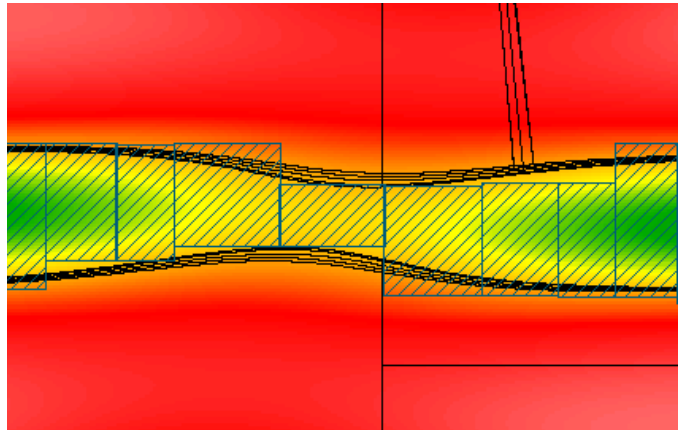
Model-Based MPC Enables Curvilinear ILT using Either VSB or Multi-Beam Mask Writers

Leo (Linyong) Pang, Yutesu Takatsukasa, Daisuke Hara,
Michael Pomerantsev, Bo Su, Aki Fujimura

D2S, Inc.

D2S Patented Technology

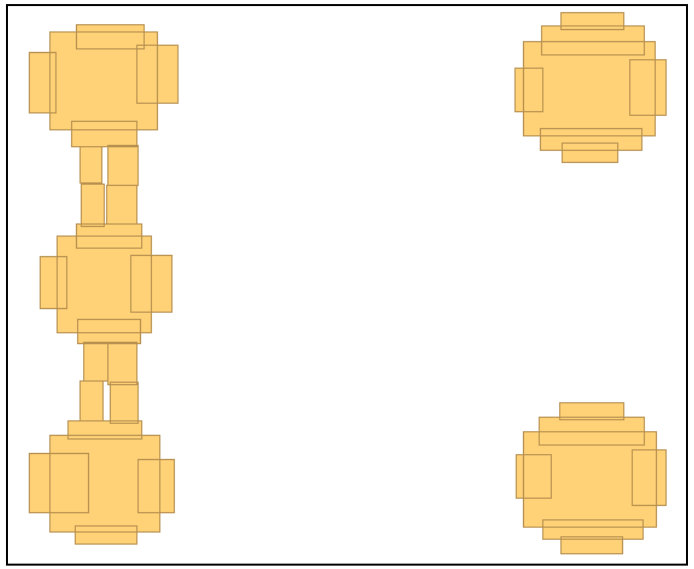
GPU can Do Many Things in Semiconductor Manufacturing



Litho Simulation

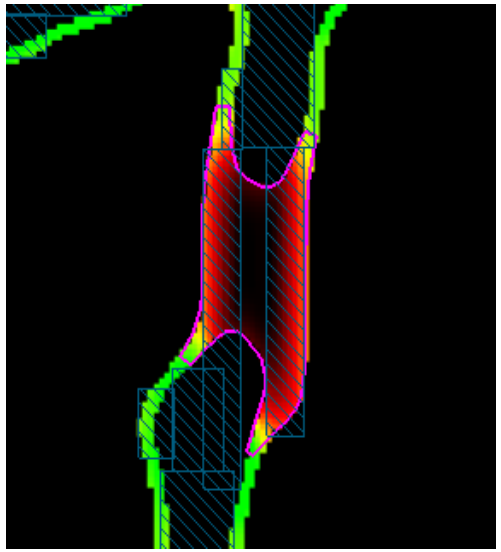
Wafer Plane Analysis (WPA) for Mask CD SEM (CSTIC paper)

High accuracy EPE measurement and Litho. Simulation capability for ILT, Kondo-san, Advantest



Mask Data Prep

MDP with overlapping shots (This paper)



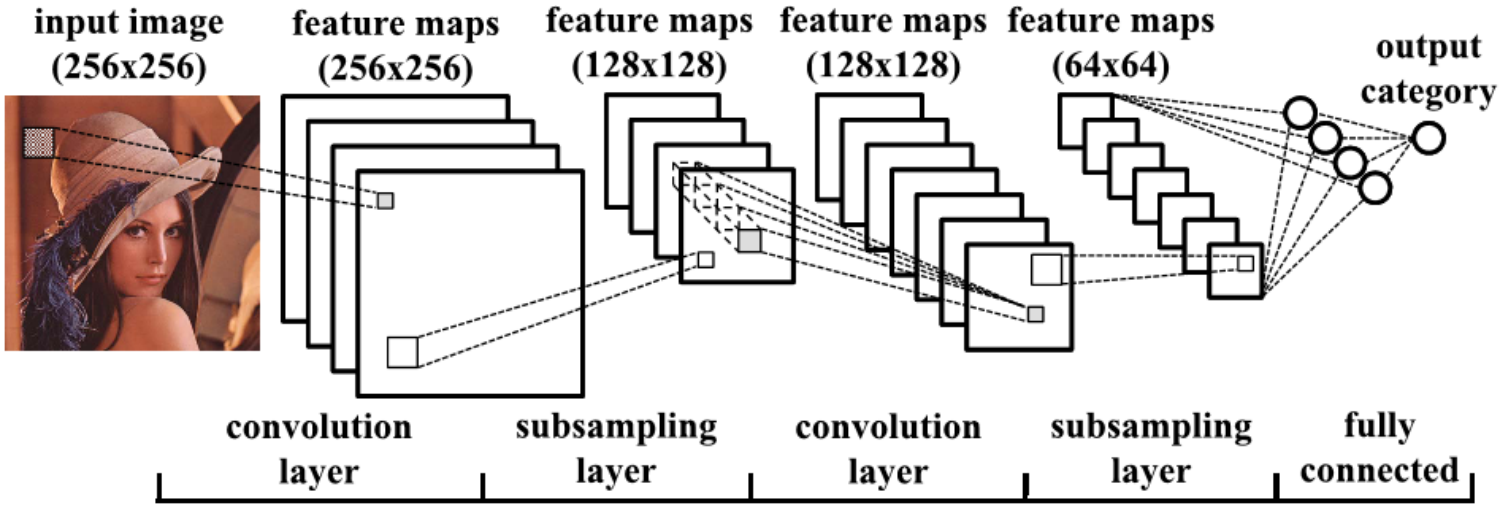
Curvilinear Geometry Engine

EUV Modeling in the Multi-Beam mask making Era, Ryan Pearman

Simulation-Based MDP Verification for Leading-Edge Masks, Bo Su

GPU can Do Many Things in Semiconductor Manufacturing

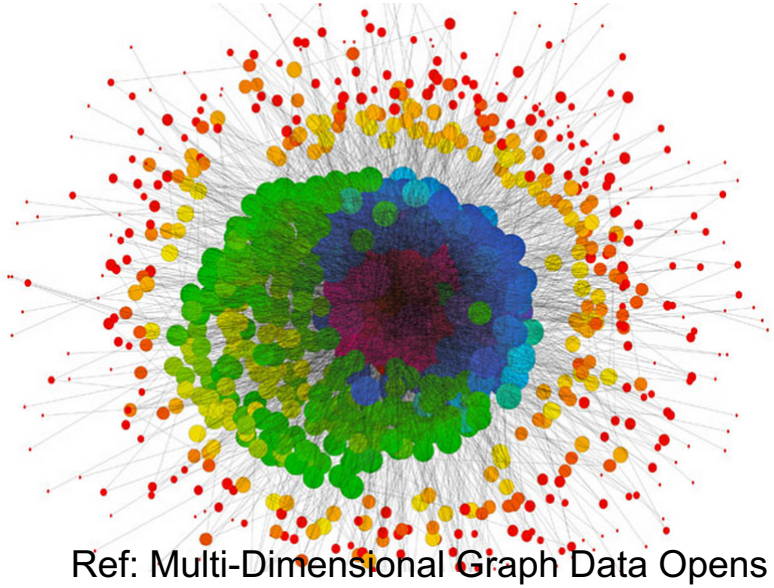
Machine learning – GPU is the great platform



Deep learning with Convolutional Neural Network (CNN)

Ref: Minimizing Computation in Convolutional Neural Networksm Jason Cong, Bingjun XiaoICANN2014

Image and multi-dimensional data manipulation & computation



Ref: Multi-Dimensional Graph Data Opens the Door to New Applications, David S. Frankel

- Electron Beam Lithographic Modeling Assisted by Artificial Intelligence Technology, Nakayamada-san, NuFlare
- Data Analytics and Machine Learning for Design-Process-Yield Optimization in Electronic Design Automation and IC Semiconductor Manufacturing, Luigi Capodieci, Motivo
- Accurate Lithography Simulation Model based on Convolutional Neural Networks, Yuki Watanabe, Toshiba
- Imbalance Aware Lithography Hotspot Detection: A Deep Learning Approach, H. Yang, Chinese University of Hong Kong /Brion (SPIE)

A Decade of ILT!

Fast Inverse Lithography Technology

Daniel S. Abrams, Linyong Pang
Luminescent Technologies, Inc., 650 Castro Street, Suite 220, Mountain View, CA 94041, U.S.A.

Email: leo@luminescent.com

6 Papers

2 Foundries

1 Memory

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ILT Adopted as the Way Forward

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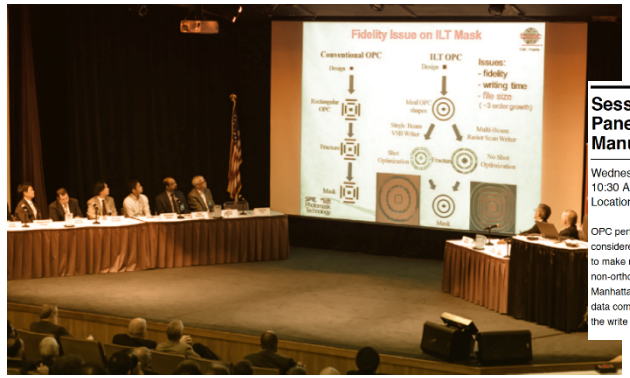


2014 panel

Session PNL:
Panel Discussion: The Impact of Full-scale Curvilinear ILT OPC on Photomask Manufacturing

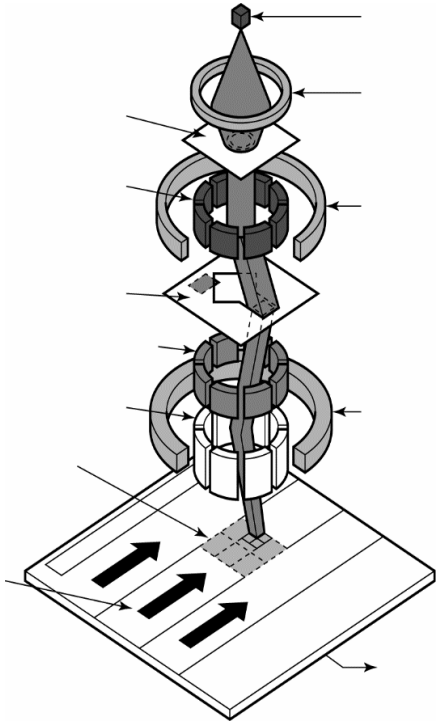
Wednesday 14 September 2016
10:30 AM - 12:30 PM
Location: Conv. Ctr. Room LL20

OPC performed with Inverse Lithography Technology (ILT) is used today primarily as a local repair process for OPC hotspot regions. ILT OPC is generally considered to be too computationally expensive to use on full layouts. Due to write time limitations, the raw curvilinear OPC output is typically "Manhattanized" to make masks manufacturable, primarily since the VSB mask writers used today are optimized for Manhattan data and slow down considerably when writing non-orthogonal figures. However, the computational cost of full-layout ILT OPC relative to its perceived value is lowering. In addition there is concern that the Manhattanization process reduces OPC accuracy. The introduction of multi-beam raster mask writers is expected to reduce the write time cost of raw ILT mask data compared to VSB writers, possibly soon making full-layout ILT OPC a reality. It is expected that the new raster writers level the playing field – both reducing the write time for ILT, but also removing the write time advantage of simpler mask patterns. Is the mask industry ready for the complexity of full-layout raw ILT?

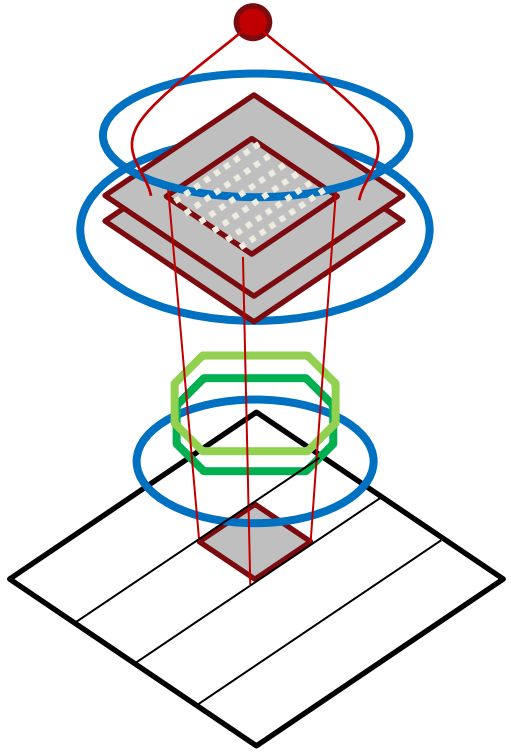
2016 panel

Mask Writing Used to be the Bottleneck for Curvilinear ILT Masks in Mask Making

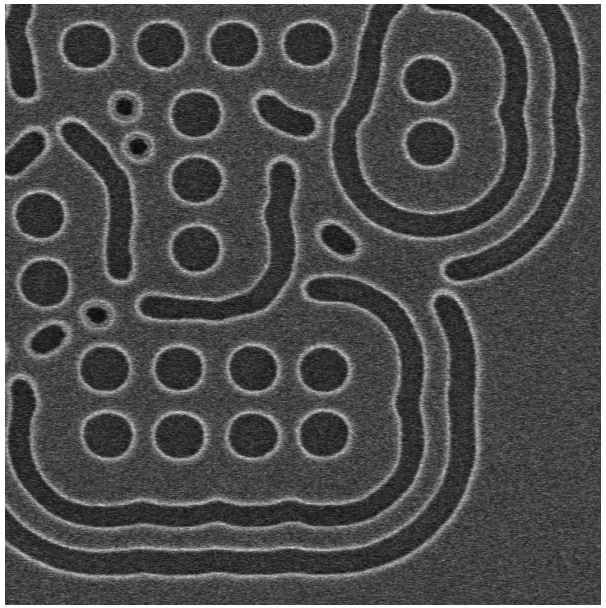
VSB Mask Writer was Designed for Manhattan Patterns
Multi-beam is Designed for Curvilinear ILT Patterns



Variable shaped Beam
Single beam, rectangular shape



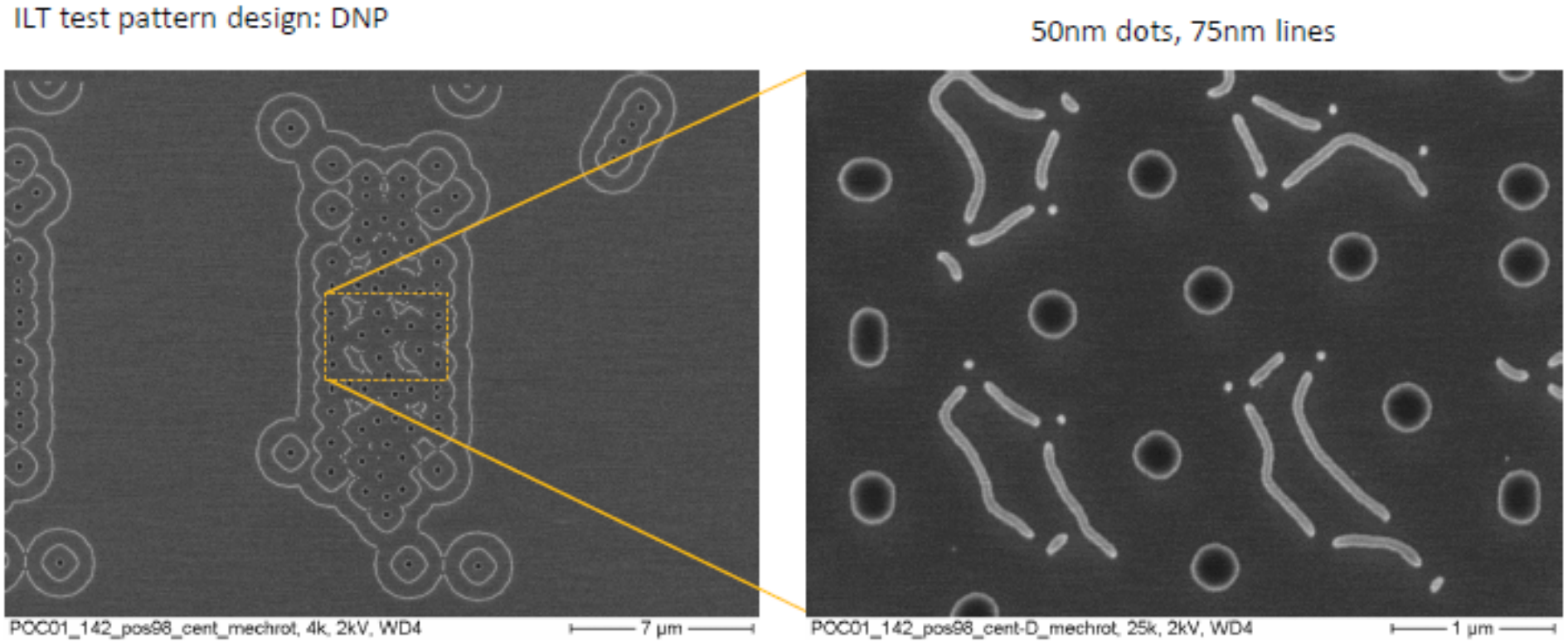
Multi-beam Mask Writing
Massive pixel array



B.G. Kim, et al., BACUS, 2012

ILT Mask Patterns

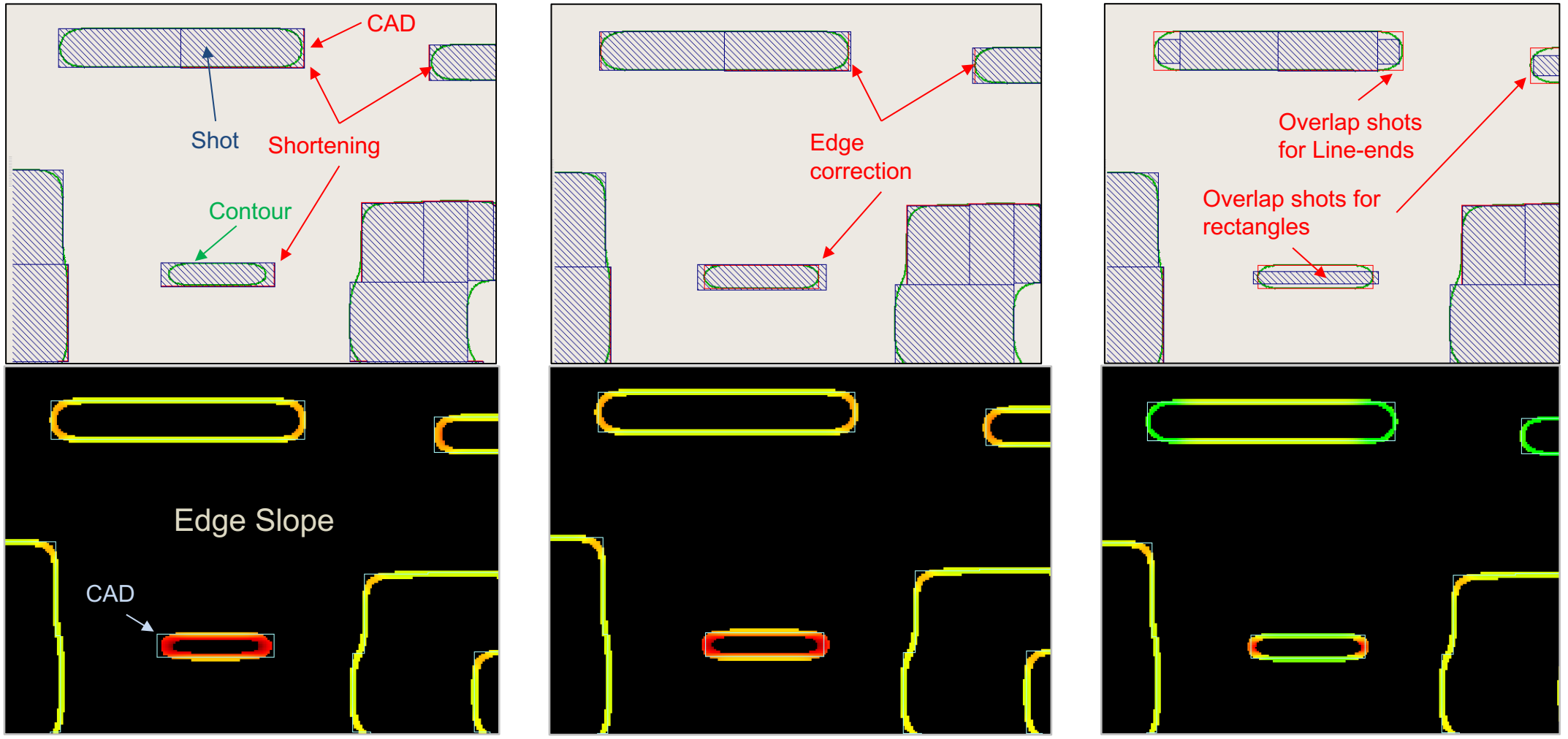
Multi-beam is Great for Curvilinear ILT



Courtesy of IMS paper: alpha machine

Multi-beam exposure without loss of TPT

MPC Needs Dose and Shape Corrections

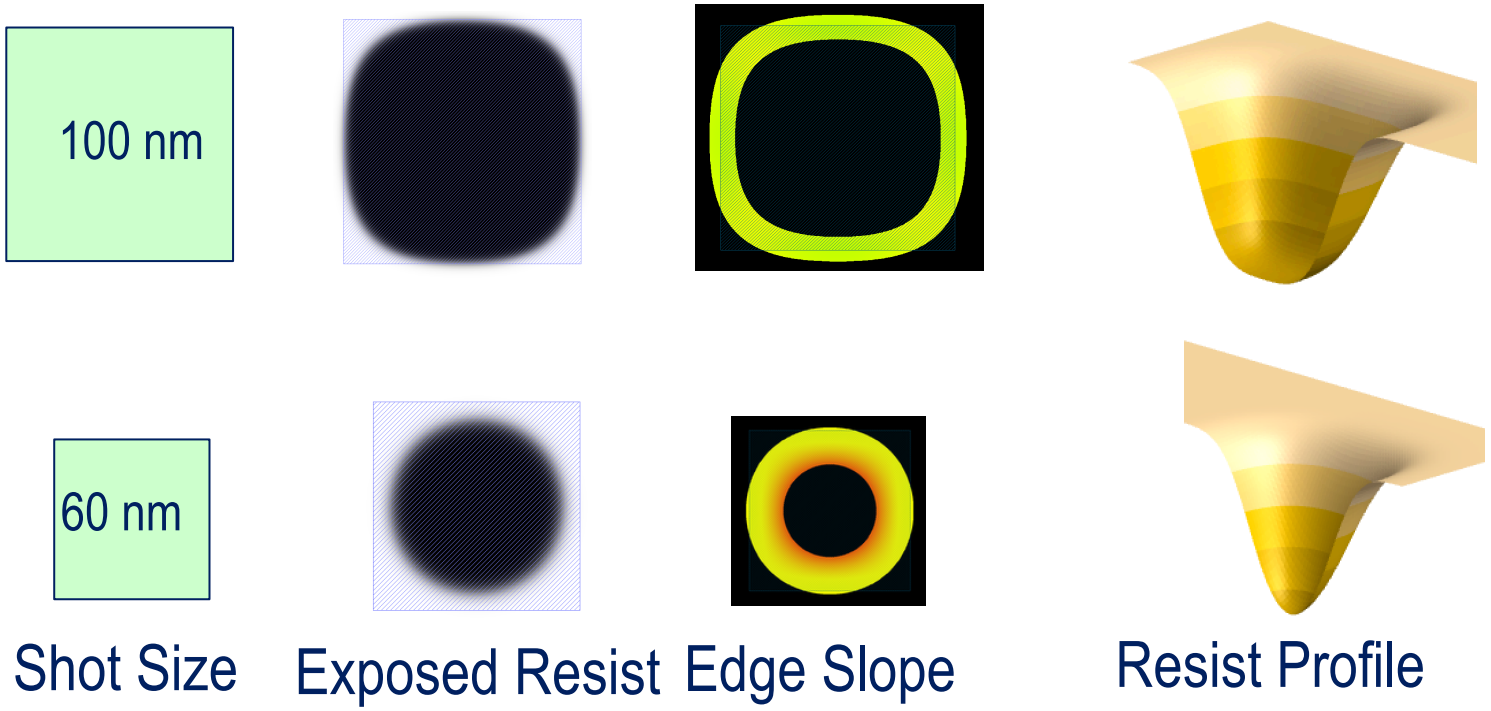


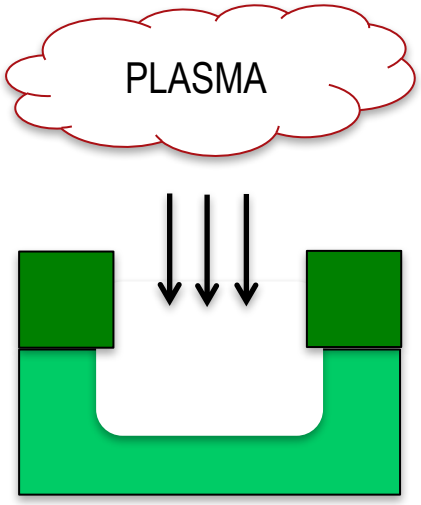
Without MPC

Shape Correction

Shape + **Dose** Correction

Curvilinear ILT MPC on VSB: Both Dose and Shape Correction Needed





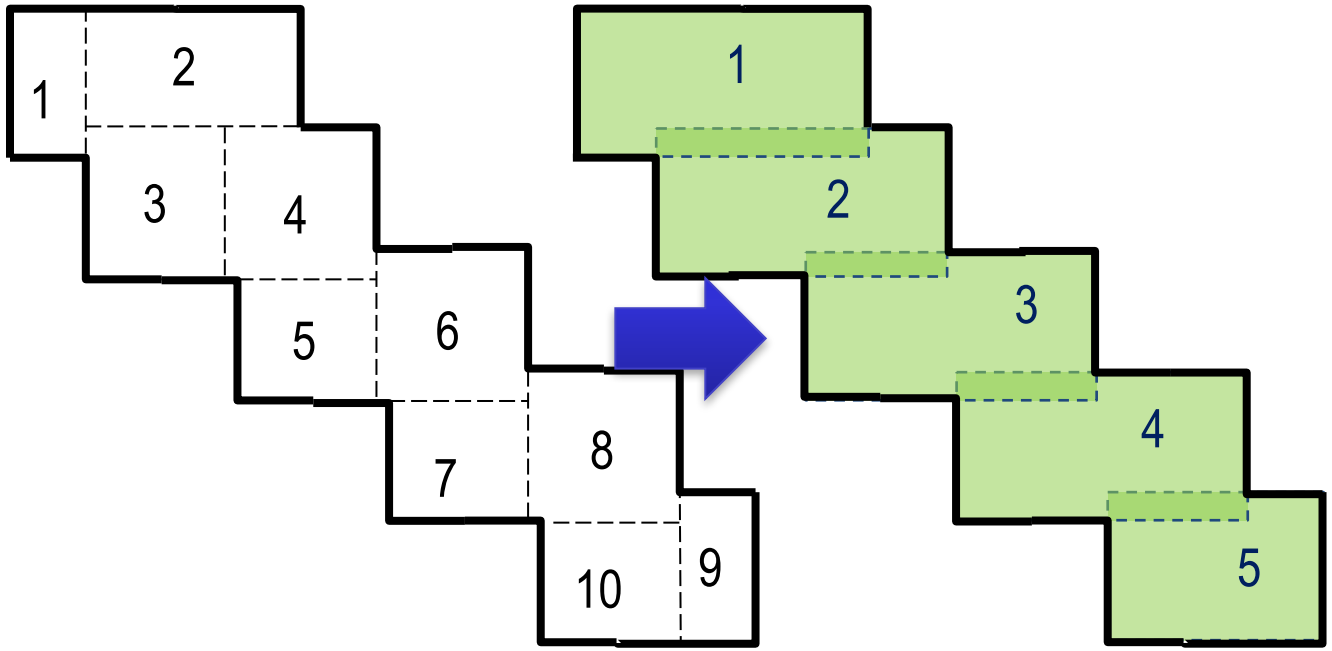
Small feature's resist profile will be bad, shape correction won't help

Resist image correction is better to be done by dose correction

Etching and nonlinearity better to be corrected by shape correction

Curvilinear ILT MPC on VSB: Overlapping Shots Help

10 conventional shots 5 overlapping shots
Plus, extra energy in overlapping areas

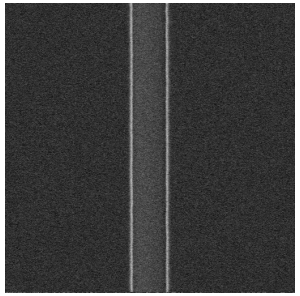


Overlapping shots cast more energy in less write time:
= Better process margin
= Better CDU
= No mask-write time vs. mask-quality compromise

Conventional Shots (2143 shots)

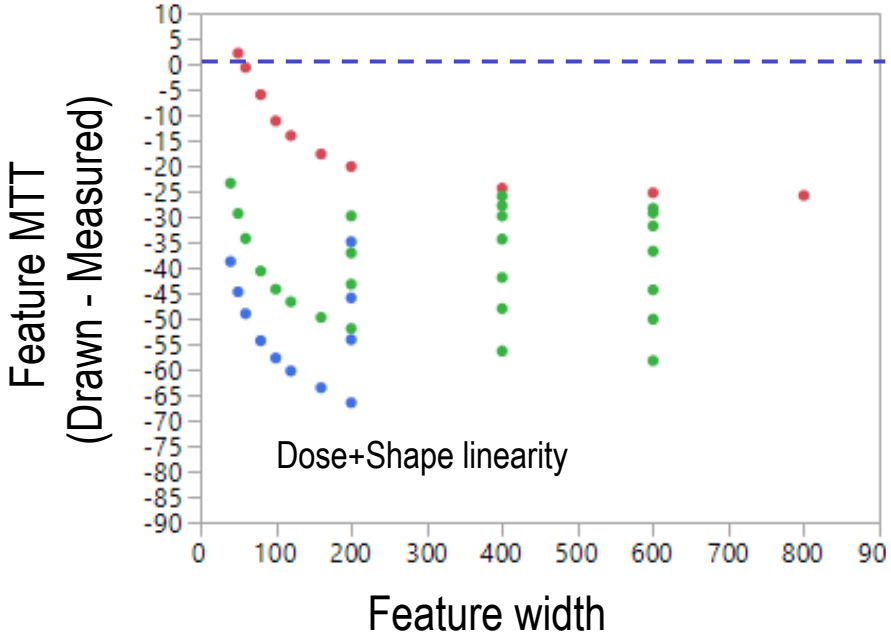
Overlapped Shots (1057 shots)

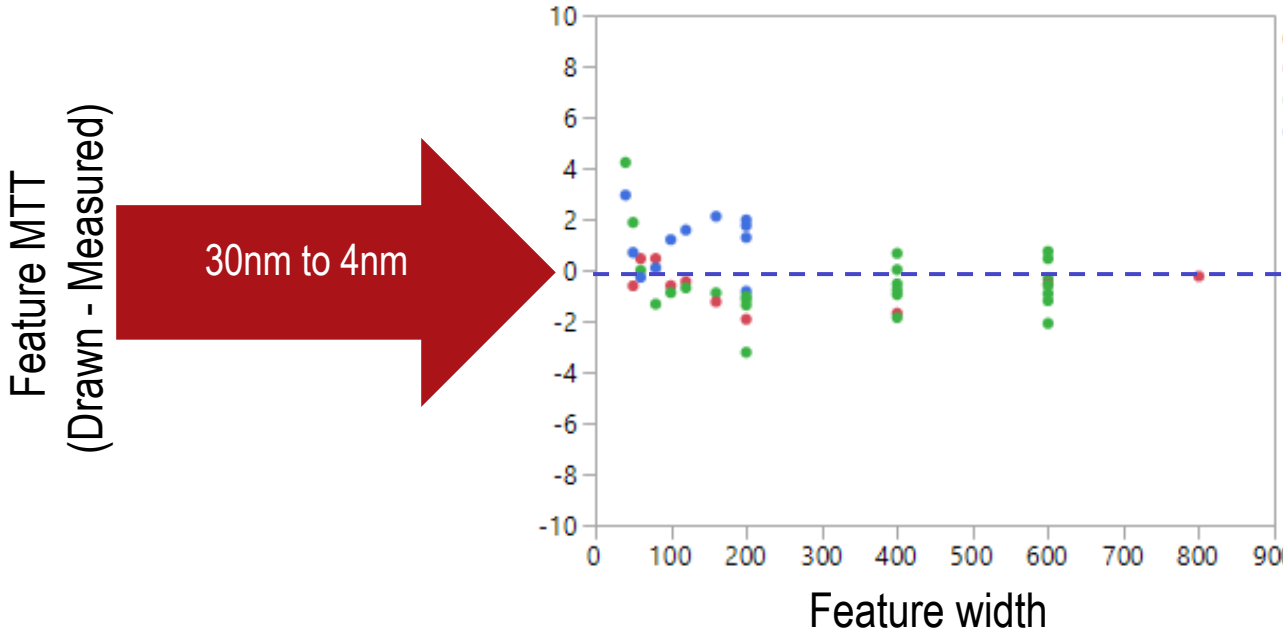
Curvilinear ILT MPC on VSB: The Mask Model Has to Consider Dose Change



Iso Lines

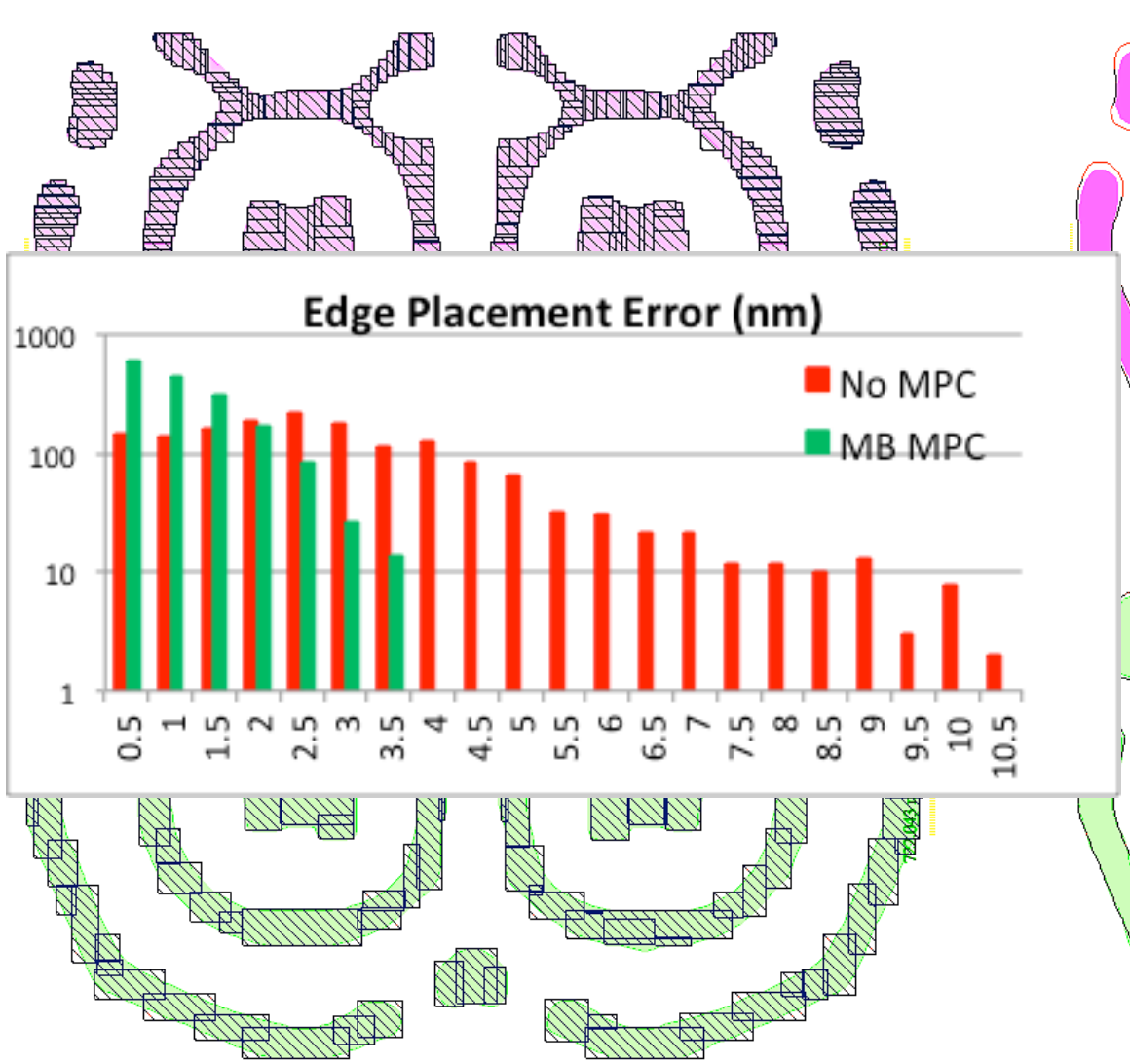
Non-zero y-axis values mean:
mask print errors if uncorrected

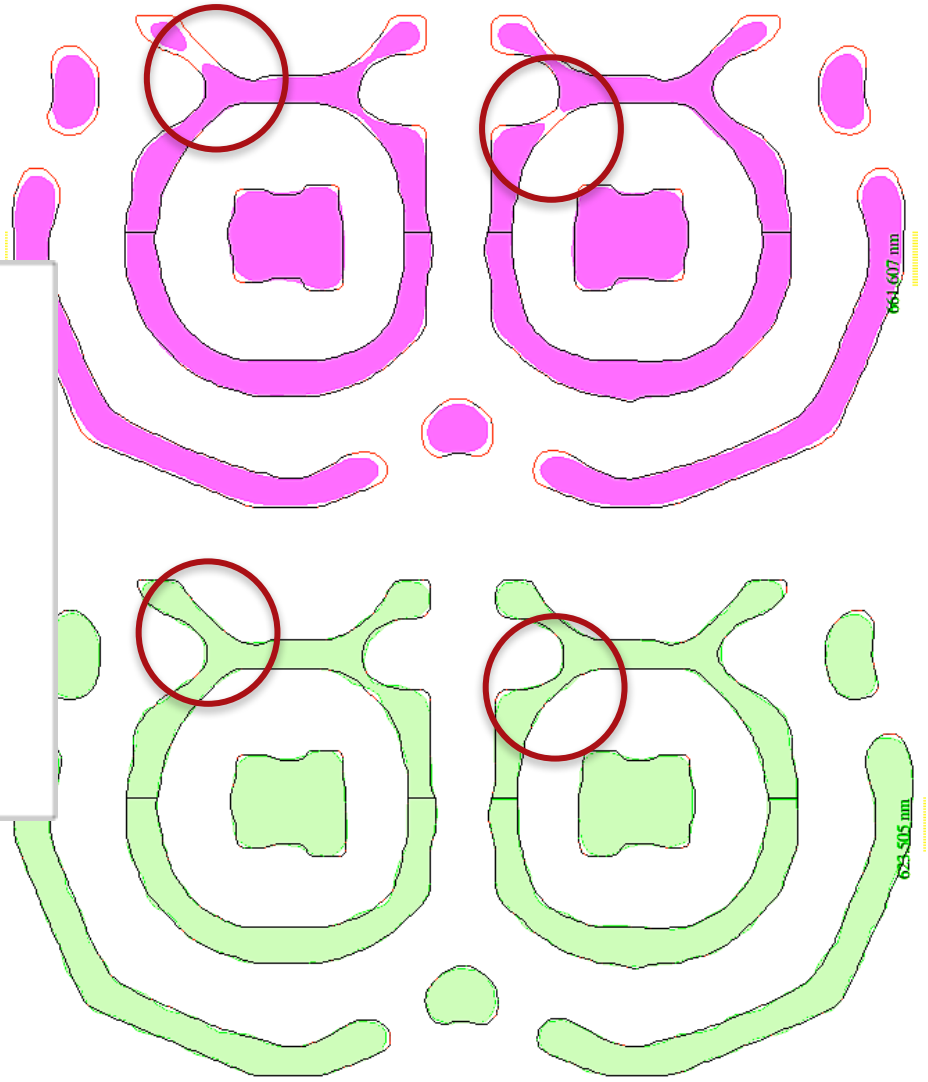




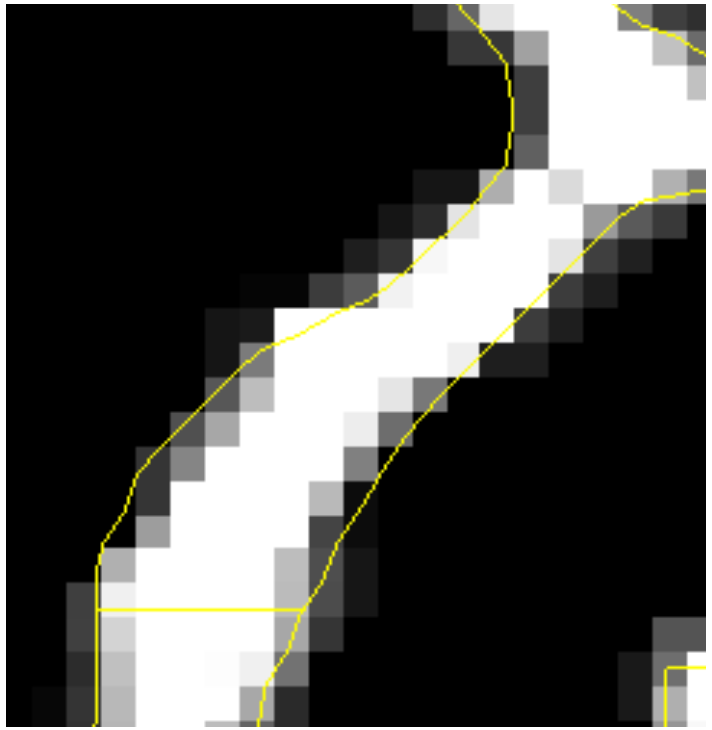
Ref: EUV Modeling in the Multi-Beam mask making Era, Ryan Pearman

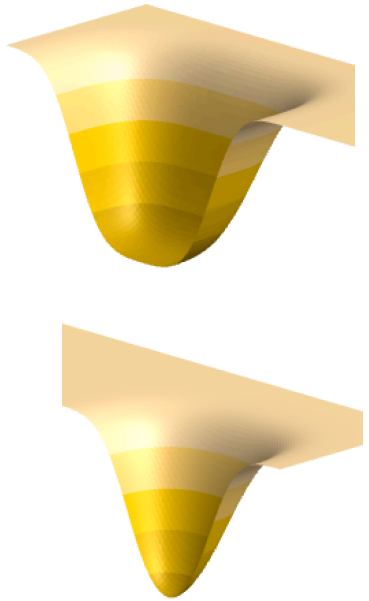
Curvilinear ILT MPC on VSB: Improving CDU



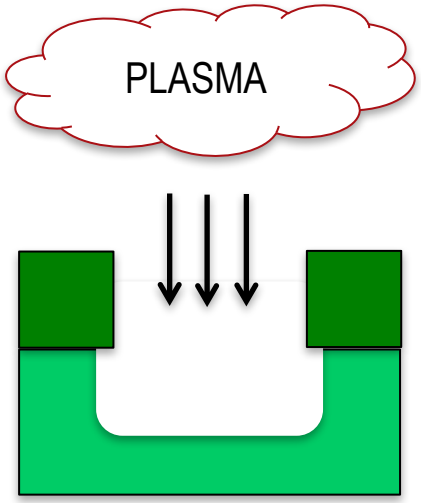


Curvilinear ILT MPC on Multi-beam: Both Dose and Shape Correction Needed





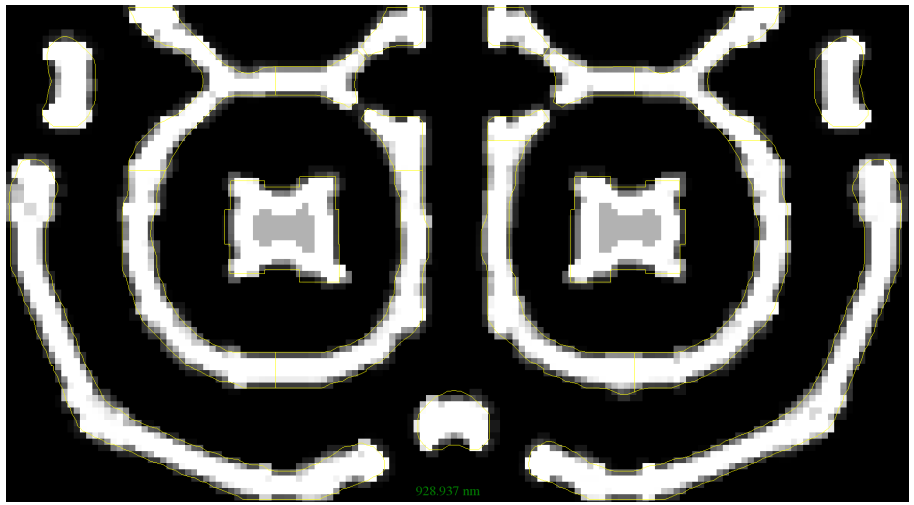
Resist Profile

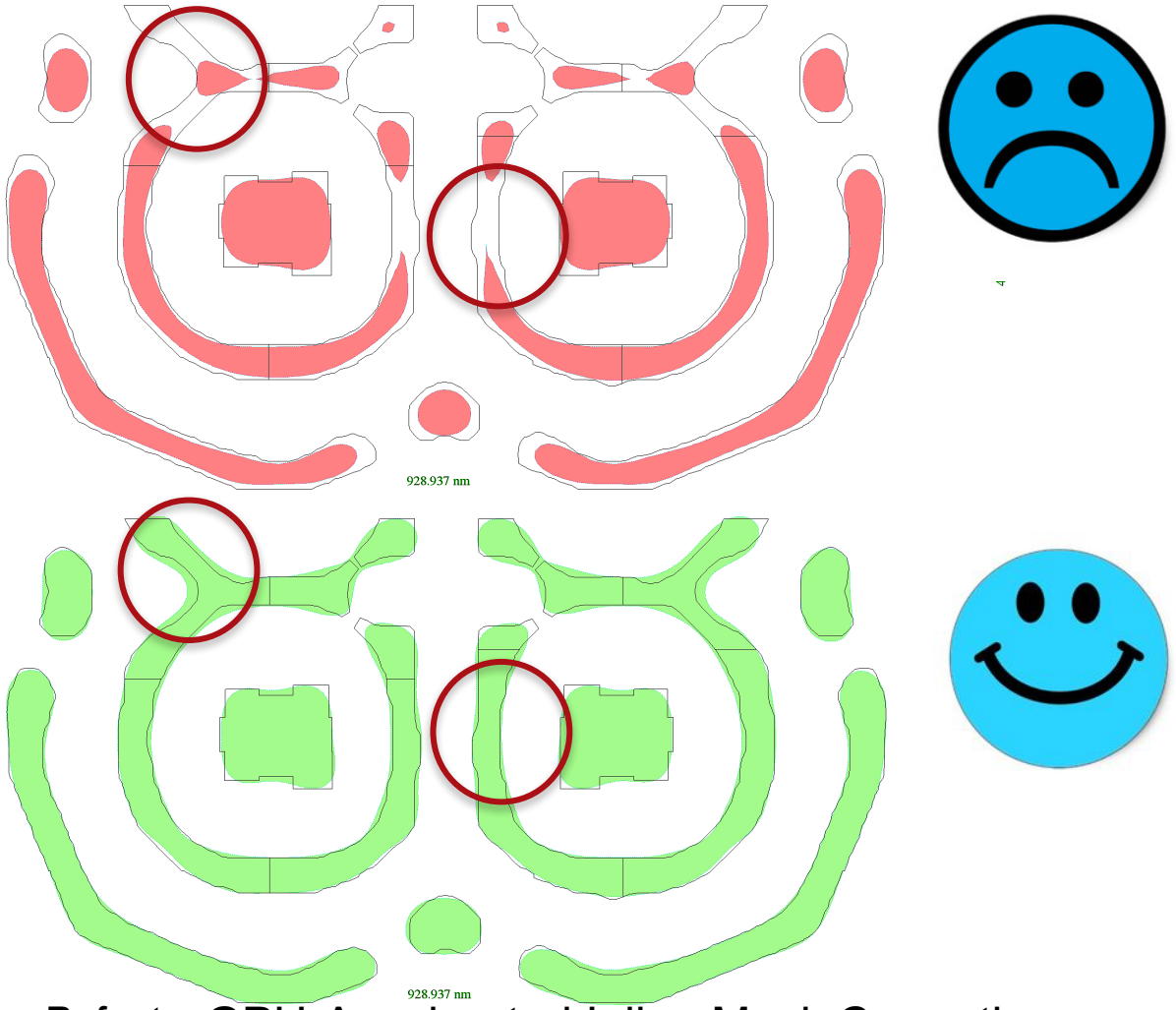


Dose modulation on each beam pixel is the best
Resist image correction is better to be done by dose correction

Etching and nonlinearity better to be corrected by shape correction

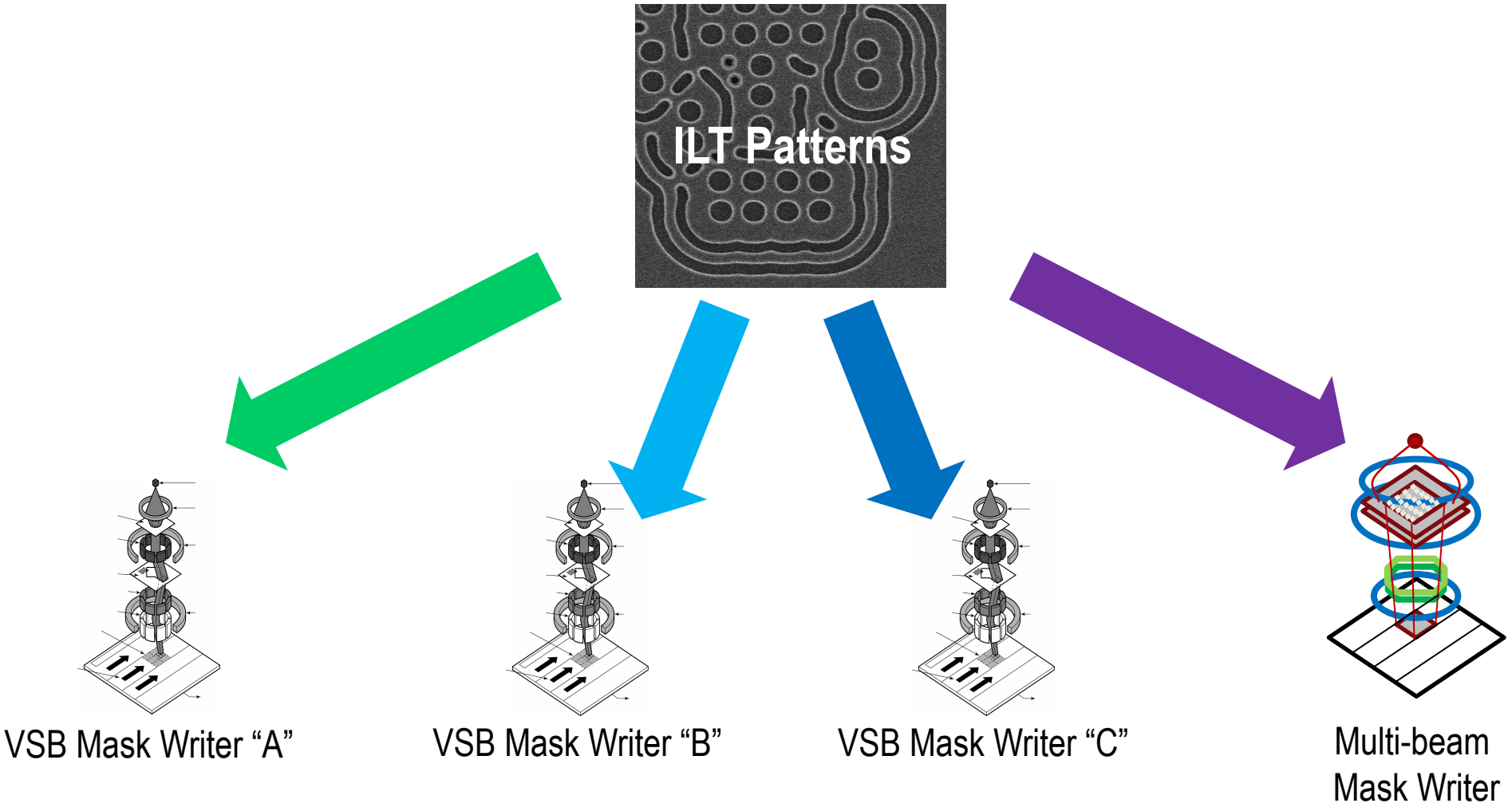
Curvilinear ILT MPC on Multi-beam: Improving CDU



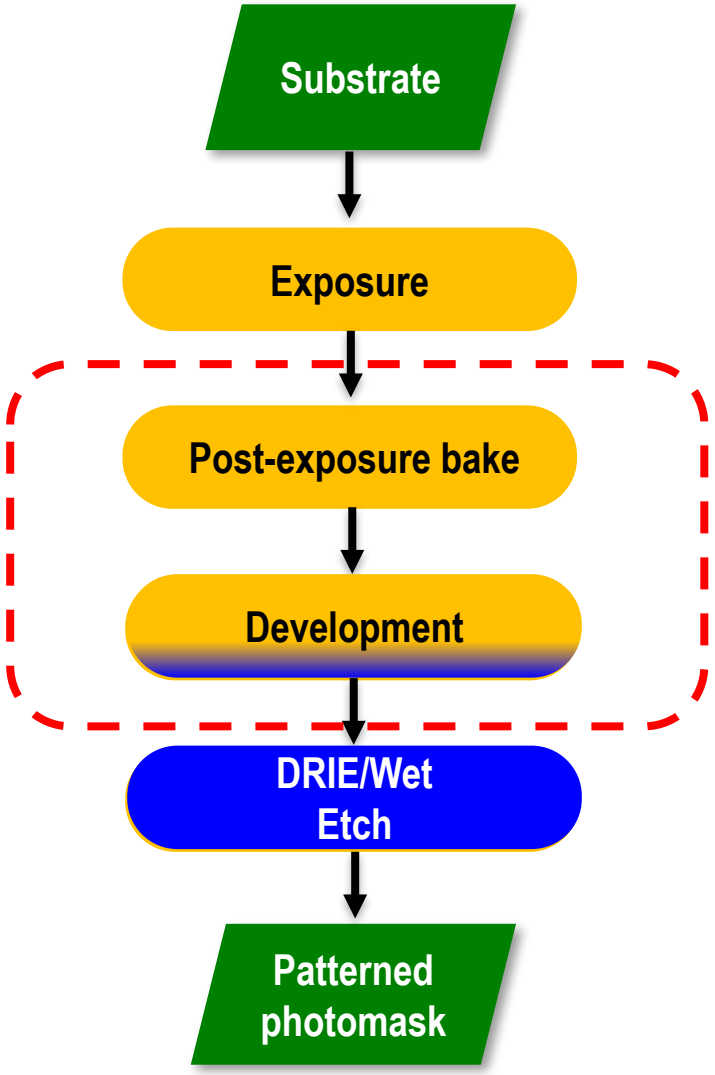


Refer to: GPU-Accelerated Inline Mask Correction for the MBM-1000, H. Zable, Aki Fujimura

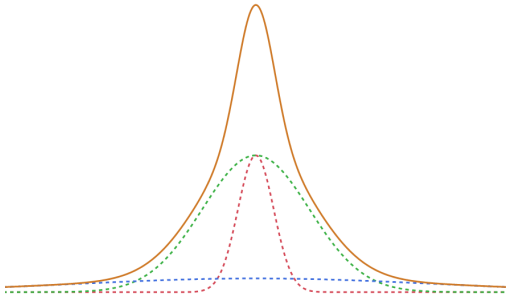
To Enable ILT MPC Portability, Model Has to be the Same

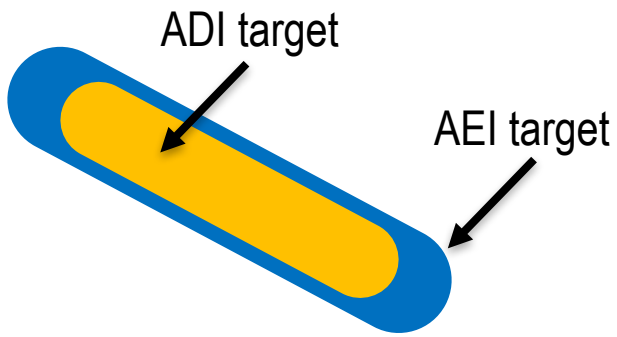


VSB and Multi-beam Can Share the Same Mask Model



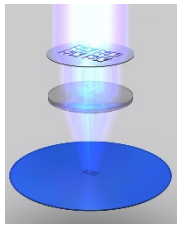
Dose effects

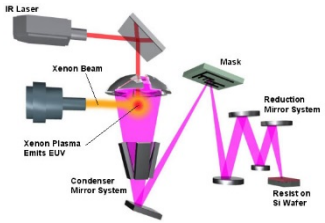




Shape effects

One Model Form is All You Need for All Masks

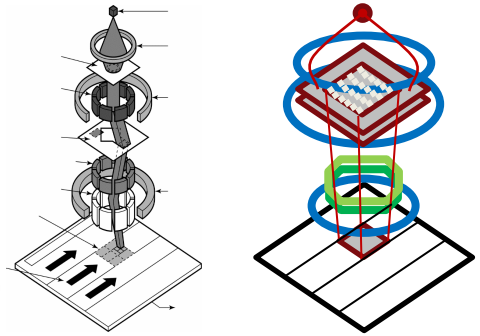




ArF or EUV

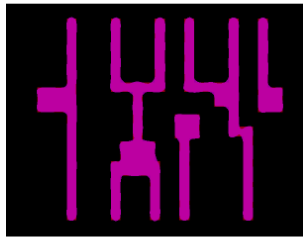
IMS Nanofabrication

NuFLARE



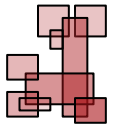
VSB or Multi-beam

TrueModel®



1D or 2D Shapes

Overlapping Shots

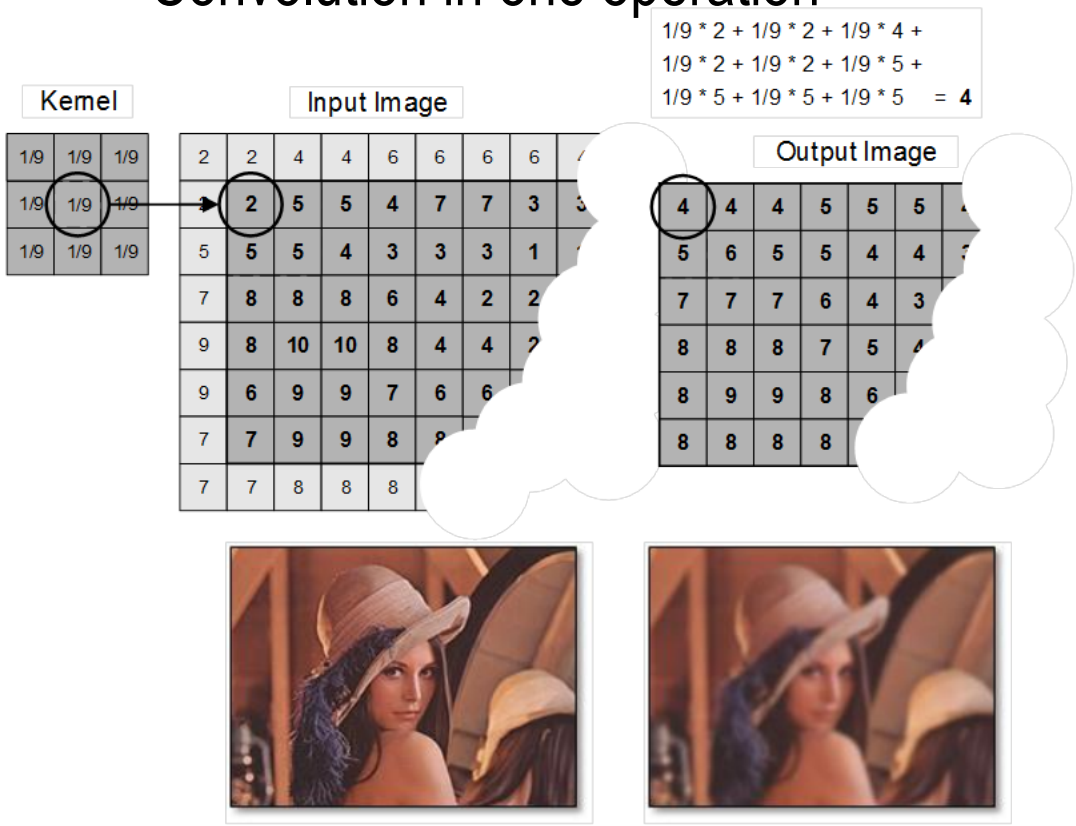


Dose Modulation

Positive or Negative Resist

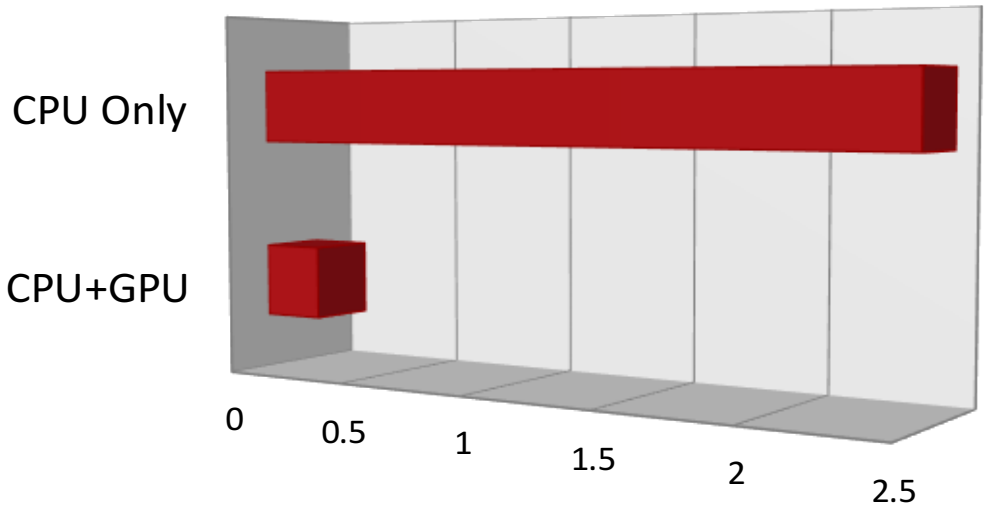
GPU is Good for Mask Model and Simulation

- GPU is designed to do image processing really fast
  - Convolution in one operation



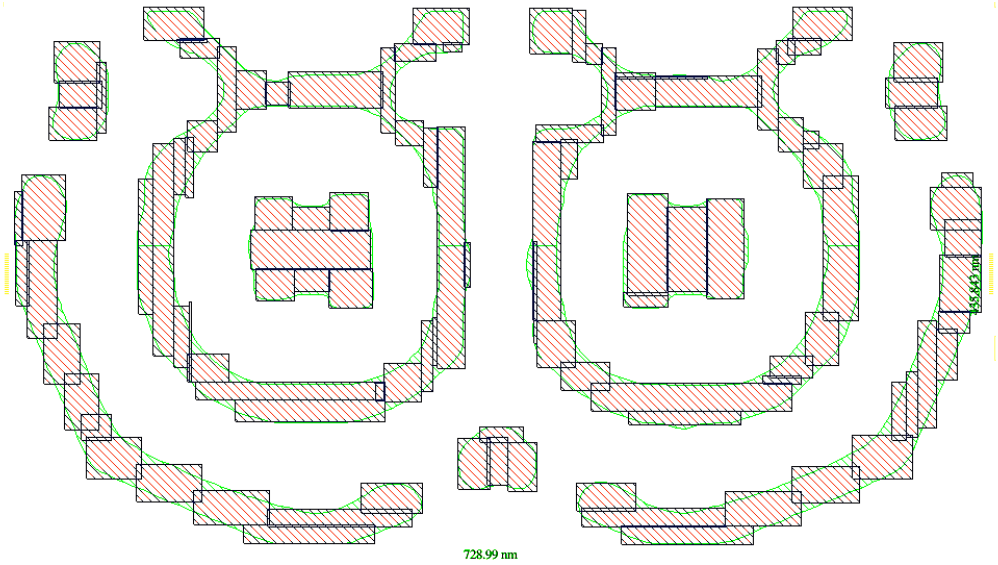
- Thousands of pipeline to massively distribute the run for same operation and multiple data

Gaussian convolution run on CPU-Only and on CPU+GPU
Data size: ~80 µm by 80µm, 10nm pixels

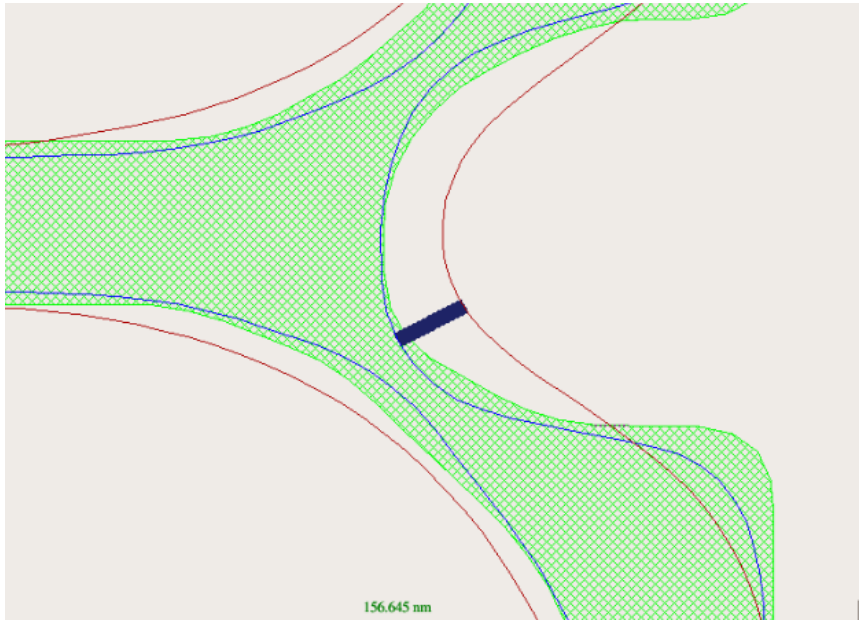


Ref: Heterogeneous compute case study: image convolution filtering, Imagination Blog

GPU is Good for Both Dose and Shape Correction



GPU is Good for Dose Correction



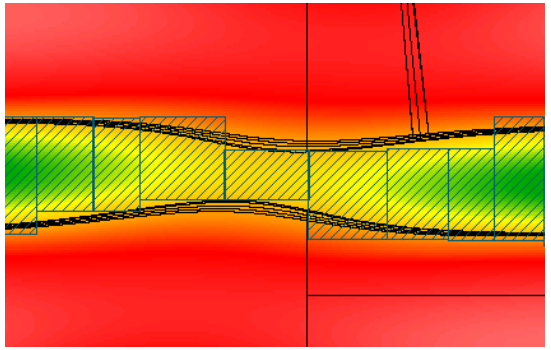
GPU is Good for All Angle Geometry Engine

Refer to: Simulation-Based MDP Verification for Leading-Edge Masks, Bo Su

GPU-Accelerated MB-MPC Enables Curvilinear ILT Using Either VSB or Multi-Beam Mask Writer

- Curvilinear ILT requires model-based mask process correction
- Multi-beam mask writer is ideal for curvilinear ILT because of the constant write time
- VSB mask writer needs to write curvilinear ILT as a backup of multi-beam
- Both dose and shape correction are required for MPC on VSB and multi-beam
- A single model can be used for both, enabling ILT portability
- GPU enables model-based MPC with reasonable runtimes
  - Fast physical model computing, dose compensation, and all-angle geometry engine

My Prediction: GPU Will Become the De Facto Computing Platform for Semiconductor Manufacturing



Simulation

B.G. Kim, et al., BACUS, 2012

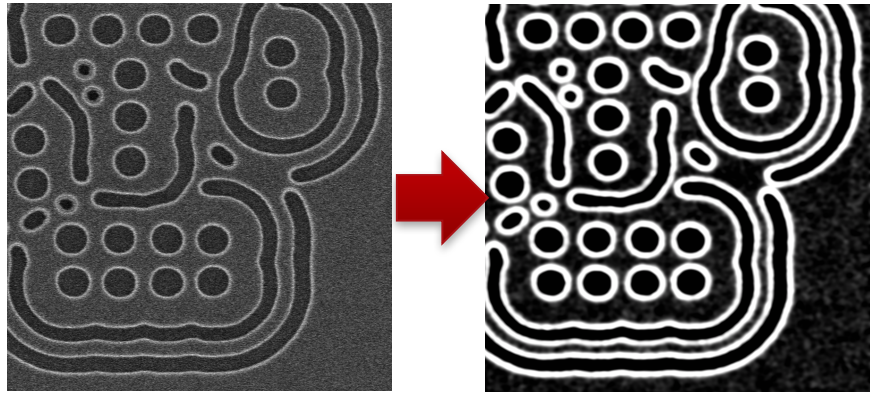
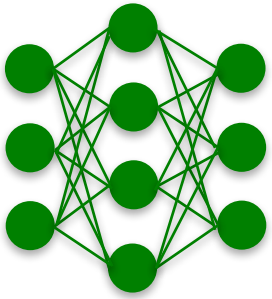


Image Processing



(Deep) Machine learning


D2S