Optics, mask, and resist implications on contact CDU

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Outline

Condenser flare
Mask CDU
Mask roughness
Shot noise
Resist blur
Summary
Source collector roughness

Source

Collector with flare

Mask plane

Flare (%)

Illum. speckle contrast (%)

Mask plane speckle contrast

Coherence elements

800
1600
3200
6400
12800
25600
51200
**Source collector roughness**

![Diagram showing the relationship between coherence area at the condenser pupil (sigma) and speckle correlation length (\(\lambda/NA\)).](image)

Source collector roughness involves the study of how the roughness of surfaces affects the coherence of light and the formation of speckles. The diagram illustrates the correlation between the coherence area at the condenser pupil (sigma) and the speckle correlation length (\(\lambda/NA\)).

**Source**

**Collector with flare**

**Mask plane**

**Graph:**

- **Y-axis:** Speckle correlation length (\(\lambda/NA\))
- **X-axis:** Coherence area at condenser pupil (sigma)

The graph shows a decreasing trend as the coherence area increases, indicating a decrease in speckle correlation length.
Source collector roughness coupling to contact CDU

NA = 0.32, quadrupole illumination, 28-nm dense contacts
Mask CDU

NA = 0.32, disk 0.7, 28-nm dense contacts
MEEF = 1.5
Results independent of aberrations up to 1 nm
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Mask roughness
Mask roughness induced speckle also impacts printed contact size variation
Randomly phased points in the diffraction-limited contact create overlapping PSFs in image plane

\[ a \exp(j \theta) = \frac{1}{\sqrt{N}} \sum_{k=1}^{N} \alpha_k \exp(j \phi_k) \]
Randomly phased points in the diffraction-limited contact create overlapping PSFs in image plane

- Assume phase on mask is zero mean Gaussian random variable with variance $\sigma^2$
- Assume constant amplitude on mask
- Assume small phase errors on mask

\[
\sigma_i^* = \frac{2 \sqrt{\frac{1}{2} \left[ 1 + \exp(-2\sigma^2) \right]} - \exp(-\sigma^2)}{\sqrt{\frac{A_c}{A_r}}} \exp\left(-\frac{\sigma^2}{2}\right)
\]

- $A_c = \text{Area of contact}$
- $A_r = \text{intra-contact mask roughness correlation area}$
Analytic approximation holds up well even at small $A_c/A_r$
Contact width ($W$) variation linked to intensity variation through image slope

$$\sigma_W = \sigma_i \frac{dW}{d\hat{I}}$$

Normalized aerial image slope

Numeric example

- 0.25 NA
- $d\hat{I}/dW = 0.019 \text{ nm}^{-1}$ (based on Prolith modeling)
- 4x mask, 120-nm square contacts on mask (30-nm at wafer)
- 80-nm mask roughness coherence diameter
- Allow only 5% reduction in process window due to mask roughness
  - Full 10% process window tolerance = 3-nm $3\sigma$
  - Allowable mask roughness contribution = 0.15-nm $3\sigma$
  - Allowable $\sigma_W = 0.05 \text{ nm}$

Allowable intra-contact mask roughness = 45 pm rms

~2x smaller than current capabilities
Outline

- Condenser flare
- Mask CDU
- Mask roughness
- Shot noise
- Resist blur
- Summary
Shot noise: higher blur implies higher dose requirements

Model includes photon stochastics only (Gallatin model)
Shot noise: higher blur implies higher dose requirements

Prolith stochastic model
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Resist blur dominant factor in total effective MEEF
Correlation measurement used to determine mask contributors to LER

LER = 4.3 nm, Average correlation = 35%, Correlated LER = 2.5 nm

Annular, 100-nm defocus
Correlation methodology also applies to mask sources of contact hole CD variation.

Average correlation = 0.29 +/- 0.05
Average 3σ CD variation = 4.9 nm
Correlated 3σ CD variation = 2.6 nm

Annular, 100-nm defocus
Correlation methodology also applies to mask sources of contact hole CD variation

Correlation = 0.29 +/- 0.05
CD variation (3σ) = 8.2 nm
Correlated CD variation = 4.4 nm

Correlation = 0.16 +/- 0.05
CD variation (3σ) = 8.1 nm
Correlated CD variation = 3.2 nm
Summary

• Mask and condenser roughness plays important in contact CDU
• Resist blur drives both dose requirements and mask specs
• Correlation methods can be used to measure mask contributions to CDU

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22-nm contacts in Inpria resist

3σ CDU = 3.6 nm