Kernel methods in computational lithography

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- **2** Kernel methods
- **3** Optimization
- 4 EUV lithography

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Optimization

EUV lithography

Lithography

• Pattern transfer



Figure 1: Litho stone

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Mask, Exposure systems(Lens), Materials, …



Figure 2: Photo-lithography

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Background	
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Patterning process



Figure 3: Working flow

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Manufacturing



Figure 4: Chips

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Background	
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Optical proximity effects



Figure 5: Optical proximity effects (B) (E) (E) (E) (C)

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Optical proximity correction

Problem

Processed mask pattern $\mathcal{I}(m(x, y)) \neq m(x, y)$.

- OPC is required for the technology node $\leqslant 22$ nm.
- The simulation of process transformation *I*_{T,p,v,α,β,γ,...}().
- Working on $|\mathcal{I}(m(x,y)) m(x,y)|$?



Figure 6: Without correction

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Optical proximity correction

Problem

Construct Δm such that $\mathcal{I}(m(x, y) + \Delta m) = m(x, y)$.

- $\#[m(x,y) + \Delta m] \sim 10^8$.
- Inverse lithography technology(ILT) \mathcal{I}^{-1} .



Figure 7: With correction

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Optical intensity

$$\mathcal{I}(x,y) = \iiint \mathsf{TCC}(f',g';f'',g'')M(f',g')M^*(f'',g'')$$
$$e^{-2\pi i [(f'-f'')x+(g'-g'')y]} df' dg' df'' dg''.$$

- Transmission cross coefficient TCC(f', g'; f'', g'') = $\int \int S(f, g)P(f' + f, g' + g)P^*(f'' + f, g'' + g)dfdg.$
- M(f', g'): the Fourier transformation of m(x, y).
- *M**(*f*", *g*"): conjunction.

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$$\mathcal{I}(x,y) = \iiint \mathsf{TCC}(f',g';f'',g'')M(f',g')M^*(f'',g'')$$
$$e^{-2\pi i[(f'-f'')x+(g'-g'')y]} df' dg' df'' dg''.$$
$$\mathsf{TCC}(f',g';f'',g'') = \iint S(f,g)P(f'+f,g'+g)P^*(f''+f,g''+g)df dg.$$



Figure 9: Optical system

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Background	Kernel methods	Optimization	EUV lithography
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Kernel decom	nosition		

• Suppose
$$\operatorname{TCC}(f', g'; f'', g'') = \sum_{k=1}^{N} \lambda_k \Phi_k(f', g') \Phi_k^*(f'', g'')$$

 $\mathcal{I}(x, y) = \iiint \operatorname{TCC}(f', g'; f'', g'') M(f', g') M^*(f'', g'')$
 $e^{-2\pi i [(f'-f'')x+(g'-g'')y]} df' dg' df'' dg''.$
 $= \sum_{k=1}^{N} \lambda_k |\phi_k(x, y) * m(x, y)|^2$

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Background

Kernel methods

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Kernel decomposition





Figure 10: Optical kernels

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Contour simulation





Figure 11: Wafer contour

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Optimization

EUV lithography

Look-up table



Background	Kernel methods	Optimization	EUV lithography
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Other effects			

$$\mathcal{I}(x,y) = \sum_{k=1}^{N} \lambda_k |\phi_k(x,y) * m(x,y)|^2 + \xi(x,y) * m(x,y)$$
$$+ \eta(x,y) * m(x,y)$$



Figure 13: Negative tone develop

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Optimization •000

EUV lithography

Process window



Figure 14: Process window

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Sub-resolution assist feature



Figure 15: Assist feature

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Source mask co-optimization



Figure 16: Source mask co-optimization

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Figure 17: Source mask co-optimization

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Optimization

EUV lithography ●○

Extreme-ultraviolet (EUV) lithography

Projection optics



20,000 parts Weight: 2 tons



Illumination system



15,000 parts Weight: 1.5 tons

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Figure 18: Source mask co-optimization

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Thanks

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