6th Annual eBeam Initiative Luncheon
SPIE – February 25, 2014

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

- Is an educational platform for eBeam technology and its impact on all lithography approaches

- Open to any company in the semiconductor design chain with an interest in eBeam technologies
“I would like the eBeam Initiative to help the ecosystem understand the value of higher quality masks.”

- Aki Fujimura
40+ Member Companies & Advisors
Now welcoming Sage-DA

www.ebeam.org
Educational Themes for 2014
Drawing on 2013 Survey Results

• Multibeam for Masks
  – Confidence increased from 75% in 2012 to 86% in 2013 that multibeam for production mask writing will occur in 2016

• GPGPUs for Simulation Intensive EDA Applications
  – More than 50% said that one third or more simulation intensive EDA applications would use GPGPUs

• Mask Hotspots
  – More than 75% said that mask hotspots will be significant by 2020; 36% see as significant today (Aug 2013)
Future of Mask Data Prep is Model Based

MB-MDP fixes mask hotspots while reducing write times

- Linearity correction (MPC)
- Dose margin enhancement (MPE)
- Full-chip model-based mask verification (MB-MV)
Mask Hotspots Escaping the Mask Shop Today

Can we identify issues earlier?

Inspection:
- Hotspots smaller than 20 nm (2D) unlikely to be identified at all
- SEM review of only flagged hotspots
Model-Based Mask Verification (MB-MV) for Full-Chip Detection

- Need to flag mask hotspots with 1-2 nm accuracy
- Need simulation-based Edge-Placement and Dose Margin error detection
- Full chip coverage requires GPGPU acceleration
MB-MV for Conventional Fracturing

- No risk to existing flow
- Finds issues before expensive mask processing
- Full-chip coverage

New Whitepaper on Mask Hotspots at www.ebeam.org
Our Next Speakers

- **Mask Complexity Issues and MB-MDP Approach**
  - Naoya Hayashi, DNP

- **Mask Synthesis for DSA**
  - Yuri Granik, Mentor Graphics

- **Q&A**
Mask Complexity Issues and MB-MDP Approach

Naoya Hayashi
Dai Nippon Printing Co., Ltd.
“Litho scaling” should continue.

EUVL still have many issues to resolve.

Optical Litho extension needed.

“Optical Lithography Extension” needs very complex mask pattern features and/or multiple masks per layer.
Trend of Number of Masks per Mask Set

Recent growth rate is ~14%.
High-end products need many masks!
Recent data file size seems to be stabilized. But maximum data size continues to rise!
Recent growth rate of average writing time is ~25%. Maximum writing time reached 2.5 days! →Need to reduce shot count!
Model Based Mask Data Preparation has some advantages regarding shot count reduction to reduce actual writing times, and accuracy of very small / complex features which are in non-linear range of an e-beam model.
MB-MDP evaluation results

- Experimental
  - Shot data generation by using MB-MDP and a conventional MDP tool for a reference
  - Mask writing on EBM-8000
  - Mask inspection check
  - Metrology

- Motif designs (Total chip size is 5mm x 5mm on wafer)

<table>
<thead>
<tr>
<th>Nodes</th>
<th>SRAM Cell</th>
<th>Standard Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>28,20,14nm</td>
<td><img src="image1.png" alt="SRAM Cell" /></td>
<td><img src="image2.png" alt="Standard Cell" /></td>
</tr>
</tbody>
</table>
# MB-MDP evaluation results

- **Pattern quality (SEM features)**
- **SRAM Metal 1 (20nm)**

<table>
<thead>
<tr>
<th></th>
<th>Metal 1 #1</th>
<th>Metal 1 #2</th>
<th>Metal 1 #3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Data</strong></td>
<td><img src="image1.png" alt="MB-MDP" /></td>
<td><img src="image2.png" alt="MB-MDP" /></td>
<td><img src="image3.png" alt="MB-MDP" /></td>
</tr>
<tr>
<td><strong>MB-MDP</strong></td>
<td><img src="image1.png" alt="MB-MDP" /></td>
<td><img src="image2.png" alt="MB-MDP" /></td>
<td><img src="image3.png" alt="MB-MDP" /></td>
</tr>
<tr>
<td><strong>Conventional MDP</strong></td>
<td><img src="image1.png" alt="MB-MDP" /></td>
<td><img src="image2.png" alt="MB-MDP" /></td>
<td><img src="image3.png" alt="MB-MDP" /></td>
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MB-MDP evaluation results

- Shot count comparison

<table>
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<tr>
<th>Nodes / MDP</th>
<th>Metal 1 #1</th>
<th>Metal 1 #2</th>
<th>Metal 1 #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>20nm / Conventional</td>
<td>635,005</td>
<td>678,823</td>
<td>2,286,066</td>
</tr>
<tr>
<td>20nm / MB-MDP</td>
<td>301,057</td>
<td>345,613</td>
<td>1,456,902</td>
</tr>
<tr>
<td>Reduction Rate</td>
<td>52.59%</td>
<td>49.09%</td>
<td>36.27%</td>
</tr>
</tbody>
</table>
Continuous device scaling requires very complex and small mask pattern features, especially for optical lithography extension option, and it will increase data size, shot count, and result in long mask writing time.

MB-MDP approach has certain advantages to reduce the shot count with equal pattern quality, and better small pattern fidelity.

Next step:
- Further results for inspection.
- Integration into production control system.
Mask Synthesis for DSA

Yuri Granik
Chief Scientist

February 2014
Outline

- DSA in IC manufacturing
- DSA grapho-epitaxy primer
- DSA mask synthesis flow
- DSA mask synthesis example
- DSA pilot production
- Conclusions
DSA in IC manufacturing

Grapho-epitaxy
 Contacts
 Poly Cuts
 Shrink
 Multiplication

Chemo-epitaxy
 FinFET lines and spaces

Contacts
Poly Cuts
Shrink
Multiplication

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DSA grapho-epitaxy primer

Grapho-epitaxy is a two-step dance
-Yan Borodovsky

- Firstly, lithography patterns guiding wells on wafer

- Secondly, block-copolymer fills wells then it is baked and etched
DSA mask synthesis flow

Litho target synthesis → OPC → Litho Verification → DSA Verification

Design → Guiding Patterns → Mask → Printing Image → DSA Cylinders
DSA mask synthesis example

- Example of **DSA contact multiplication** technology
- Mask is synthesized by industry-standard ILT tool **pxOPC** by Mentor Graphics
- Generic 193 immersion
- Clip from a contact layer
- 20 nm CD
- MRCs are ignored
Regular Litho without DSA

- Litho alone does not work: no process window
  - Outer and nominal PV-contours are OK
  - Inner PV-contour collapses
Aggressive smooth mask for DSA

- Aggressive pxOPC mask results in maximum Litho EPE of 2.8 nm
Modest Manhattan mask for DSA

- Modest pxOPC mask of 40 nm fragments
- Maximum Litho EPE is 12.8 nm
Nature of DSA resolution enhancement

- PV-bands are acceptable even though pinching is present in outer contour

DSA enhances resolution by forming correct final contacts even when guiding pattern fidelity is compromised
Error versus mask aggressiveness

- **pxOPC** mask fragmentation flavors from 0 (smooth mask) to 50 nm are demonstrated.

For coarser masks printing image degrades and can cause failure of guiding pattern to control positions of DSA cylinders.
DSA pilot production

- Pilot production starts this year 2014 for **DSA contact shrink** technology

- Severe design restrictions are enforced
  - vertical/horizontal bars
  - one size of contacts across design
  - uniform pitch within a bar

- Traditional OPC should suffice

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**Not a bar**

**Pitch vary**

**Size vary**

**Not Manhattan**

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**Guiding pattern**

**DSA cylinders**
Conclusions

DSA is dirt cheap

- C. Grant Willson

- DSA chemical components are cheap
  — Come think of it, DSA actually costs nothing to mask makers

- DSA contact shrink is easy
  — Minimal impact on mask making
  — Traditional OPC should suffice

HOWEVER...

- DSA contact multiplication for optical lithography is hard

- Inverse Litho Corrections are desirable to control guiding patterns through process window
Acknowledgements

My colleagues from Mentor Graphics Alex Tritchkov and Aleks Bezman setup and run experiments
Thank you for attending!

Q & A