The Latest Progress in Model-Based Mask Data Preparation

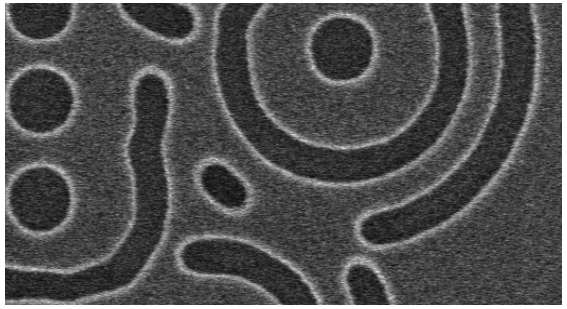
Linyong (Leo) Pang

Bo Su

D2S, Inc.

A Decade of ILT!

2005



6	2	1	1
Papers	Foundries	Memory	Mask shop

Luminescent TECHNOLOGIES™

Enter the complex mask…

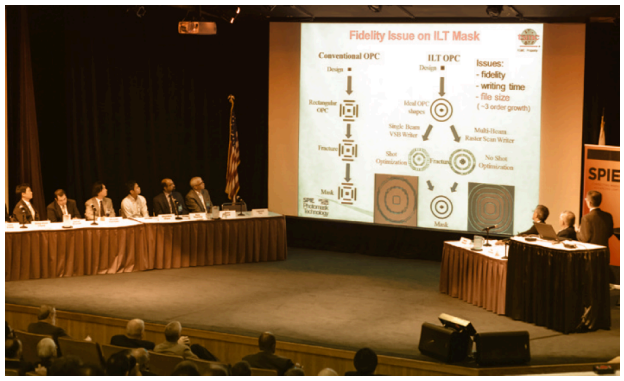
ILT Adopted as the Way Forward

>200

Papers

Officially announced

Today



ILT expertise proliferated

2014 panel

Complex Masks Pose Challenges

Long VSB write-times

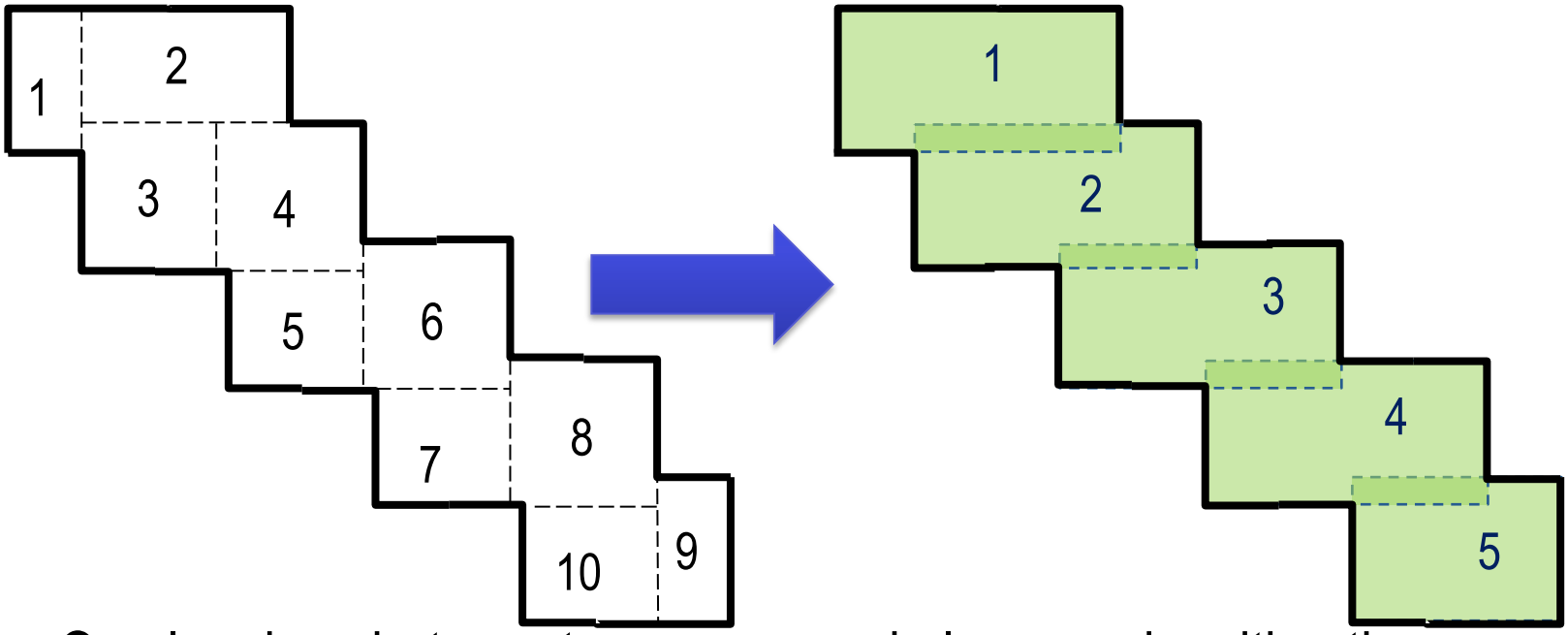
Low accuracy
due to proximity effect

Overlapping Shots = Reduced Shot Count

10 conventional shots

5 overlapping shots

Plus, extra energy in overlapping areas



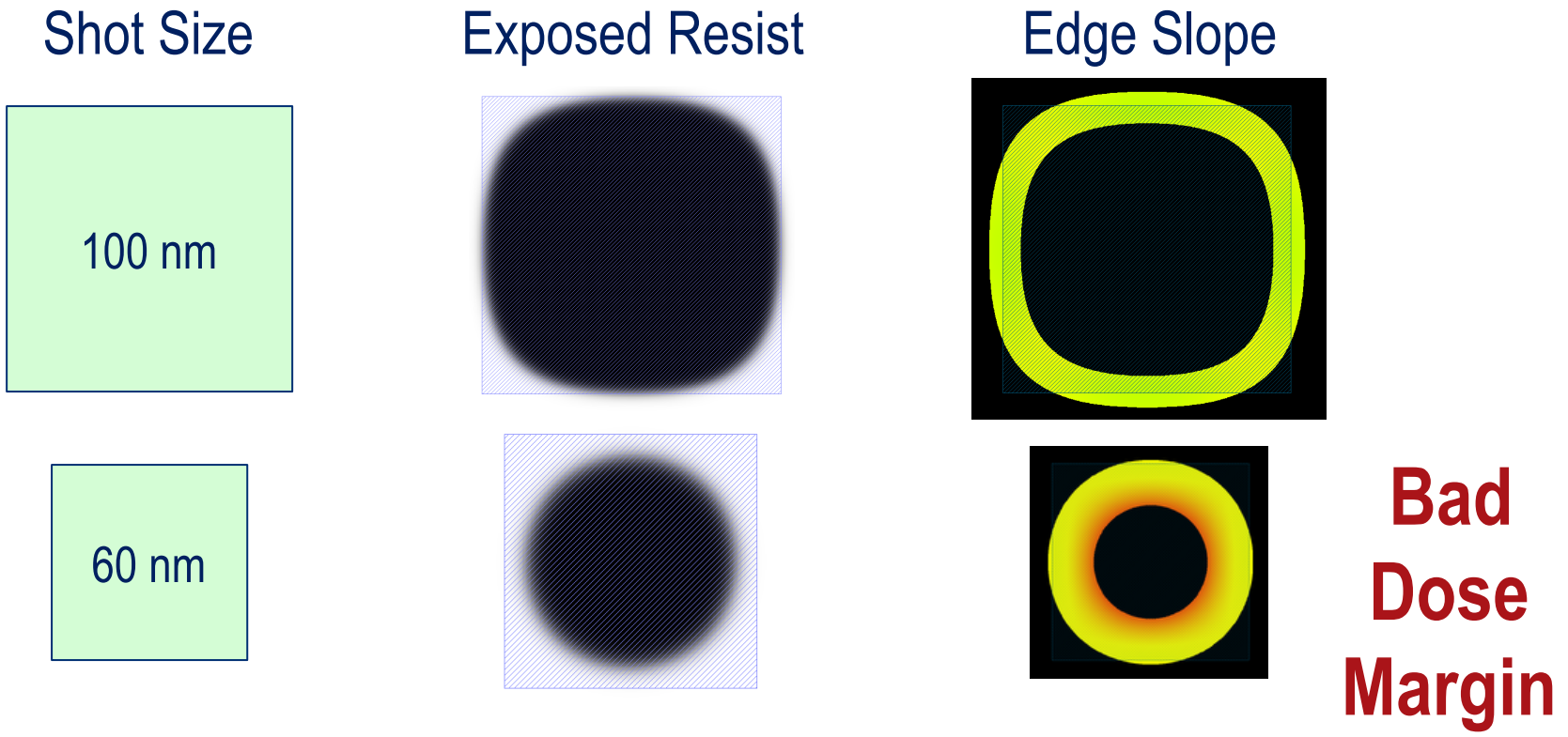
Overlapping shots cast more energy in less mask-writing time:

= Better process margin

= Better CDU

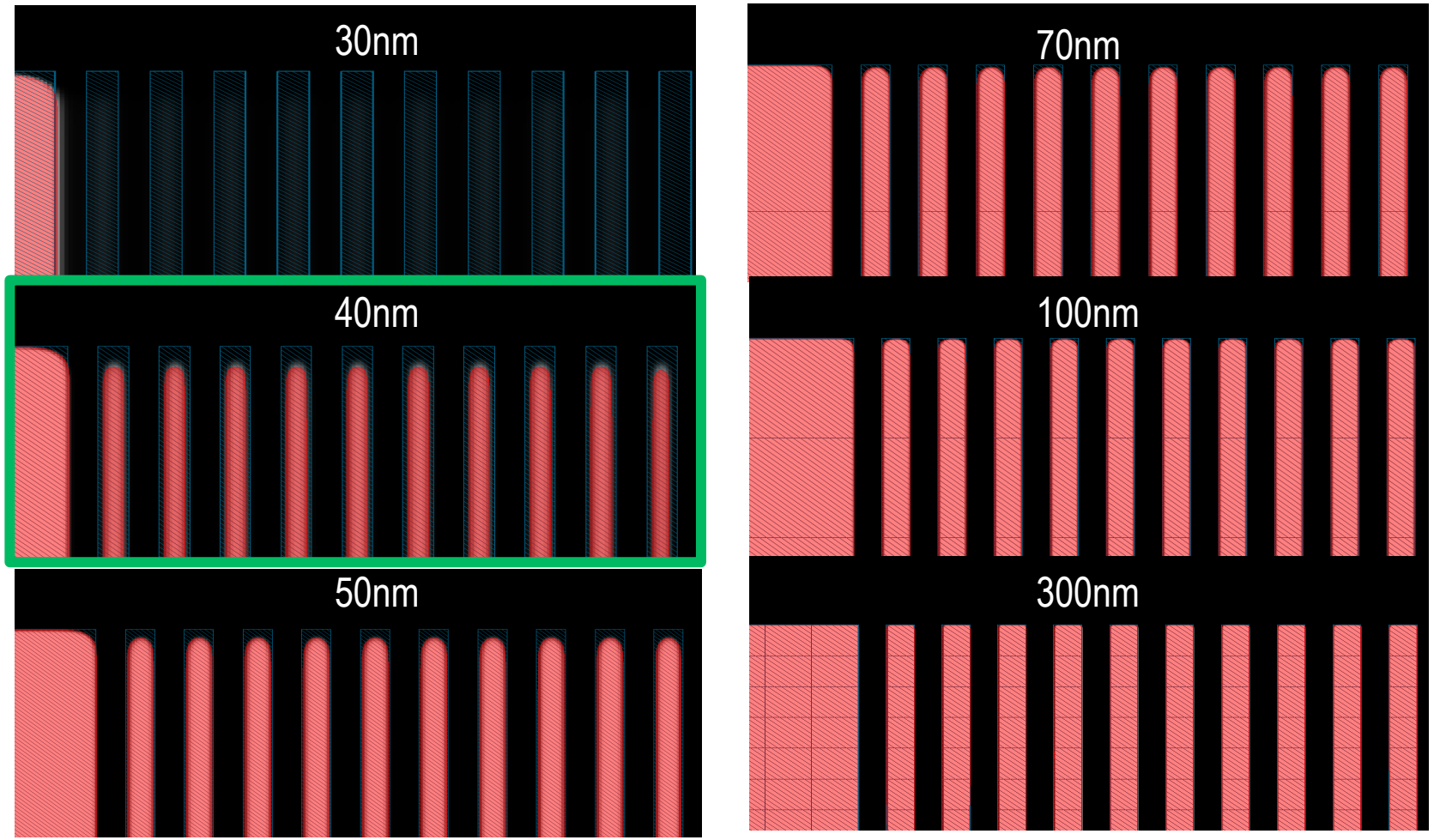
= No mask-write time vs. mask-quality compromise

eBeam Needs Proximity Correction



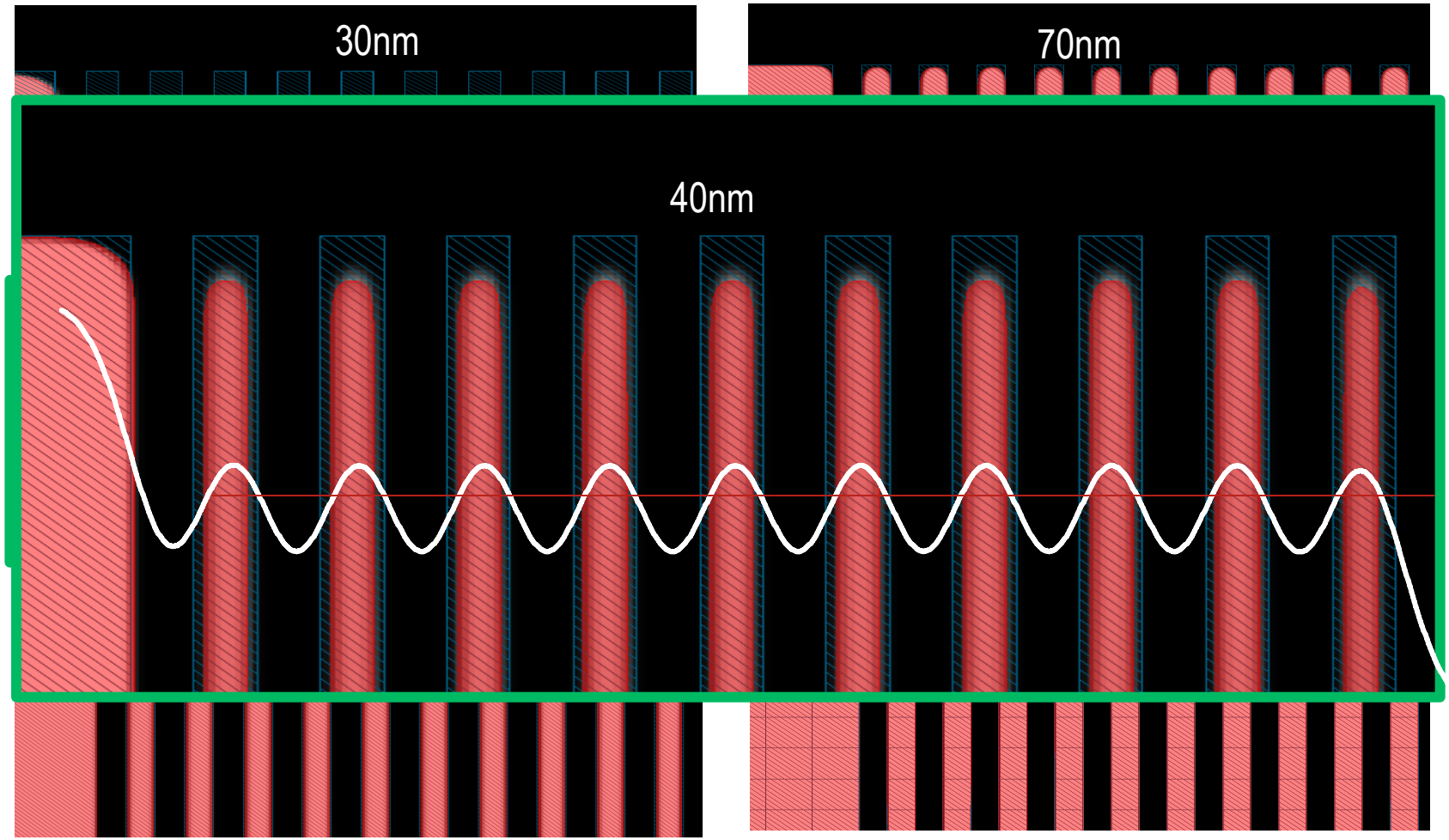
- At 20nm node, eBeam writing is no longer “faithful”
- Needs proximity correction, like OPC at 90/65nm
- Dose margin is the problem

< 50nm, Context is Critical



Pictures enlarged to show contour

< 50nm, Context is Critical



Pictures enlarged to show contour

Model-Based MDP is the Answer for ILT

- 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 answer

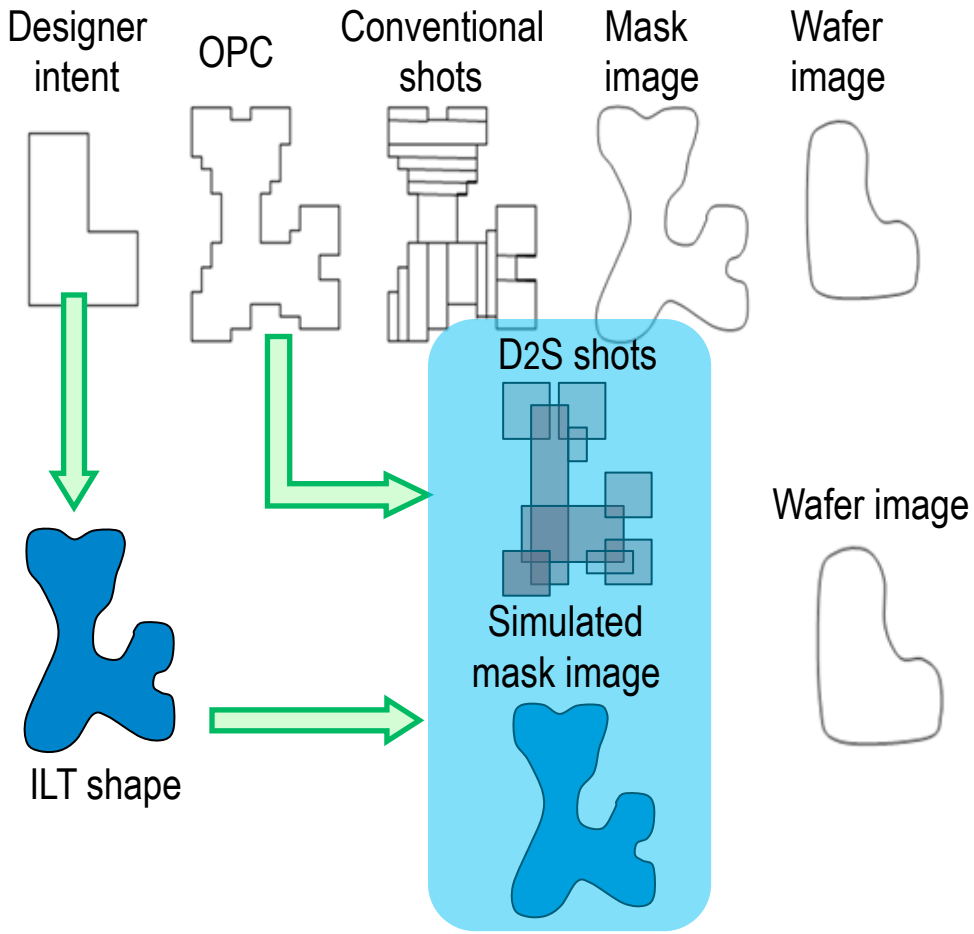
MB-MDP, Overlapped Shots Required with VSB for Complex Masks

Conventional solution:

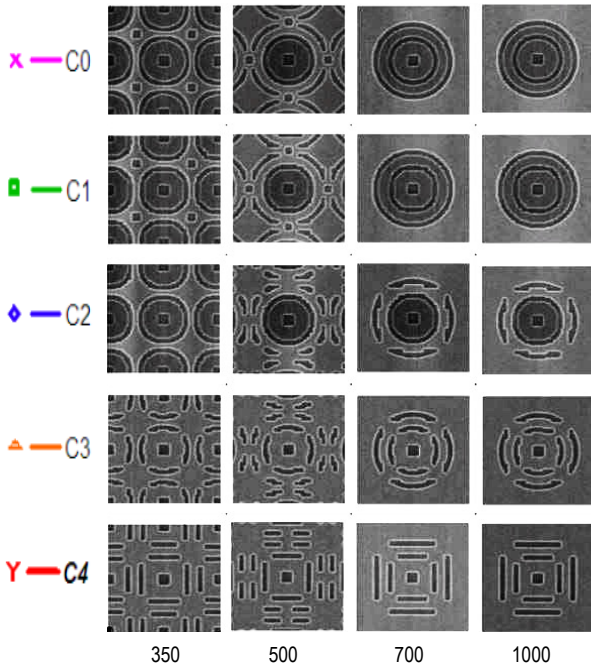
- Geometry-based
- Shots cover OPC layout without overlapping
- Higher shot count and worse mask fidelity

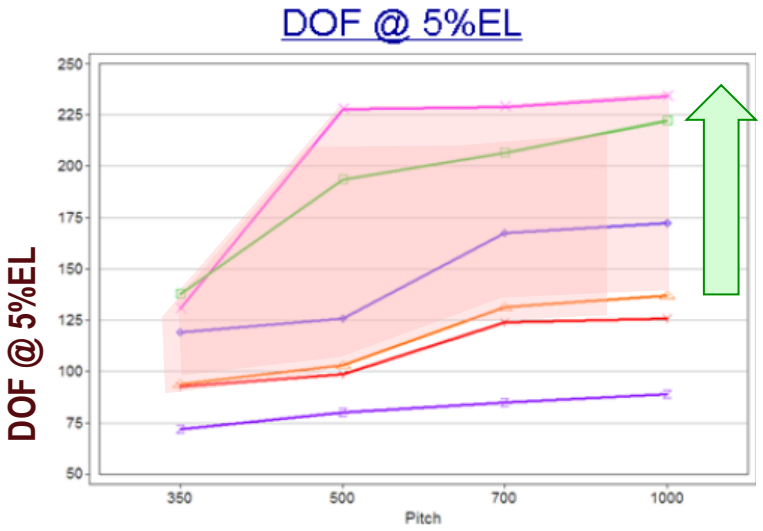
D2S solution:

- Model-based, better CDU control
- Overlapping shots to maximize shot contribution to the final mask shapes
- Lower shot count and better mask fidelity



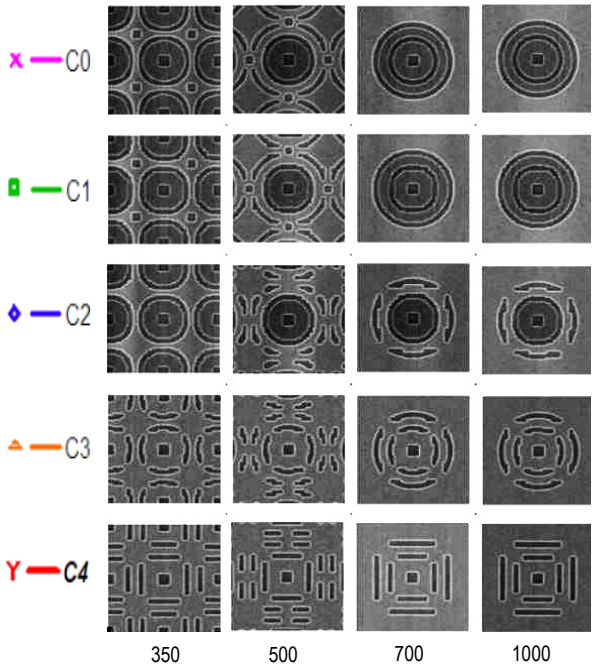
Complex Shapes are only Feasible with MB-MDP and Overlapped Shots

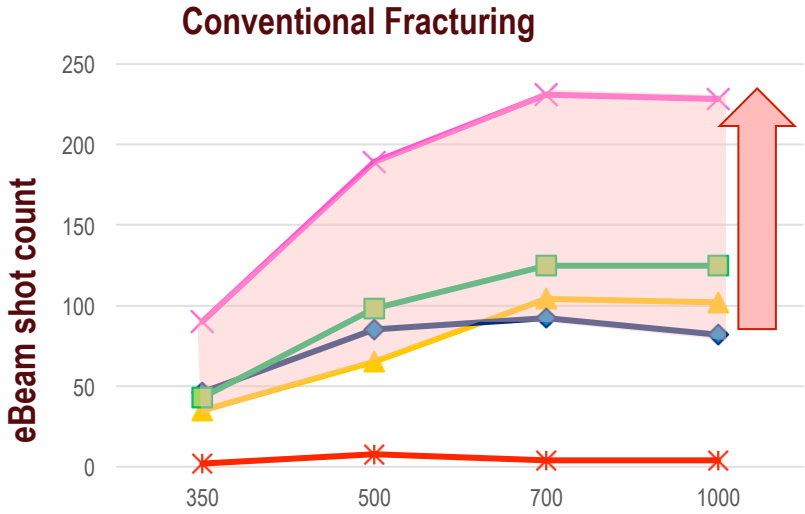




Much better DOF possible with unconstrained shapes

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

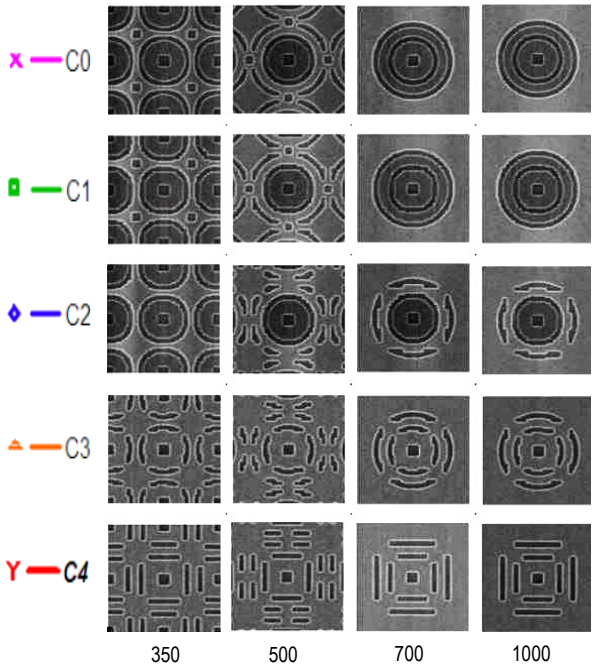


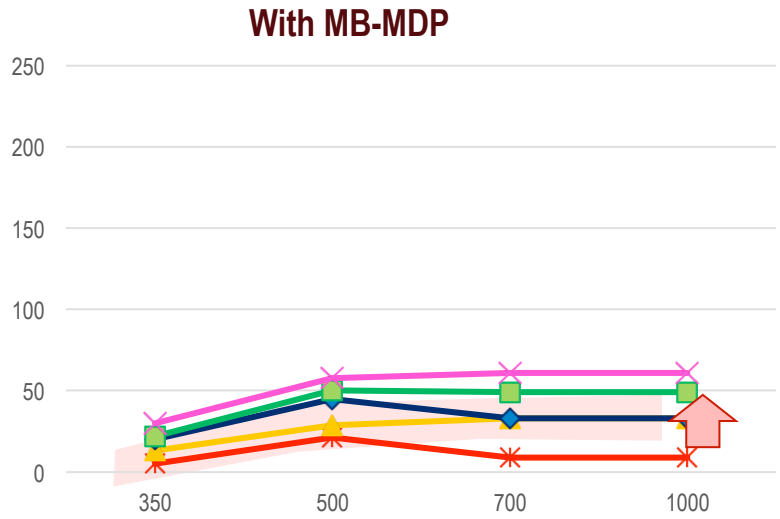


But mask-write times exploded

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

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

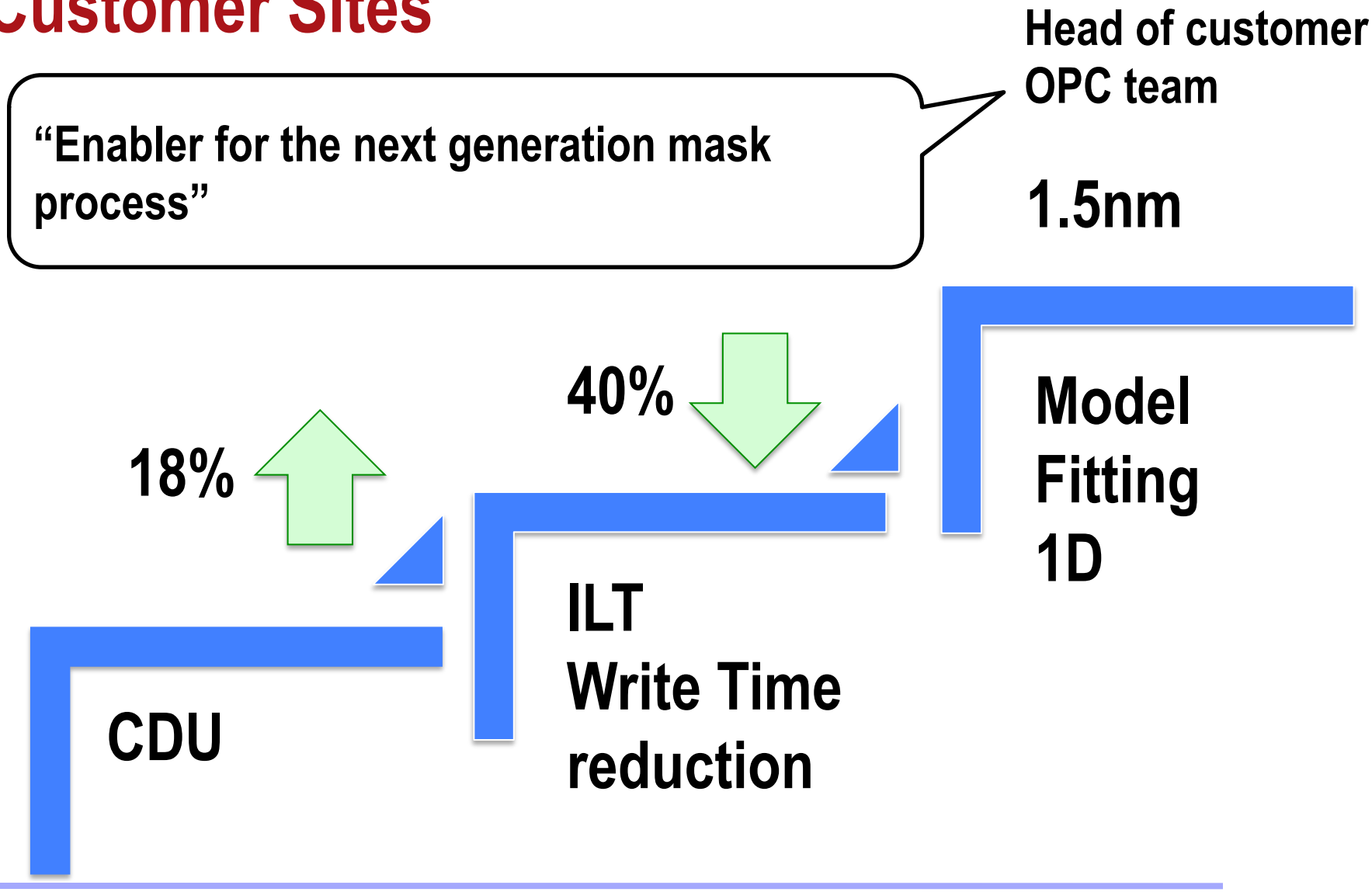




Mask-write times do not explode with MB-MDP

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

Benefits of MB-MDP Proven at Key Customer Sites



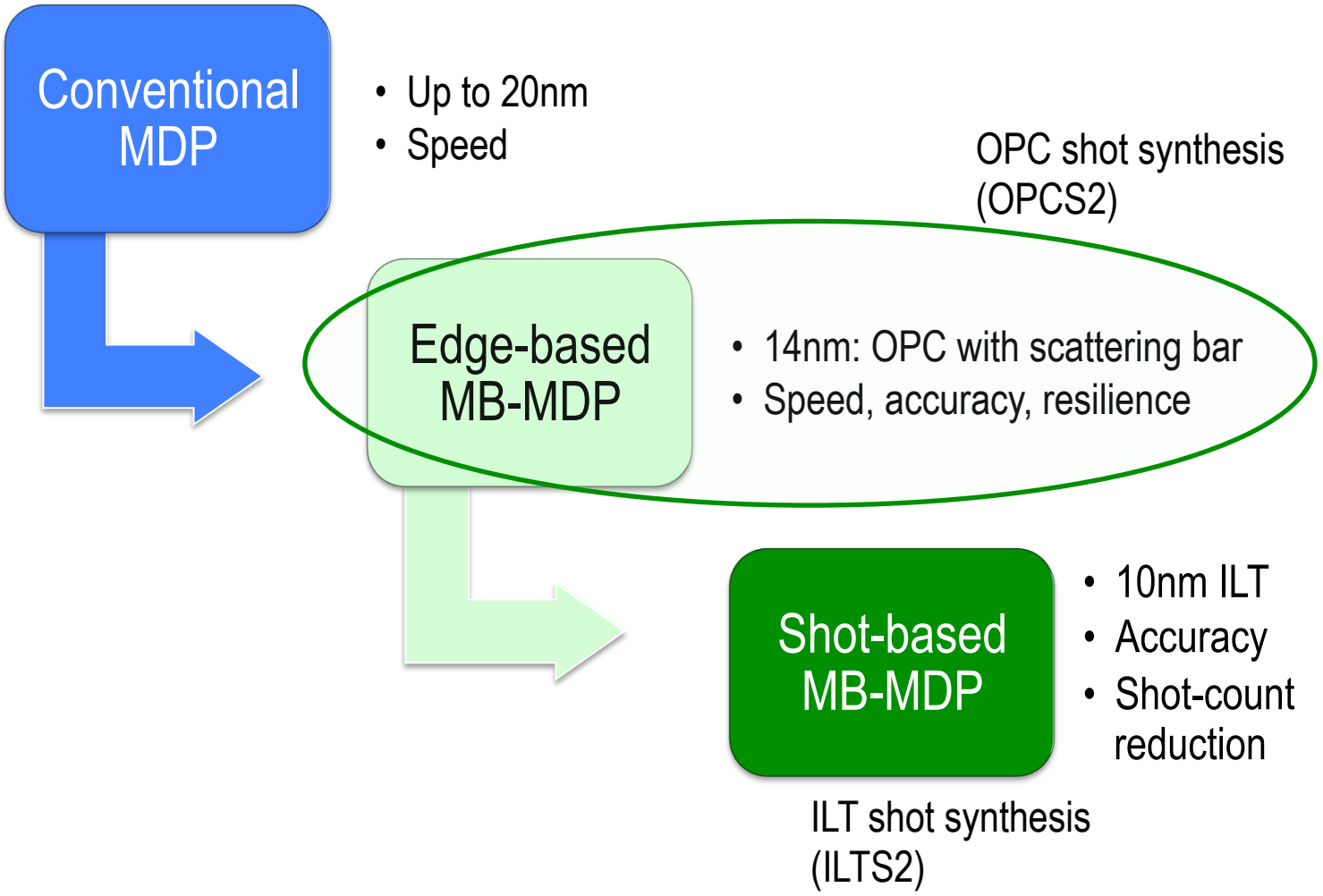
MB-MDP is Recognized by Industry Leaders at Semicon Taiwan 2015

imec	**Opening Speech with Market Overview: Infrastructure for IoT (PDF Download)** Dr. An Steegen, Senior Vice President Process Technology, imec
tsmc	**EUV Lithography for Sub-10-nm CMOS Technology (PDF Download)** Dr. Anthony Yen, Director, TSMC
ASML	**EUV Lithography Insertion (PDF Download)** Dr. Kars Troost, Senior Product Manager, ASML
14:55-15:20	**Break**
SYNOPSYS®	**A Computer Science Perspective on Computational Challenges for Sub-10nm Mask Synthesis (Not Authorized)** Mr. Srinivas Raghvendra, Vice President, Synopsys
tsmc	**Computational Lithography Technology for Foundry (Not Authorized)** Dr. Ru-Gun Liu, Deputy Director, TSMC
D2S®	**Removing the Last Road Block of Deploying ILT into 10nm Node by Model-based Mask Data Preparation and Overlapped Shots (PDF Download)** Dr. Leo Pang, Chief Product Officer and Executive VP, D2S

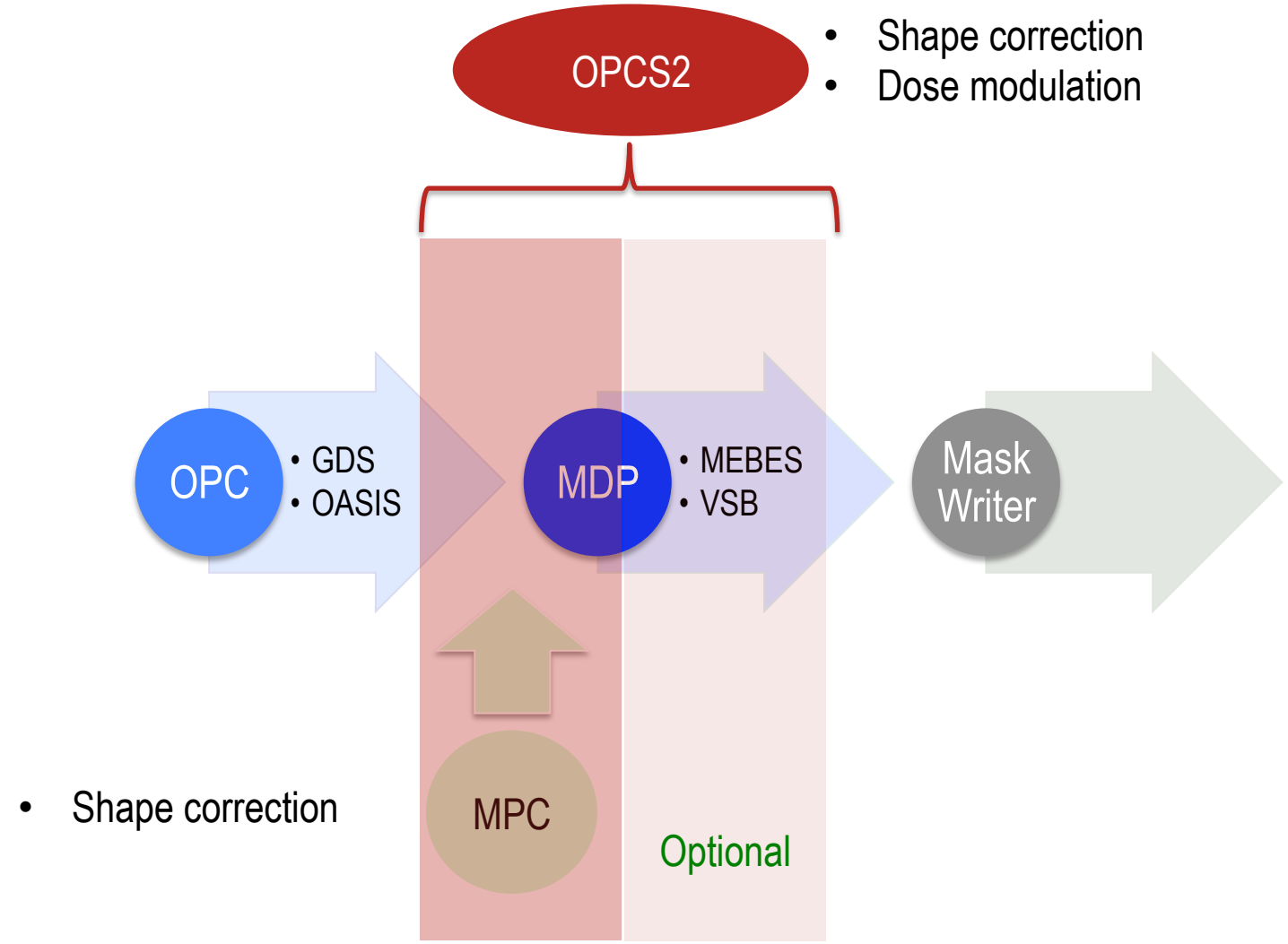
"Innovative mask technology by D2S"

TSMC
Deputy Director
Dr. Ru-Gun Liu

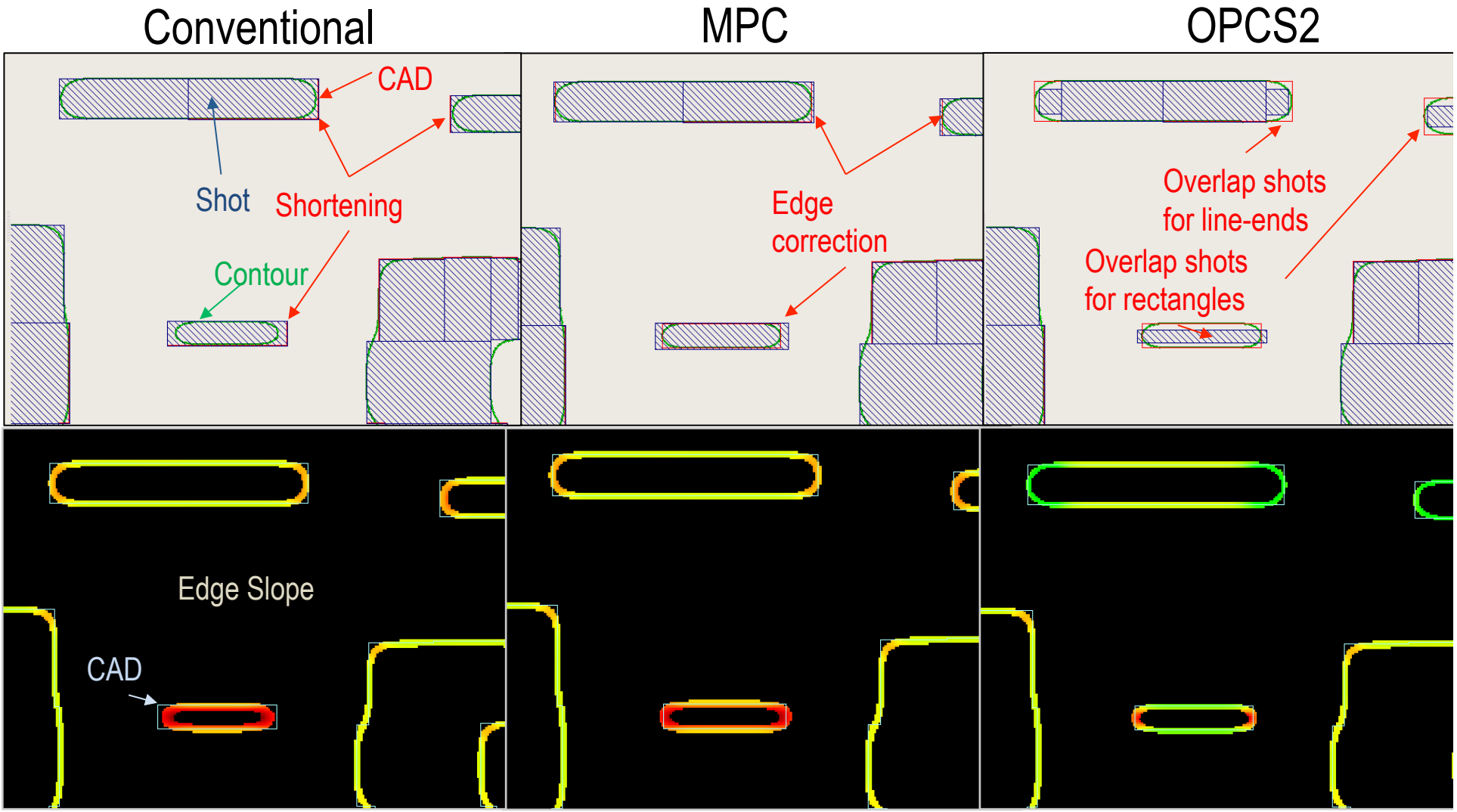
New Edge-Based Correction Feature Added to MB-MDP for Non-ILT Masks



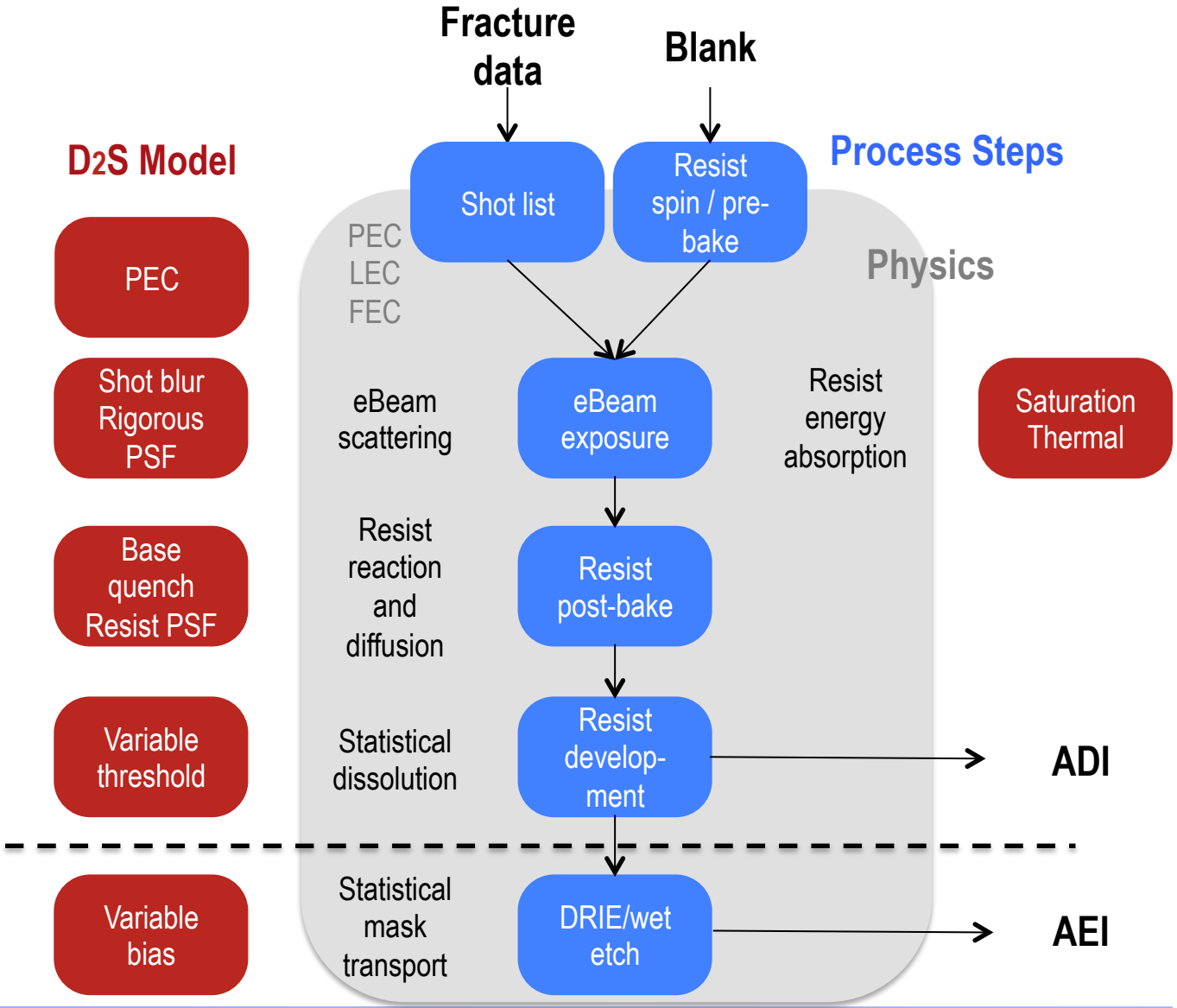
OPCS2 = MPC+ Dose Modulation + (Conventional MDP)



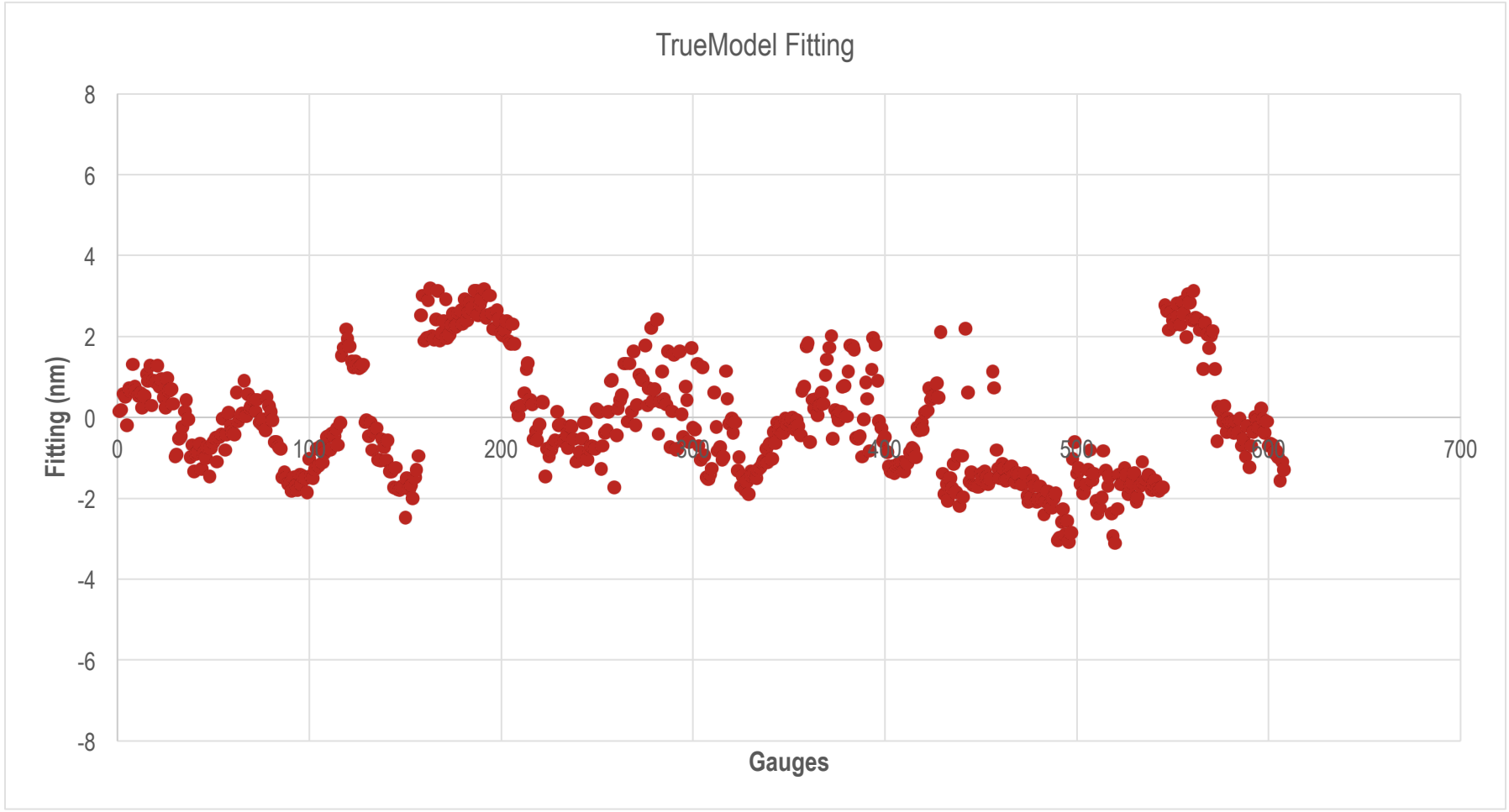
OPCS2 Efficiently Improves SRAF Printing and Linearity for Normal OPC



The Mask Model is the Key



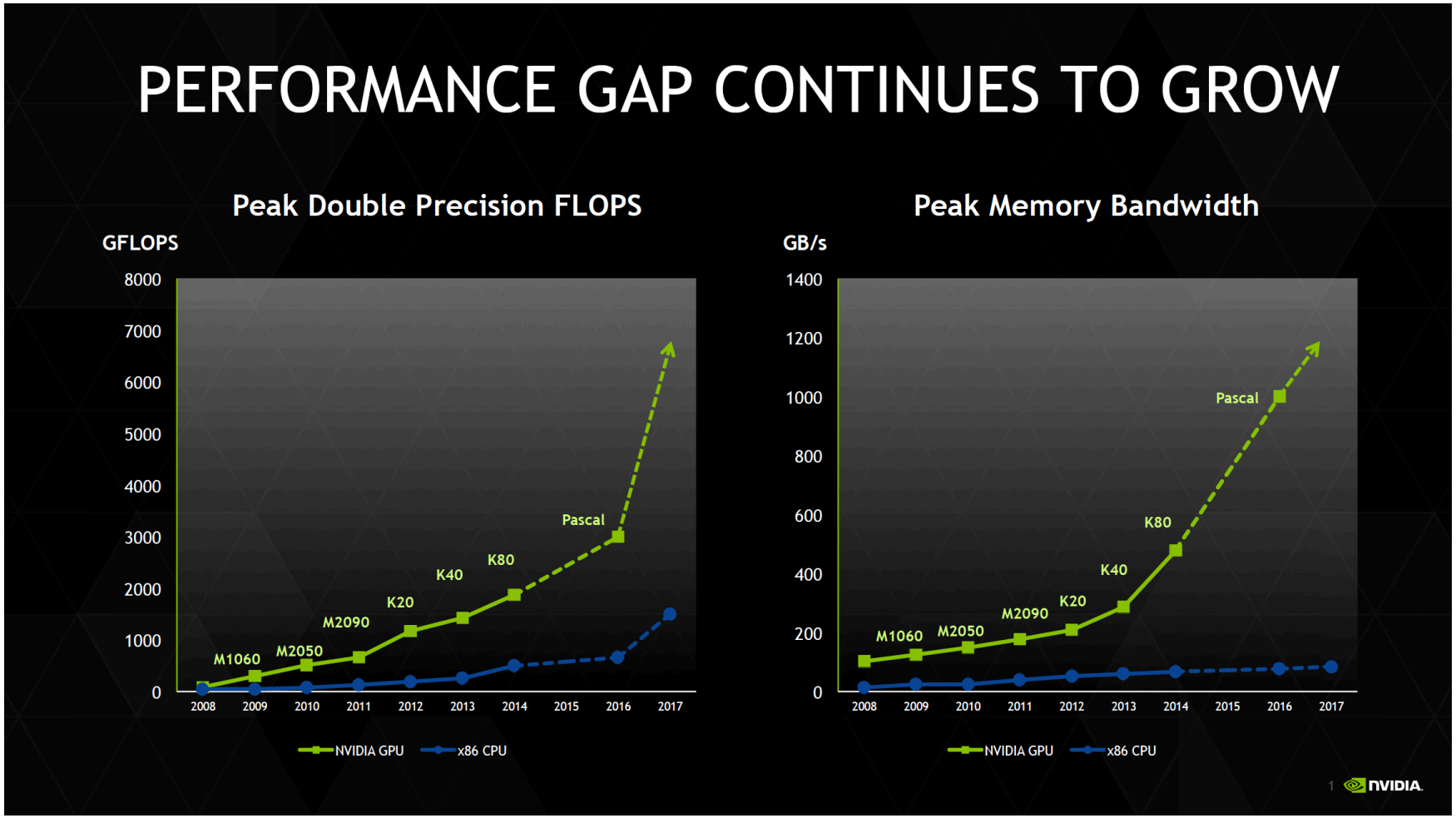
D2S Mask Model is Reaching 1.5nm RMS



Is MB-MDP Run Time Ready for Production Use?

- Over 100X more computation than MB-OPC
- Mask scale 4X than wafer scale
  - Imagine calculation on every 1nm on 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)
- Full mask vs full chip: 10X bigger

Scientific Computing Is Moving to GPU



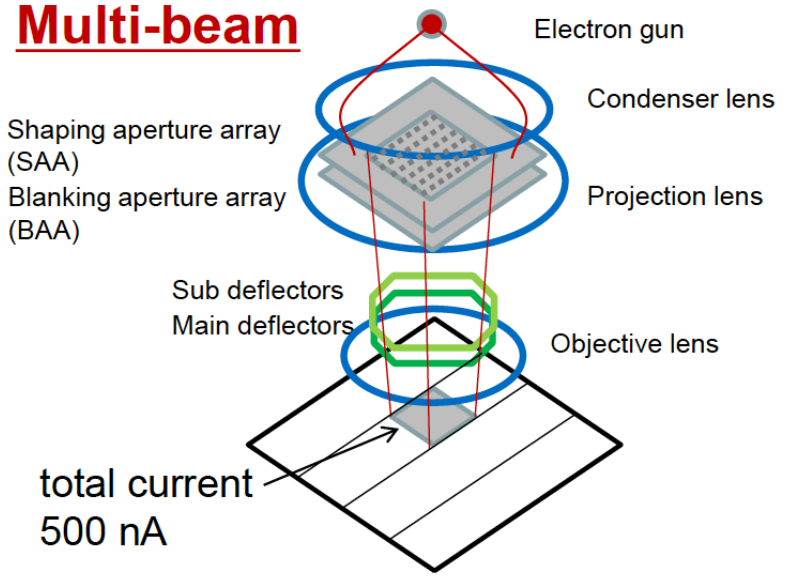
Jen-Hsun Huang, CEO of NVIDIA, GPU Technology Conference, 2015

D2S 400TFLOPS CDP Using GPUs Is In Production Use at Mask Shops

- 400 TFLOPS
- In production use
- Part of NuFlare EBM 9500
- Simulates the entire mask plane
- All standard parts, with built-in redundancy

Multi-Beam Mask Writer Will Need MB-MDP Even More

- Multi-beam mask writer is the ultimate answer for ILT
  - Write-time independent of mask complexity
  - Use slower resist
    - Smaller features
- It requires MB-MDP
  - Large data set to process
  - Needs dose modulation



H. Matsumoto, 2016 Introduction and recent results of Multi-beam mask writer MBM-1000, SPIE 2016 eBeam Initiative Luncheon Event

MB-MDP is Being Deployed in Production

- ILT is being deployed in production at the leading edge
- Mask makers are faced with ILT masks
- Overlapped shots and MB-MDP enable 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
- Multi-beam mask writer will require MB-MDP, too

D2S