Kernel methods in computational lithography

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Lithography

- Pattern transfer

Figure 1: Litho stone

Photo-lithography

- Mask, Exposure systems(Lens), Materials, ···

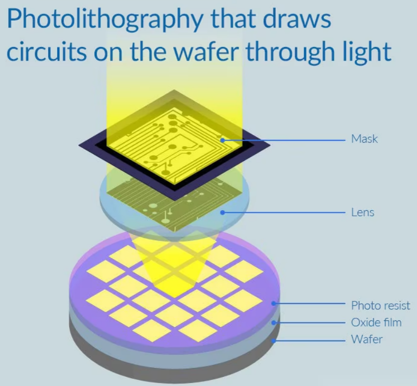


Figure 2: Photo-lithography

Patterning process

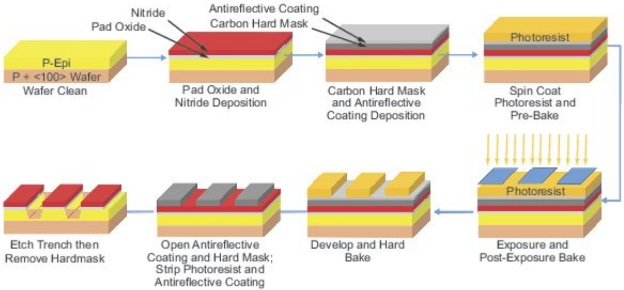


Figure 3: Working flow

Manufacturing

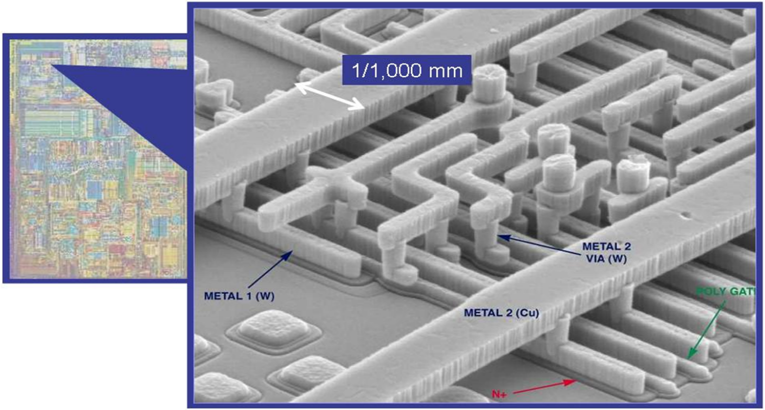


Figure 4: Chips

Optical proximity effects

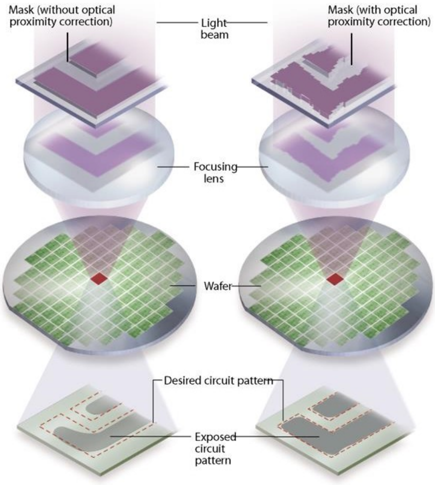


Figure 5: Optical proximity effects

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 $\mathcal{I}_{T,p,v,\alpha,\beta,\gamma,\cdots}(\quad)$.
- Working on $|\mathcal{I}(m(x,y)) - m(x,y)|$?

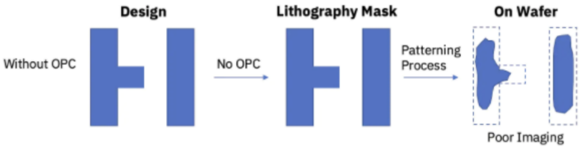


Figure 6: Without correction

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

Optical intensity

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

- Transmission cross coefficient $\mathrm{TCC}(f',g';f'',g'') = \iint S(f,g)P(f'+f,g'+g)P^*(f''+f,g''+g)\mathrm{d}f\mathrm{d}g$.
- $M(f',g')$: the Fourier transformation of $m(x,y)$.
- $M^*(f'',g'')$: conjunction.

Scanner

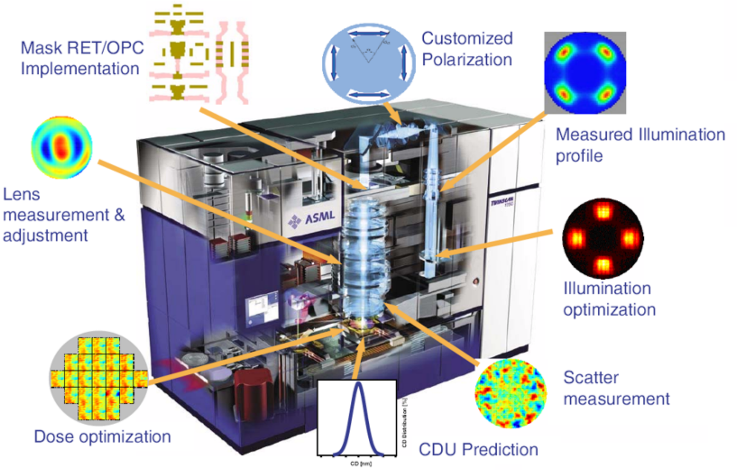


Figure 8: Scanner

Optical model

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

$$\mathrm{TCC}(f',g';f'',g'') = \iint S(f,g)P(f'+f,g'+g)P^*(f''+f,g''+g)\mathrm{d}f\mathrm{d}g.$$

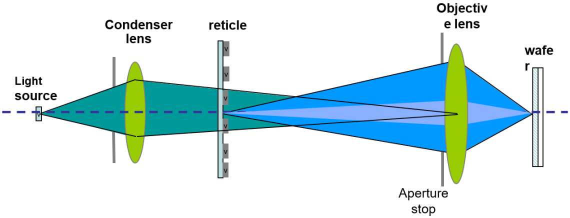


Figure 9: Optical system

Kernel decomposition

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

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

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

Kernel decomposition

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

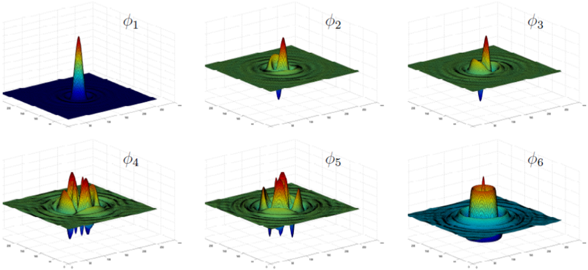


Figure 10: Optical kernels

Contour simulation

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

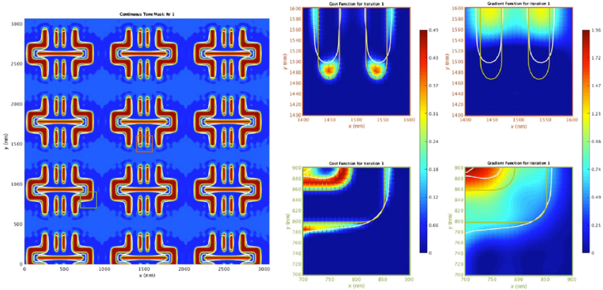
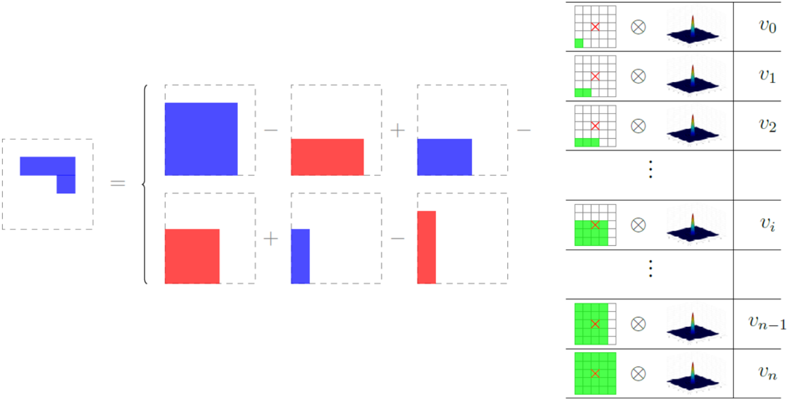


Figure 11: Wafer contour

Look-up table



(a) (b)

Other effects

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

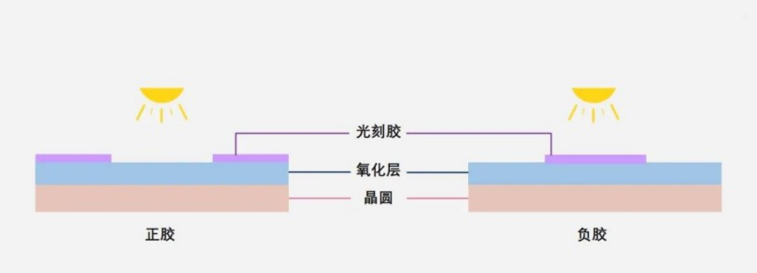


Figure 13: Negative tone develop

Process window

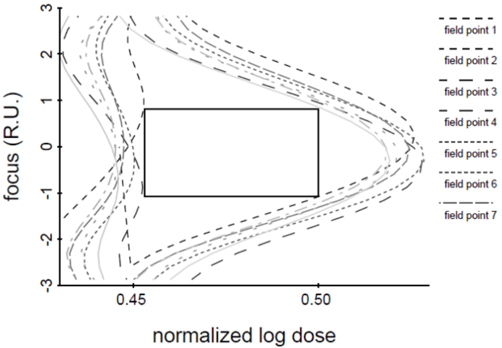


Figure 14: Process window

Sub-resolution assist feature

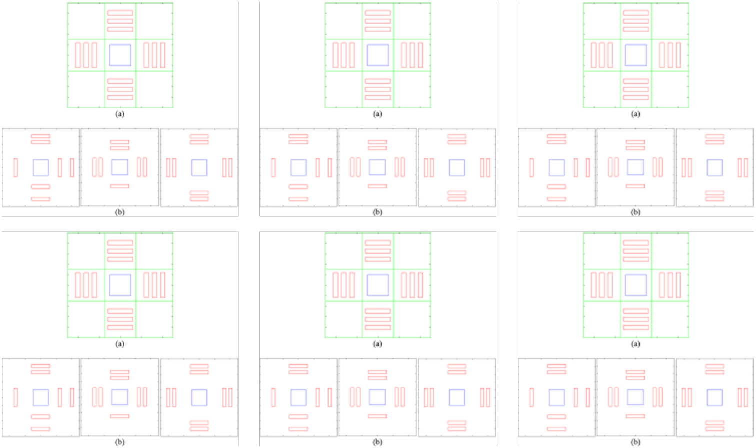


Figure 15: Assist feature

Source mask co-optimization

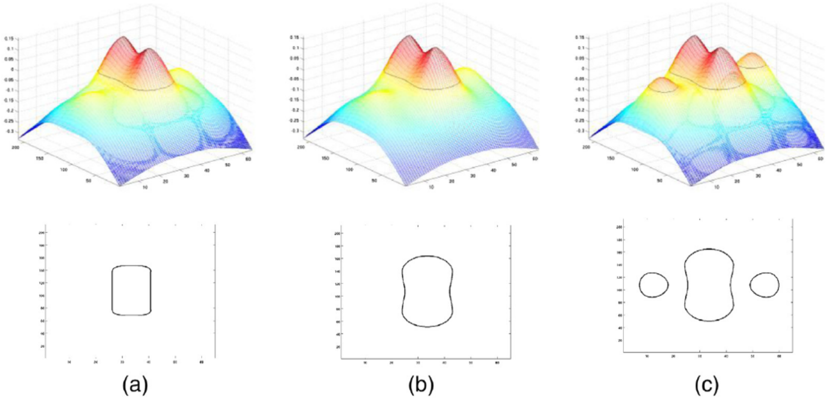


Figure 16: Source mask co-optimization

Source mask co-optimization

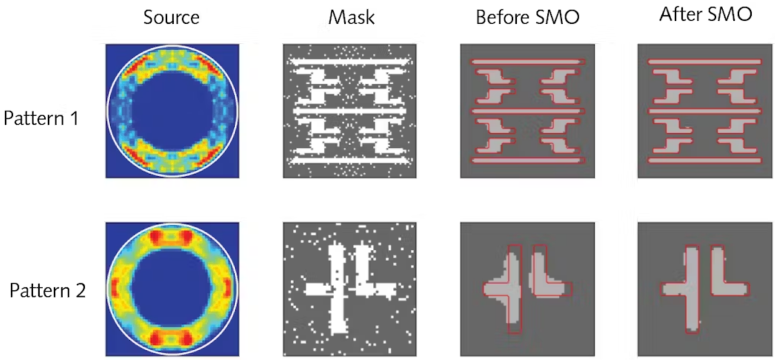


Figure 17: Source mask co-optimization

Extreme-ultraviolet (EUV) lithography

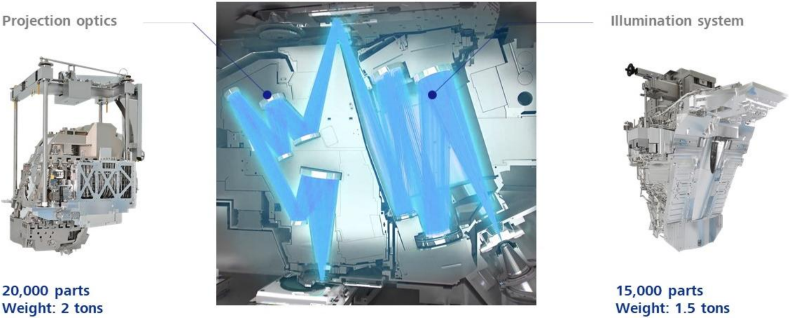


Figure 18: Source mask co-optimization

Thanks