Removing the Last Road Block of Deploying ILT into 10nm Node by Model-based Mask Data Preparation and Overlapped Shots

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193i Needed to be Extended and Extended

- Inverse Lithography Technology (ILT), Source-Mask Optimization (SMO), and Pixelated Masks invented
- The enabler is mask with small (assist) or/and complex features

Source: SPIE 8680-3
Source: SPIE 7640-4
Source: SPIE 6924-13
The Last Road Block: How to Write Such Complex Masks?

- Shot count
- Pattern fidelity
Overlapped Shots Are the Answer to Reduce Shot Count for Complex Shape

10 conventional shots to write

5 overlapping shots to write

Extra energy in overlapping areas

Overlapping shots cast more energy in less mask writing time:
- Better process margin
- Better CDU
- No mask writing time and mask quality compromise
Now eBeam Also Need Proximity Correction just Like OPC at 90/65nm Node

- Discontinuity at 20nm logic node
- eBeam writing is no longer “faithful”
- Mask Linearity is one issue: but the problem is bad Dose Margin
  - Lack of resiliency to manufacturing variation: LER and CDU problems
< 50nm, Context is Critical

Each picture is scaled up to show the contour
< 50nm, Context is Critical

Each picture is scaled up to show the contour
Simulation-Based Mask Data Processing Is the Answer for ILT Mask Pattern Fidelity

- 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 inevitable answer
MB-MDP and Overlapped Shots are Must with VSB for Complex Masks

- **Conventional solution:**
  - Geometry-based
  - Shots cover CAD layout without overlapping
  - More shot count and worse mask fidelity

- **D2S solution:**
  - Model-based, better CDU control
  - Utilizes overlapping shots to maximize shot contribution to the final mask shapes
  - Less shot count and better mask fidelity
Complex Shapes are only Feasible with MB-MDP and Overlapped Shots

But Mask Write Times Exploded

Conventional Fracturing

350 500 700 1000

DOF @ 5%EL

Much better DOF possible with unconstrained shapes

With MB-MDP

Mask Write Times do not explode with MB-MDP
Complex Mask Write Time: w’ Conv. MDP – Impossible; w’ MB-MDP – Under Control

**Conv. fracturing**
Manhattanizing resolution
- 25nm = 59%
- 15nm = 100%
- 5nm = 320%

**MB-MDP**
Shot count wrt MR = 15nm
- 57%
- 45%
- 33%

Evidence: Images Identical w’ 77% Reduction in Shot Count with MB-MDP

Pattern and measurement courtesy, Dai-Nippon Printing, Ltd.
Recent ILT full chip tape-out for 10nm node

- Shot Count Reduction: ~50%
- Write Time Reduction: ~40%
Complex Mask Pattern Fidelity: Conv. MDP – Not Acceptable, MB-MDP: Great

Conventional MDP

Shot Number driven MB-MDP

CDU driven MB-MDP


L. Pang, Enabling ILT at Advanced Nodes with Simulation-based Mask Data Preparation
Complex Mask Inspectability: Conv. MDP: Out of Control, MB-MDP: Good

- Both of Shot Number and CDU-driven MB-MDP are clearly more effective in reducing size variations.

Is MB-MDP Possible?

- Over 10X more computation than MB-OPC
  - Mask scale 4X than 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)
The Answer is GPU:
- Scientific Computing Is Moving into GPU

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

PERFORMANCE GAP CONTINUES TO GROW

Peak Double Precision FLOPS

Peak Memory Bandwidth
D2S Has Built 400TFLOPS Computational Design Platform Using GPUs

D2S’ Computational Design Platform (CDP)

- Could rank in the top 100 Super Computers in the Word (June, 2014)
- In production use
- Part of NuFlare EBM 9500
- Simulates the entire mask plane
- All standard parts, with built-in redundancy

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<th>System Description</th>
<th>Performance Metrics</th>
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TrueMask® MDP is a GPU Based General Simulation Platform

- Conventional Shot Generation
  - Compatibility
- Overlapping Shot Generation
  - Write-time reduction + CDU/LER improvement
- Dose Enhancement
  - Linearity + CDU/LER improvement of narrow features
- Shape Correction
  - Simulation-based general EPE Optimization
- Double Simulation
  - GPU-accelerate Mask-Wafer double simulation for Wafer Plane analysis
- Simulation-Based Mask Verification and Hotspot Detection
- TrueModel® mask models
Summary:
Using GPUs, ILT Mask Shapes Prevail

- ILT is being deployed at 10nm node
- Mask makers is facing ILT masks
- Overlapped shots and MB-MDP enables 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
- MB-MDP and Dose Modulation will also offload mask inspection and review work