Mask Process Modeling in the Multi-beam Era
One Model Form for All Masks

ArF or EUV

1D or 2D Shapes

Overlapping Shots

Dose Modulation

VSB or Multi-beam

Positive or Negative Resist
Questions About the New Mask-Writing Era

- What’s different about the multi-beam era?
- What’s the same?
- What do we need to consider when modeling a multi-beam system?
- Mask process modeling in the multi-beam era
What’s different about multi-beam?
Multi-beam Uses Many Beamlets in Parallel

Source: IMS Nanofabrication
Huge Opportunity to Make Masks Great

• Any shape can be written in the same write time
• Dose profiles can be optimized

Multi-beam era moves us into the curvilinear domain!
What will remain the same?

D2S Patented Technology

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Mask Process Physics is the Same...

Mask
Input data

Substrate

Exposure

Post-exposure bake

Development

DRIE/Wet Etch

Patterned photomask

Resist CD
“ADI”

Etch CD
“AEI”

Dose effects

ADI target

AEI target

Shape effects
...Just More Complex

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Resist CD “ADI”

Etch CD “AEI”

Dose effects

ADI target

AEI target

Shape effects
What do we need to consider when modeling a multi-beam system?
Printed Mask Data Contains Both Shape and Dose Effects

Shape (etch) bias
AND
Dose linearity

We need to separate dose from shape effects!
Today: Dose Models Used for Shape Correction

Standard model uses Gaussians to model this
Gaussians are intended to emulate dose scattering...
...shape correction may no longer be valid
Dose: Needed to Correct for Resist Effects

Linearity: scattering kernels larger than width of the features

In the standard 3G model, these effects are degenerate with the variable etch bias
Also Needed for Complex Dose Manipulation

Linearity effect = scattering kernel larger than feature size

Complex dose profiles = many small features
Precise details of the dose model matters more
Printed Mask Data Contains Both Shape and Dose Effects

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

Test structures needed to separate dose from shape effects!
Today’s Simple Models are not Sufficient

Non-zero y-axis values mean: mask print errors from model

Best fit “3G + constant threshold” model: Still 14nm of error!
- Fit overcompensates for the dose profile effects (3x dose)
- Fails to fully compensate for the small CD effect
- Demonstrates broken shape and dose degeneracies in the multi-beam era
Standard 3G Models Do Not Predict Resist Data

Non-zero y-axis values mean: mask print errors from model

Best fit “3G + constant threshold” model
• Better, but still does not meet requirements
• Overall dose trends better
• Remember: there is more physics than simple scattering terms…
Dose-Specific Physics are Required

Non-zero y-axis values mean: mask print errors from model

It is possible to make more physical models that meet desired tolerances
Just need to add the correct physics.
Multi-beam Era is More Complicated

<table>
<thead>
<tr>
<th>VSB</th>
<th>Multi-beam</th>
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</thead>
<tbody>
<tr>
<td>Dose profiles are “simple”</td>
<td>Dose profiles will be complex</td>
</tr>
<tr>
<td>Typically only “1” or “2” doses to worry about</td>
<td>Many dose values to predict</td>
</tr>
<tr>
<td>Can use dose terms &lt;n&gt;G to assist bias terms.</td>
<td>Dose terms no longer degenerate to Etch terms; more complex dose models are needed</td>
</tr>
<tr>
<td>Etch done on rectilinear shapes</td>
<td>Etch needs to be done on curvilinear shapes</td>
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</tbody>
</table>

Bias models based on 1D data are under-constrained
Shape effects depend on:
• Open area “shadowing”
• Local pattern density “loading”
• Local radius of curvature
A good etch model needs to encompass a wide variety of 2D features
TrueModel® Mask Modeling for the Multi-beam Era
Multi-beam Era Requires Dose + Shape Models

• The underlying physics is the same for VSB and multi-beam systems
  – We *do* need to start paying attention to the dose profiles
  – We *do* need to augment the simple shape effect model.
  – Challenge: isolate and model both dose and shape effects

• We do need to ensure a dose-aware model
• We will need to model this on curvilinear systems
• TrueModel has a test chip ideally suited for the new regime
TrueModel Understands Dose/Shape Separation

TrueModel has experience with this for predicting overlapping shots in TrueMask® MDP
Printed Mask Data Contains Both Shape and Dose Effects

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

Shape (etch) bias
AND
Dose linearity

Only dose effects

Test structures needed to separate dose from shape effects!
TrueModel Predicts Shape Effects and Dose Effects Simultaneously

TrueModel results based on dose profile to resist data. 90nm of MTT can be brought to +/-2nm.

Dose linearity well predicted to 60nm

Simulation covers up to 3x dose
TrueModel Predicts Both Shape and Dose Effects

TrueModel results based on dose profile to resist data. 90nm of MTT can be brought to +/-2nm

Model fit summary, including calibration data (circles) and prediction data (squares)
TrueModel is Ready for the Multi-beam Era

Modeling results correctly separate shape effects from dose effects...independent of tool