 1 = highest.

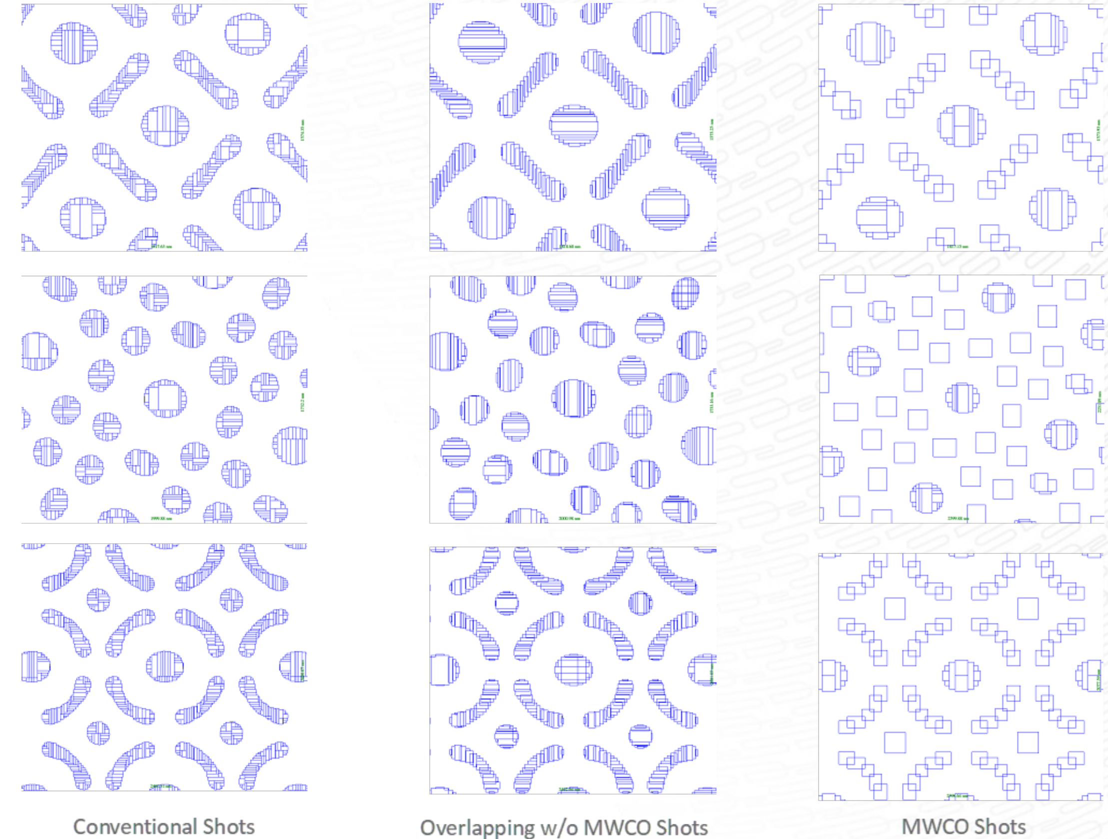
VSB can be Used for 193i Curvy Mask Shapes

For EUV, only Multi-Beam is Practical



(a) VSB shot count

Source: TrueMask® ILT MWCO: full-chip curvilinear ILT in a day and full mask multi-beam and VSB writing in 12 hrs for 193i", Pang, et al., Proc. SPIE 11327, Optical Microlithography XXXIII, 113270K (31 March 2020); https://doi.org/10.1117/12.2554867



(b) VSB shot configurations for 3 contact arrays; note POR OPC shot configurations not shown

MWCO : Mask-Wafer Co-Optimization

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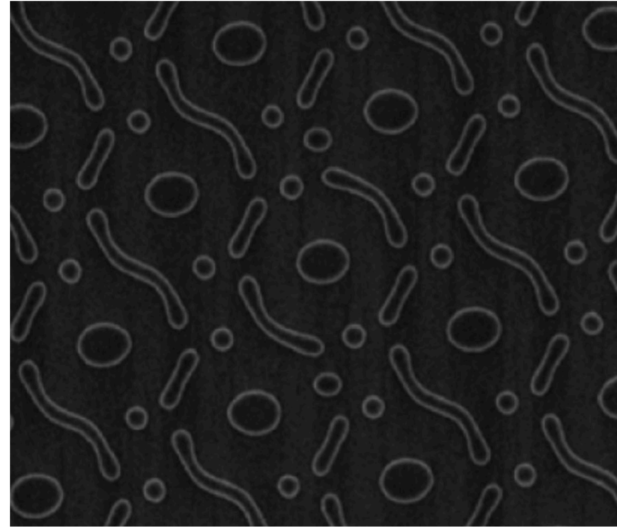
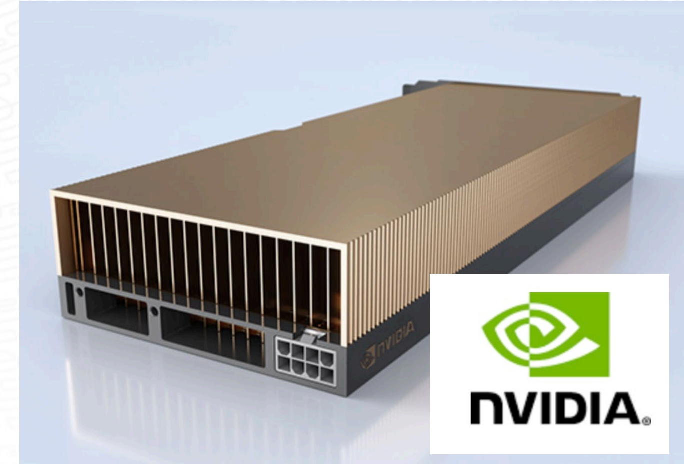
Pixel Manipulation Enables Curvy Masks

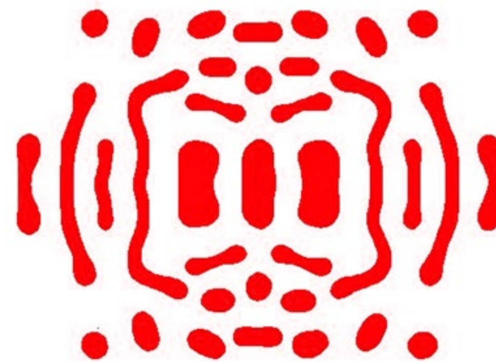
Multi-beam Mask Writer



Curvy ILT



GPU Acceleration



Curvy Masks

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The Mask Ecosystem is Ready for Curvy ILT

Mask Data Preparation
- MDP
- MPC
- Mask Verification

Mask Writing
- VSB
- Multi-beam

Mask Metrology
- CD SEM
- Wafer Plane Analysis

Mask Inspection
- MPI
- WPI

Mask Review
- AIMS

Mask Repair
- eBeam
- Atomic force

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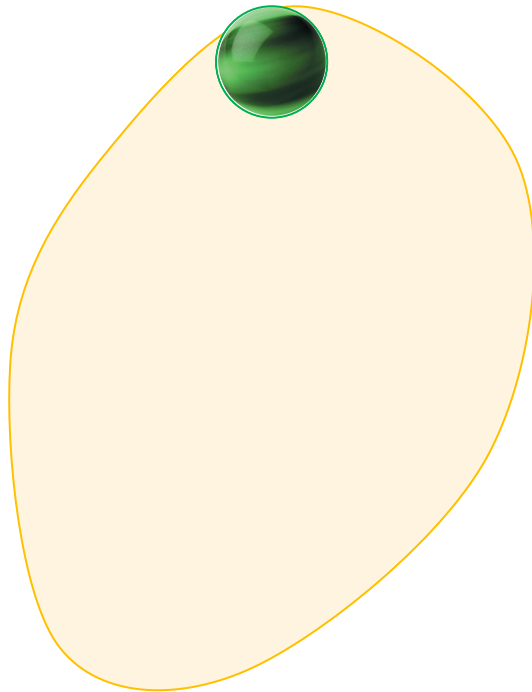
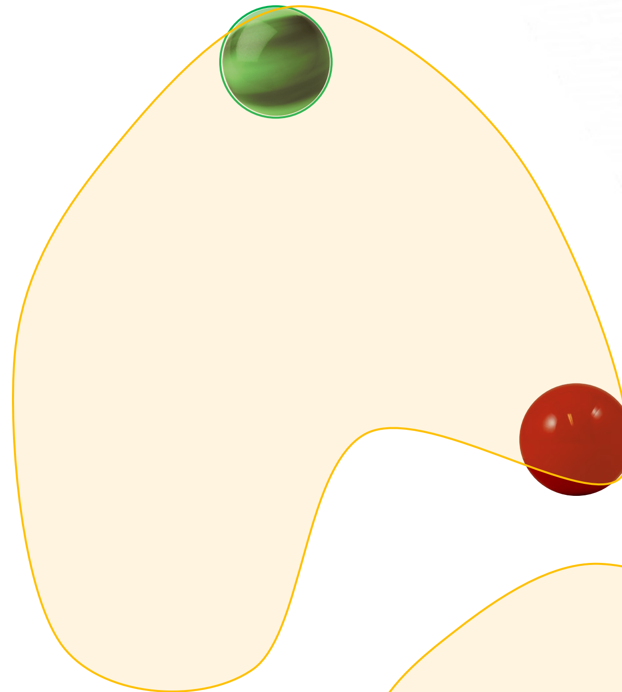
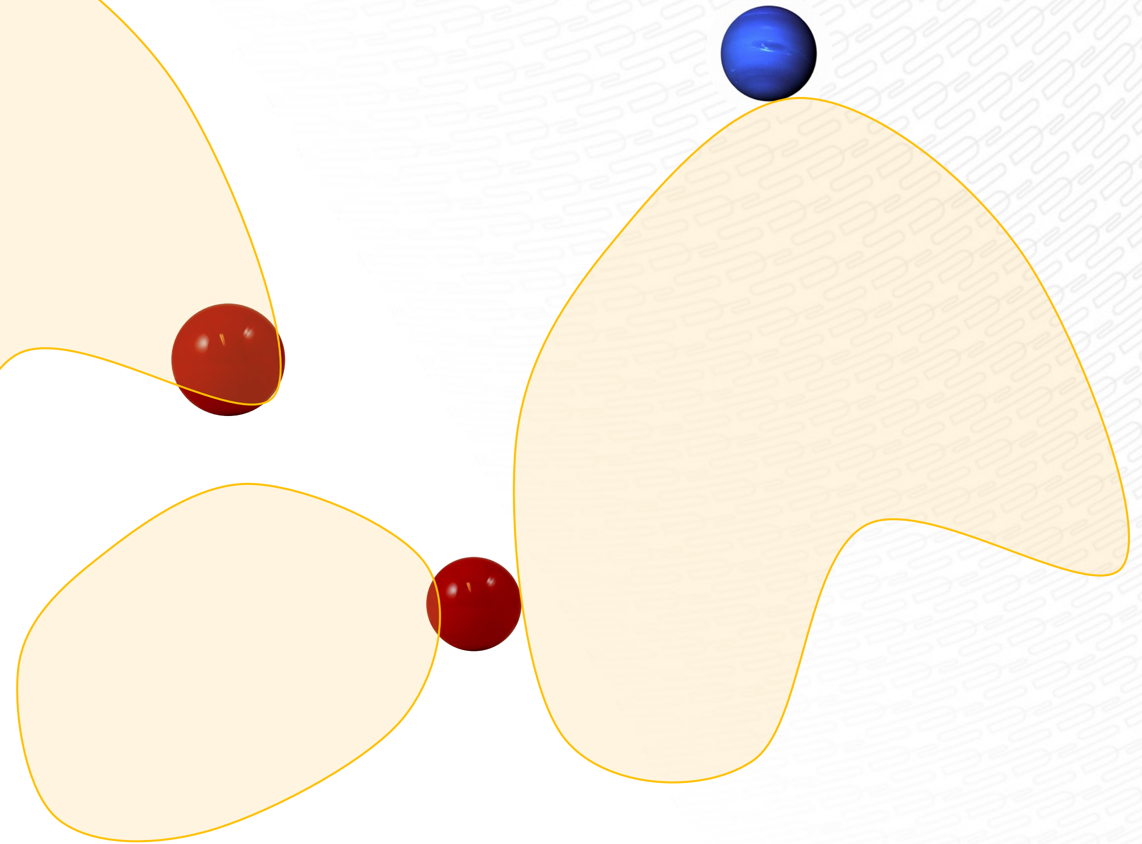
Mask Rule Checking (MRC) for Curvy is Simpler

Large Curvatures are More Reliably Manufacturable







Pearman, et al, PMJ 2019

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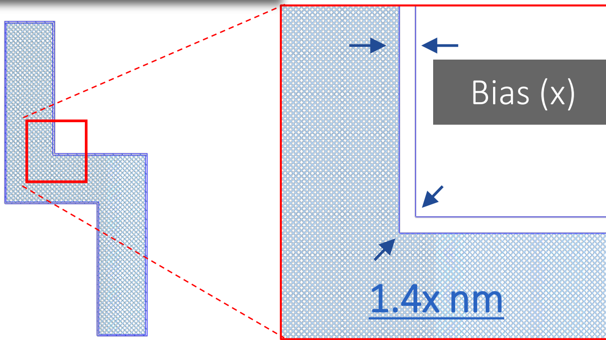
Curvy Masks Bias More Faithfully

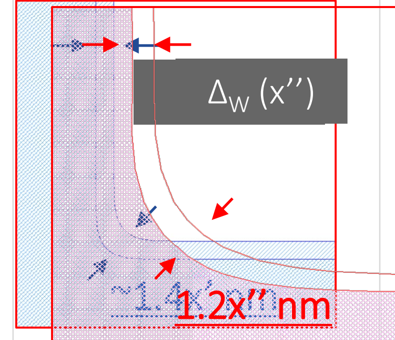
Design

193i sim

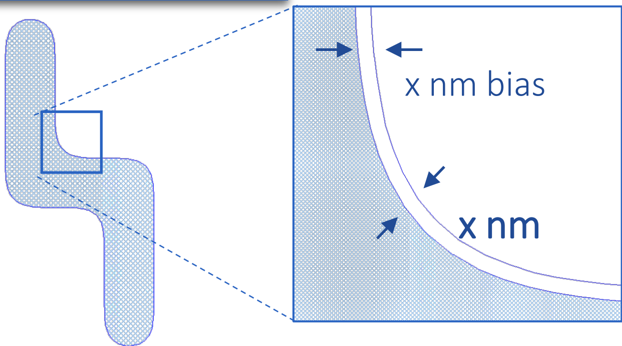
10nm bias on curvy mask produces 10nm change on simulated mask

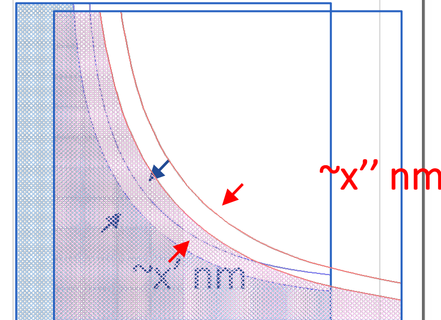
Rectilinear

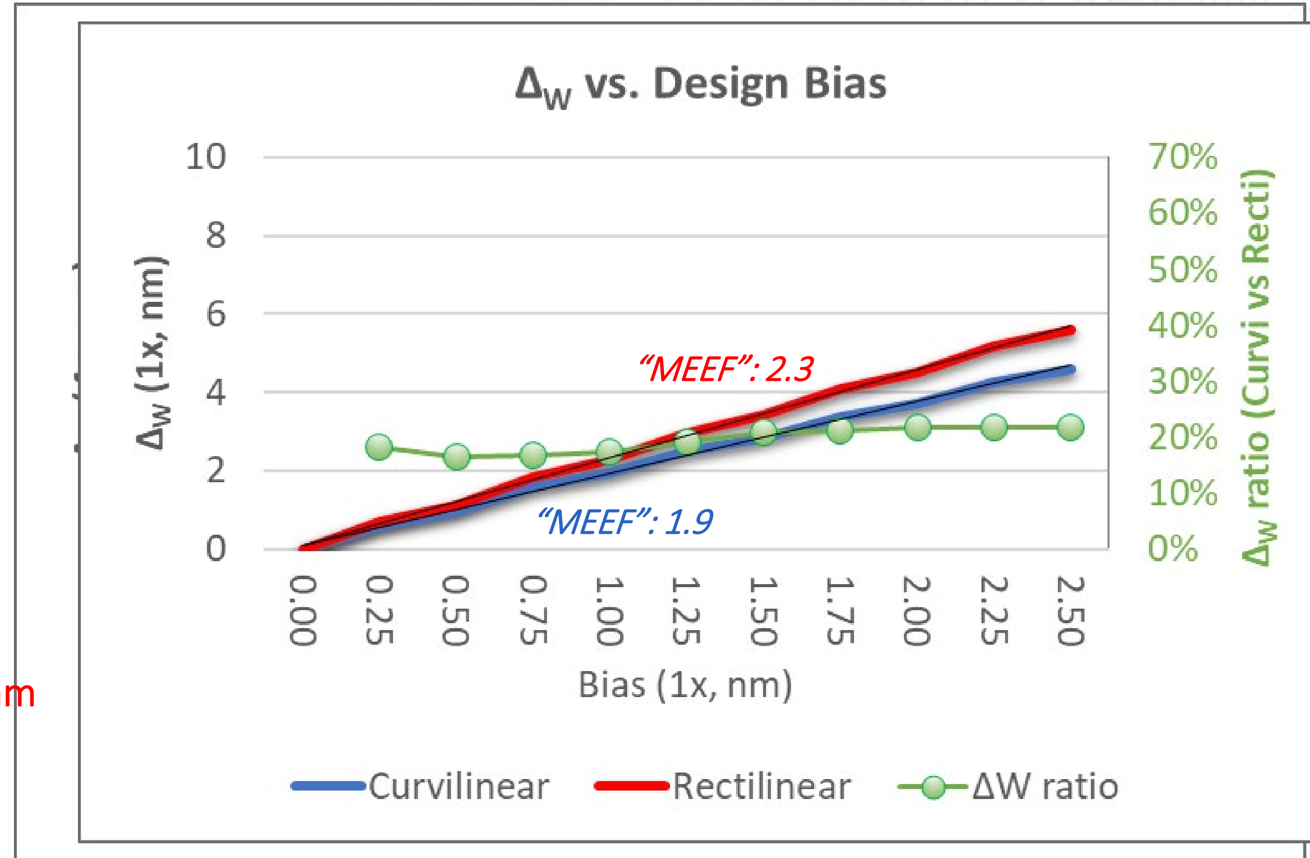




Curvilinear







[1] Δ_M: edge displacement on the mask in nm

[2] Δ_W: edge displacement on the wafer in nm

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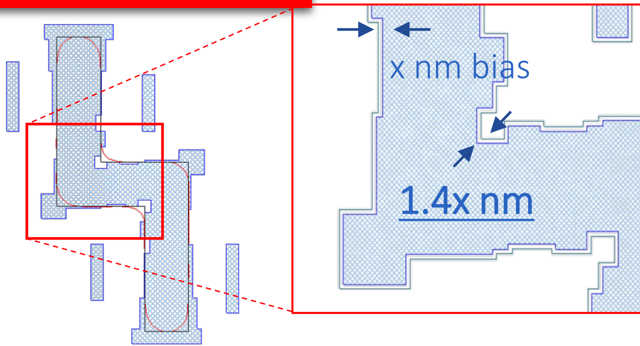
Mask Bias Translates Better to Wafer with Curvy

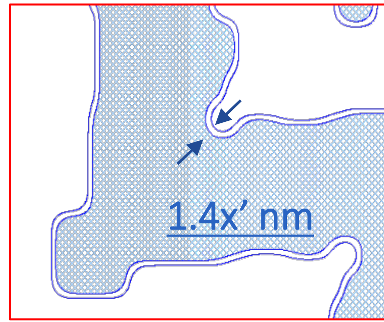
Design

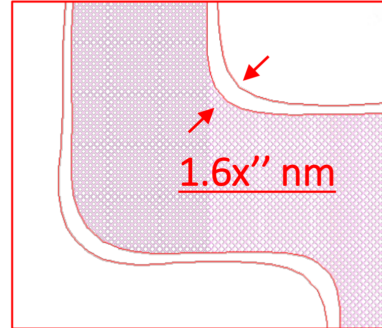
eBeam sim

193i sim

Rule-Based OPC

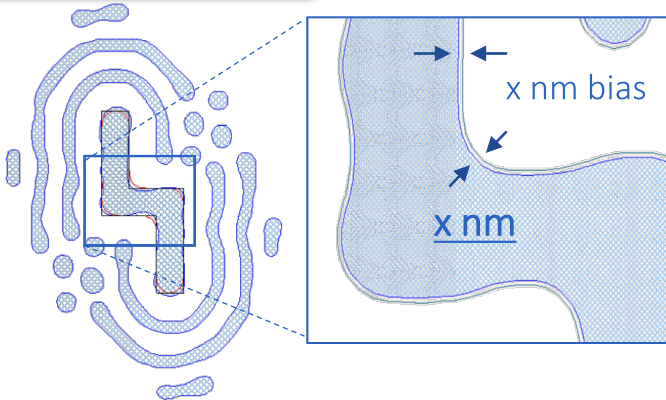


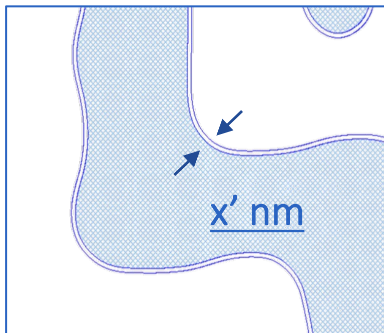


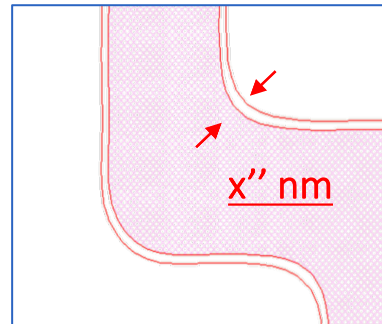


1.6x'' nm

TrueMask® ILT

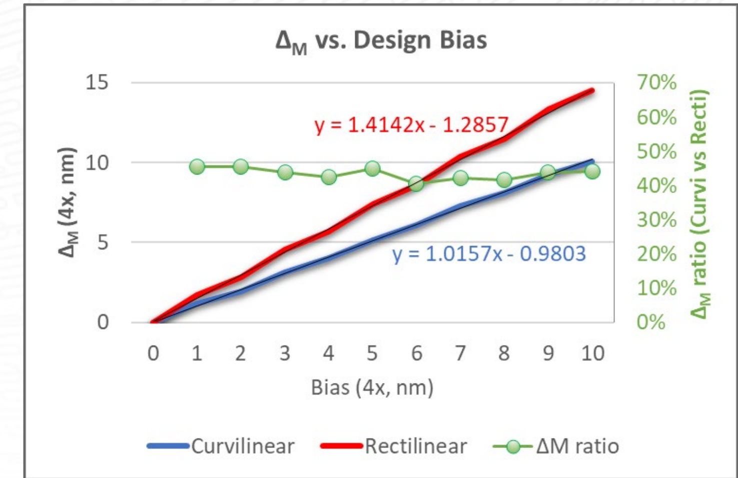




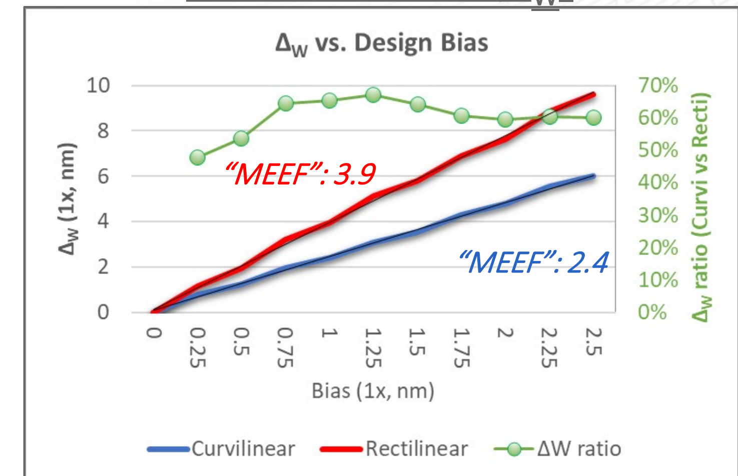


x'' nm

eBeam Simulation (Δ_M)



193i Simulation (Δ_W)



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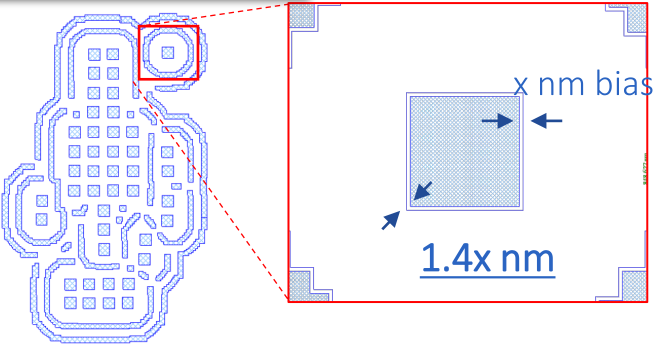
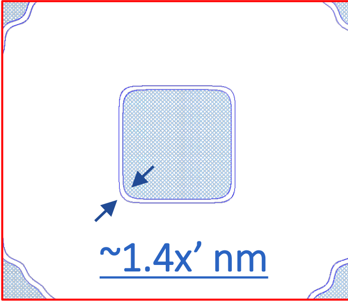
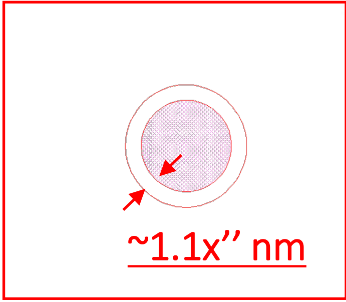
Curvy is 10% More Faithful to Mask Bias in ΔArea

Design | eBeam sim | 193i sim

Rectilinear ILT

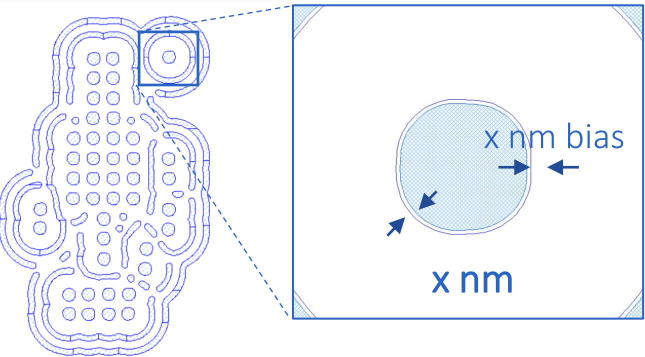


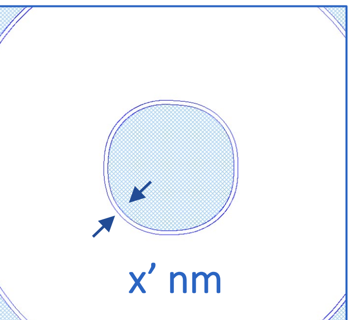


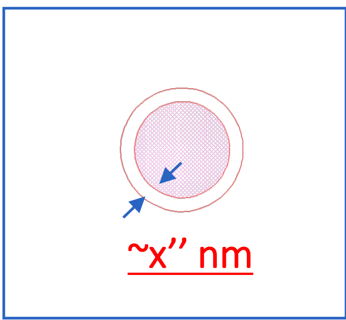


~1.1x'' nm

TrueMask® ILT

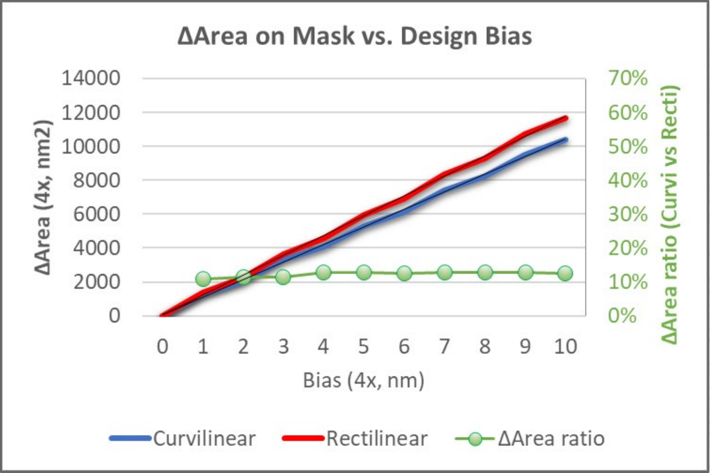




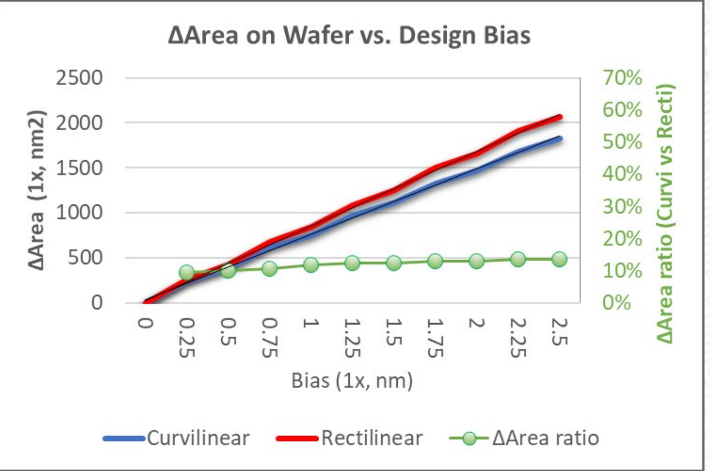


~x'' nm

eBeam Simulation (ΔArea)



193i Simulation (ΔArea)



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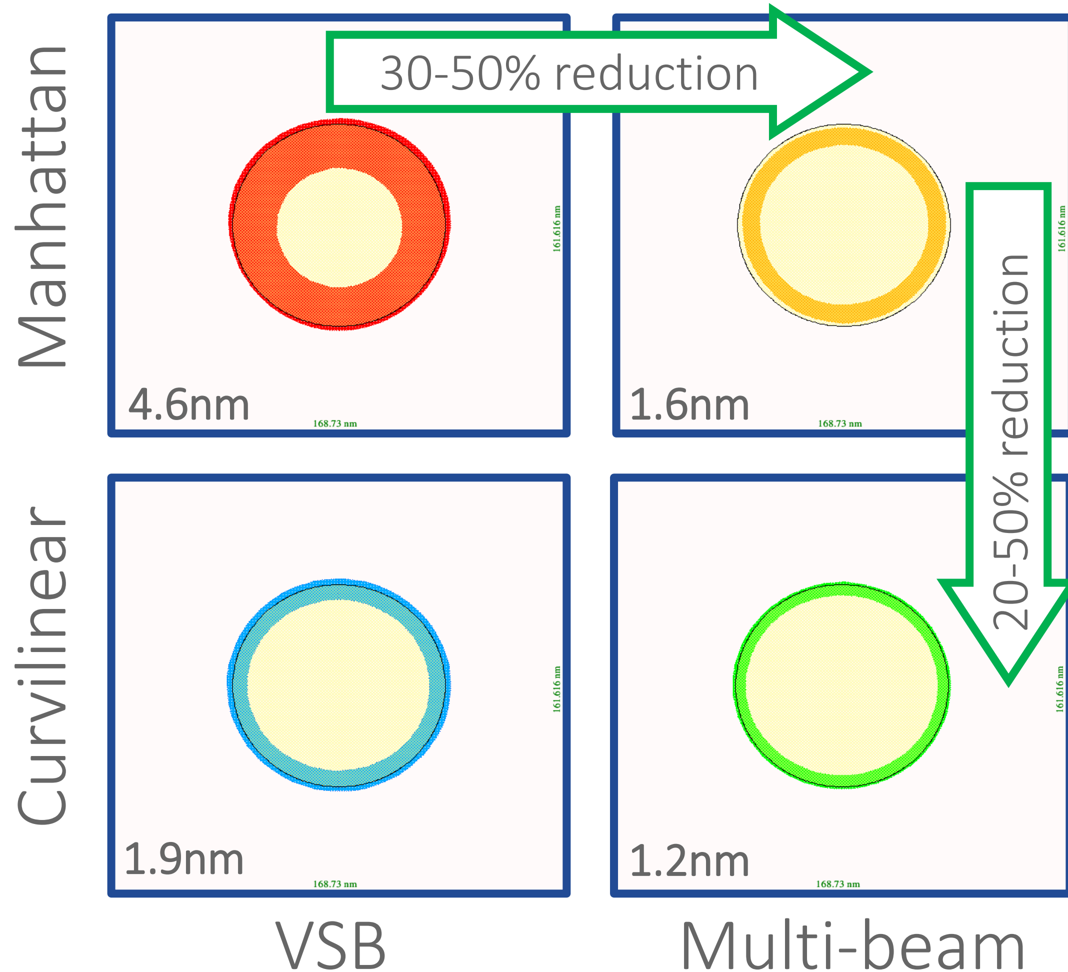
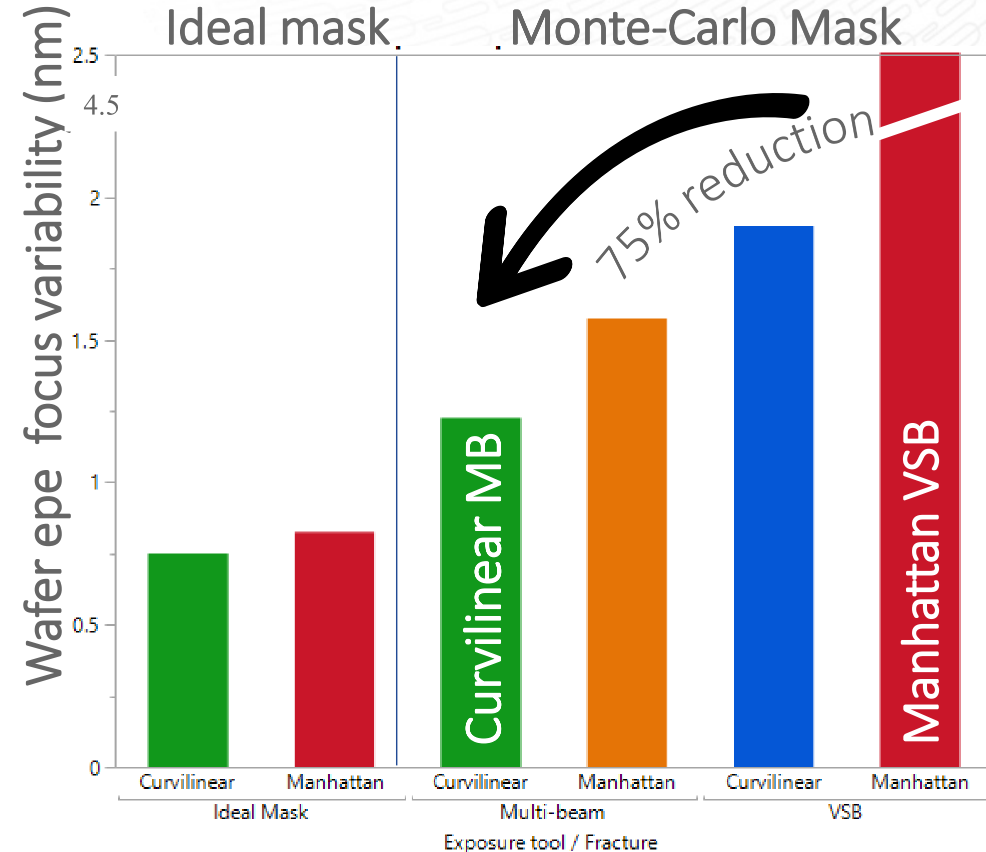
Curvy Masks are More Reliably Manufacturable





Ryan Pearman, et al, "How curvilinear mask patterning will enhance the EUV process window: a study using rigorous wafer+mask dual simulation", PMJ 2019

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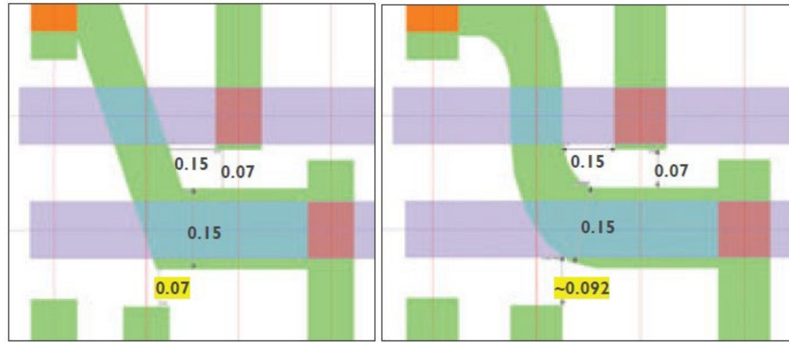
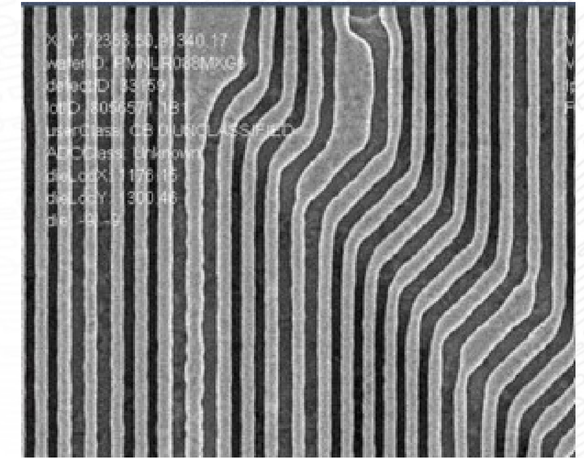
Curvy Masks Enable Curvy Designs

Curvy Designs are More Reliably Manufacturable, too



Source: imec poster at
Photomask Technology 2019

Curvy Designs :
- Better Yield
- Less power
- Faster
- Smaller



Source: Micron presentation at
eBeam Initiative lunch SPIE-AL 2020

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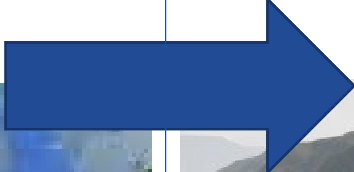
Curvy Design?

Semiconductor Design Today

Old | New

Semiconductor Design Tomorrow



Minecraft, Mojang (Microsoft)

Death Stranding, Kojima Productions

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