Reconciling Resist Resolution Metrics

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Outline

• RLS Tradeoff

• Deprotection distributions in 1D, 2D, and 3D
  • Two parameters

• Resist Resolution Metrics
  • LER based: “Blur” fit to PSD
  • CD based: MTF, Corner Rounding, Contact Hole, …

• Data Comparison of PSD “Blur” and Contact Hole Metric

• Model Comparison of PSD and Contact Hole Metric

• Conclusion
“RLS” Tradeoff

Chemically amplified resists “live” on this surface

Resist Blur

Resist Resolution

Line Edge Roughness ➔ LER

Dose ➔ Sensitivity

Standard chemically amplified resists ➔ Very difficult to get Resist Blur, LER and Dose all arbitrarily small at the same time.

Also called other things….

“Lithographic Uncertainty Principle”
“Triangle of Death”

**PEB Reaction-Diffusion Equations**

\[ \rho_D(\vec{x}, t) = 1 - \exp \left[ -k \int_0^t dt \, e^{D t \nabla^2} \delta(\vec{x}) \right] \]

- **Deprotection Density**
- **Deprotection Rate Units**: \( nm^d/sec \)
- **Diffusion Range = Resist “Blur”**
  \[ R = \sqrt{D t} \]

\( d = \#\) Dimensions

**Acid Diffusion**

**3D**:
\[ \rho_D(\vec{r}, t) = 1 - \exp \left[ -\frac{kt}{4\pi R^2} \left( 1 - \text{erf} \left( \frac{r}{2R} \right) \right) \right] \]

**2D**:
\[ \rho_D(\vec{r}, t) = 1 - \exp \left[ -\frac{kt}{4\pi R^2} \Gamma \left( 0, \frac{r}{2R} \right) \right] \quad \Gamma(a, b) = \text{Incomplete Gamma Function} \]

**1D**:
\[ \rho_D(\vec{r}, t) = 1 - \exp \left[ -kt \left( \frac{1}{\sqrt{\pi R}} e^{-r^2/2R^2} - \frac{r}{2R^2} \left( 1 - \text{erf} \left( \frac{r}{2R} \right) \right) \right) \right] \]
Analytic form of the deprotection “blur”

- Matches full numerical simulation Hinsberg, et. al, SPIE 03
- And experimental shape Hoffnagle, Opt. Letts. 02

Numerical Chemical Kinetics Result

Analytic Form
Graphs of Deprotection Density

For all 3 Graphs $R = 15\, nm$

$k = \{0.1, 0.316, 1, 10, 31.6, 100\}$

Increasing $k$

3D $\rho_D$

2D $\rho_D$

1D $\rho_D$

Kang, et. al., SPIE 6519 (2007)
**Graphs of Deprotection Density**

For all 3 Graphs

\[ R = 15 \text{nm} \]

\[ k = \{0.1, 0.316, 1, 10, 31.6, 100\} \]

Increasing \( k \)

Kang, et. al., SPIE 6519 (2007)
**Graphs of Deprotection Density**

For all 3 Graphs

\[
R = 15\text{nm}
\]

The value of \(k\) and the space dimensionality both have a very strong effect on the effective resist blur.

\[
k = \{0.1, 0.316, 1, 10, 31.6, 100\}
\]

Kang, et. al., SPIE 6519 (2007)
LER Metrology

1. Apply edge finding algorithm and determine best fit straight line for each edge

2. Subtract straight line fit to obtain roughness residual

3. Compute things... such as $3\sigma$ per edge

...FFT and square to obtain frequency content = “PSD”

Average $3\sigma = 6.83$ nm
Analytic PSD

\[
PSD(\beta) = N \times \frac{1}{(R\beta)^3} \left[ 2(R\beta)e^{-2(R\beta)^2} \left( \sqrt{2\pi} - 2\sqrt{\pi}e^{(R\beta)^2} \right) + 2\pi \left( 1 - 2(R\beta)^2 \right) \text{erf}(R\beta) + \pi \left( 4(R\beta)^2 - 1 \right) \text{erf}\left( \sqrt{2}R\beta \right) \right]
\]

Normalization factor \( \sim \sigma_{LER}^2 \)

Valid for small \( k \)

PSD “shape”: Depends only on \( R\beta = R2\pi \nu \)

Can determine resist parameters from roughness data

- rms roughness \( \rightarrow \sigma_{LER} \rightarrow N \)
- Intrinsic resist “blur” \( R \) is determined by fitting the analytic PSD “shape” to \(|\text{FFT(data)}|^2 / N\)

\( \nu = \text{Spatial Frequency (cycles/micron)} \)
Effect of the $k$ parameter on the PSD

Very little difference in PSD shape for $k \leq 30$

- Analytic PSD is a good approximation in this range
- Difficult to use it to determine $k$
**Contact Resolution Metric**: CD vs. Dose → Resist “Blur” = Resist Resolution

**Through-Dose Contact Printing as Resolution Metric**

- 50-nm contacts with different levels of resist blur

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Results from the Sematech Sponsored RLS Project

- Red dots = “5435” (EUV2D)
- Green dots = “5271” (MET2D)
- Blue dots = “5496”
- Black dots = “EH27”
- Red Circle = MET1K (old data)
- Green Circle = EUV2D (old data)
- Blue Circle = “A”
- Black Circle = “B”
- Red Squares = “C” (PEB temps)
- Green Square = “D”

$R$ (nm)
Determined by fitting analytical PSD to data PSD
**Modeling the Contact Resolution Metric**

1. Compute the Net Deprotection Distribution for particular $R$ and $k$
2. Pick a different $k$ and do a least squares fit to find the $R$ which produces the best match of the new Net Deprotection Distribution to the one computed in Step 1.
How does Least Squares Fit $R$ value depend on $k$?

Least Squares Fit $R$ Value (nm)

- $k = 5$ curve
- $k = 10$ curve
- $k = 15$ curve

Fitted $R$ value
- $>$ Real value
- $<$ Real value

Actual $R$ value set to 15nm
How does Least Squares Fit $R$ value depend on $k$?

Least Squares Fit $R$ Value (nm)

Actual $R$ value set to 15nm

If you fit the data using a $k$ value much smaller than the real value then the computed “Blur” is larger than the PSD determined $R$ value.
Results from the Sematech Sponsored RLS Project

Red dots = “5435” (EUV2D)  Green Circle = EUV2D (old data)
Green dots = “5271” (MET2D)  Blue Circle = “A”
Blue dots = “5496”  Black Circle = “B”
Black dots = “EH27”  Red Squares = “C” (PEB temps)
Red Circle = MET1K (old data)  Green Square = “D”

Cluster of generically larger “blur” values can be accounted for by the effect of $k$ on the fitted “blur” value.

$R$ (nm)
Determined by fitting analytical PSD to data PSD

Contact hole resolution measurement (nm)
Conclusions

• “Size/Shape” of the deprotection distribution depends strongly on the deprotection rate constant $k$.
  
  • Small $k$ and Large $R$ ~ Small $R$ and Large $k$

• This dependence can account for at least part of the disconnect between the PSD determined resist blur and contact hole method.

• Difficult to “see” the effect of $k$ when looking at just the PSD

• Refit contact hole data allowing for the value of $k$

• Getting the correct deprotection shape is very important for getting the CD’s correct when modeling EUV printing capabilities.

• Thank you for your attention!