Institut für Mikroelektronik Stuttgart

Resolution Optimization for i-Line Litho

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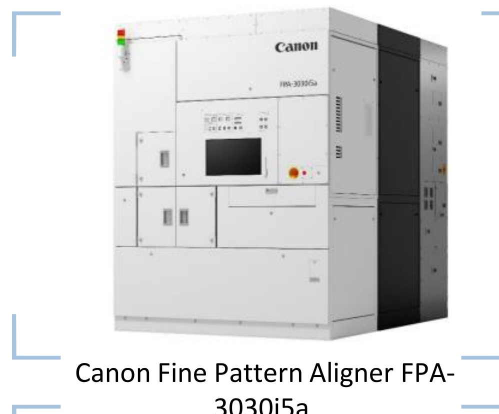
Outline

- Motivation
- Basics
- Optimization of Resist thickness
- Resolution Enhancement by double patterning
  - Stepper: Litho-Etch-Litho-Etch
  - Laser: Litho-Litho-Develop
- Conclusion

Motivation



Canon Fine Pattern Aligner FPA-3030i5a

Laser-Maskenschreiber ULTRA der Firma Heidelberg Instruments

- <u>Optical Litho Tools @ IMS</u>
  - **Wafer-Stepper** Canon FPA 3030i5a
    - Hg lamp i-line $\boldsymbol{\lambda = 365\,\mathrm{nm}}$
  - **Laser Writer HIMT ULTRA**
    - DPSS Laser $\boldsymbol{\lambda_{\mathrm{eff}} = 355\,\mathrm{nm}}$
- Resolution limited by optical wavelength for both tools
- <u>Change to shorter wavelength would mean:</u>
  - <u>New tools (€€)</u>
  - <u>New resists, including optimization an integration</u>
  - <u>Less flexibility</u>
- <u>->Make best out of given tool platform</u>

Basic: optical Lithography

Geometric Optic

Fotomaske

Fotolack

Substrat

Entwicklung

Positivlack

Negativlack

Fotomaske Lichtstrahl Lackschicht

Strahlenbündel

b

Lichtstrahl

Intensität I_0

Optische Lithografie and diffraction

Image reduction 5:1

1000 nm | 1000 nm | 1000 nm

b_{Mask} = 1750 nm
b_{Wafer} = 350 nm

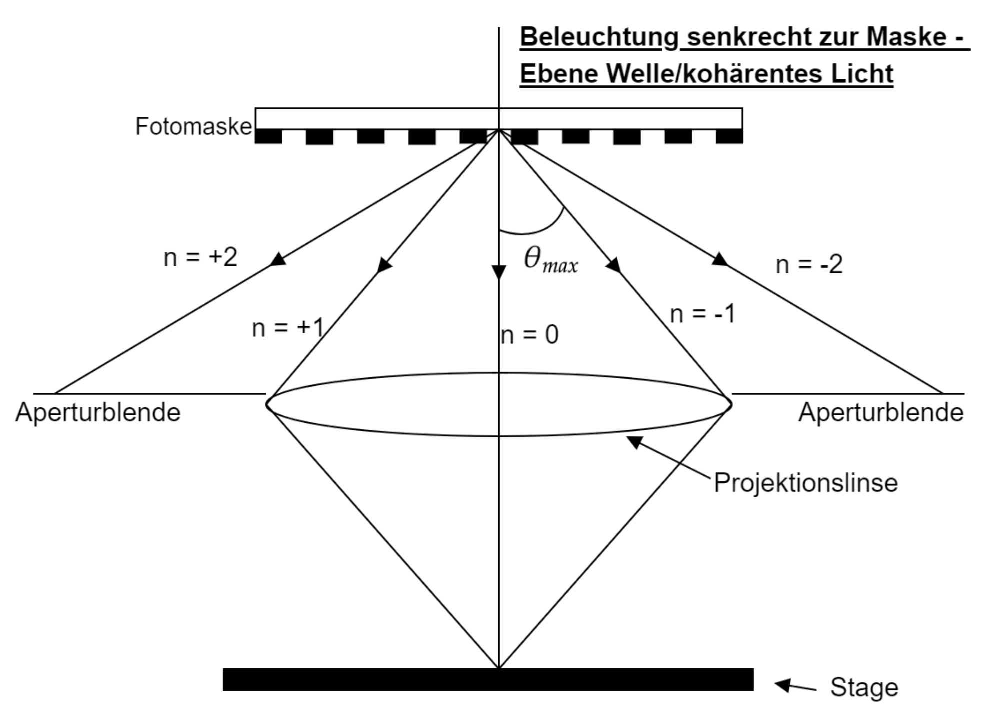
b_{Mask} = 1500 nm
b_{Wafer} = 300 nm

b_{Mask} = 1250 nm
b_{Wafer} = 250 nm

$\lambda = 365$ nm $\quad \frac{b}{\lambda}$ ↓ Diffraction ↑

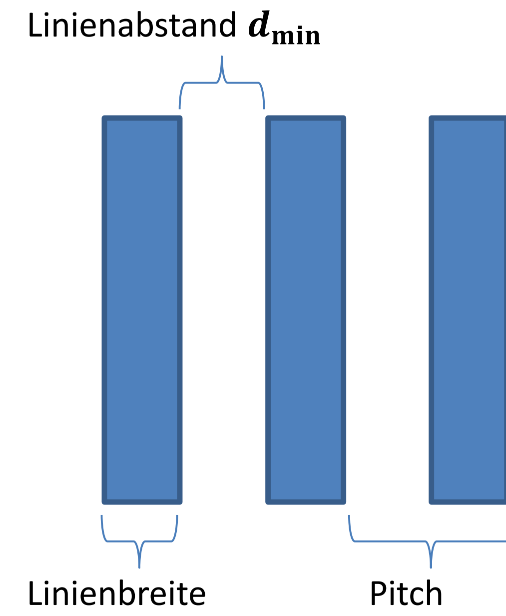
Resolution Limit Lines/Spaces

- More than one diffraction order is necessary to resolve the grating
- **Resolution limit is given by**:
  - $d_{min} = k_1 \cdot \frac{\lambda}{NA}$
- Numeric Aperture (NA)
  - $\mathrm{NA} = \mathrm{n} \cdot \sin\theta_{\mathrm{max}}$



Resolution Lines/Spaces

- The Smallest Pitch is limited by diffraction limit and optics
- The smallest linewidth is also defined by resist chemistry, dose and resist thickness



Resolution Lines/Spaces

Pattern Collapse is triggered by high aspect ratio

1000 nm

1000 nm

1000 nm

Dose

Line width

Relative density

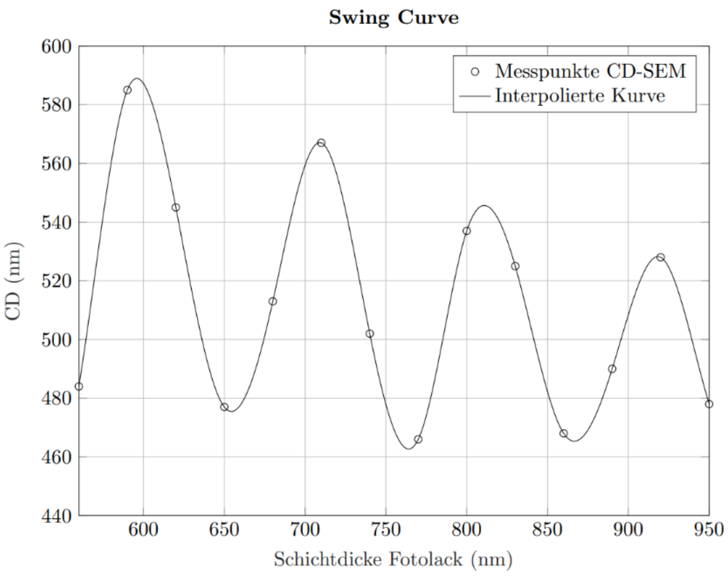
Resolution Lines/Spaces

- Wafer-Stepper:
  - $\lambda = 365\,\mathrm{nm}$
  - $\mathrm{NA} = 0{,}63$
  - $d_{min} = 0{,}5 \cdot \frac{\lambda}{NA} = 290\ nm$

Parameter: $d_{\mathrm{Lack}} = 1067\,\mathrm{nm}$; $H = 1700\,\mathrm{J\,m^{-2}}$; $F = 0\,\mu\mathrm{m}$

Pattern	$CD_{\mathrm{line}}/\mathrm{nm}$		$CD_{\mathrm{space}}/\mathrm{nm}$		$CD_{\mathrm{pitch}}/\mathrm{nm}$	
	target	mean	target	mean	target	mean
70	700	646	700	759	1400	1405
60	600	542	600	664	1200	1206
55	550	494	550	613	1100	1107
50	500	442	500	563	1000	1005
45	450	389	450	516	900	905
40	400	342	400	462	800	804
35	350	302	350	402	700	704
30	300	267	300	336	600	603
25	250	-	250	-	500	-
20	200	-	200	-	400	-
15	150	-	150	-	300	-

Optimization of resist thickness



measured

Swing Curve - Simulation LAB - Stepper

data
fitted curve

CD (nm)

Resist Thickness (nm)

620 600 580 560 540 520 500 480 460 440

600 650 700 750 800 850 900 950

Simulated by LAB

Resolution Enhancement Techniques

Multi Patterning

Reduced Wavelength
(EUV-Lithography 13,5 nm)

$$d_{\min} = k_1 \cdot \frac{\lambda}{NA}$$

Higher NA
(Immersion)

k_1-Faktor
- Off-Axis Illumination
  - Annular, Quadrupole, Dipole
- Optical Proximity Correction
- Phase Shift Masks…

Double Patterning

Single Patterning

Double Patterning

Double Patterning
Layer 1

Double Patterning
Layer

- **Reduction of Pattern Density by separating exposure into two complementary masks:**
  - 1. Mask:
    - Blue Pattern
  - 2. Mask
    - Red Pattern

Wafer-Stepper: Double Patterning

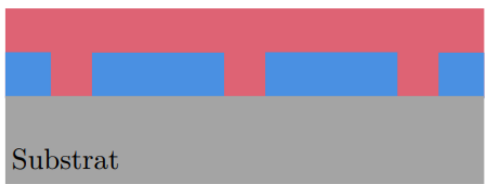
Integration approach: Litho-Etch-Litho-Etch

(a) Fotolack auftragen

(b) Belichten und Entwickeln

(c) Trockenätzen von SiO_2

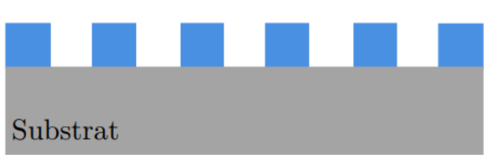
(d) Lack-Strip und Reinigung



(e) Fotolack auftragen

(f) Belichten und Entwickeln

(g) Trockenätzen von SiO_2

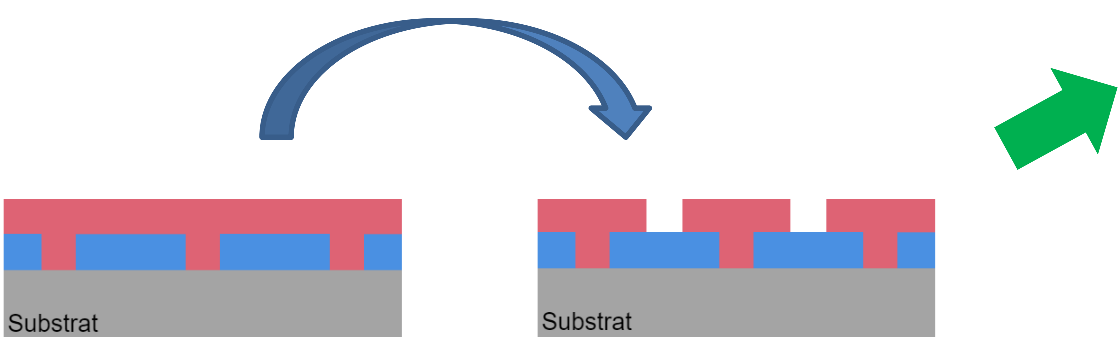


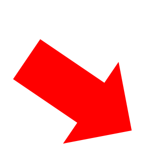
(h) Lack-Strip und Reinigung

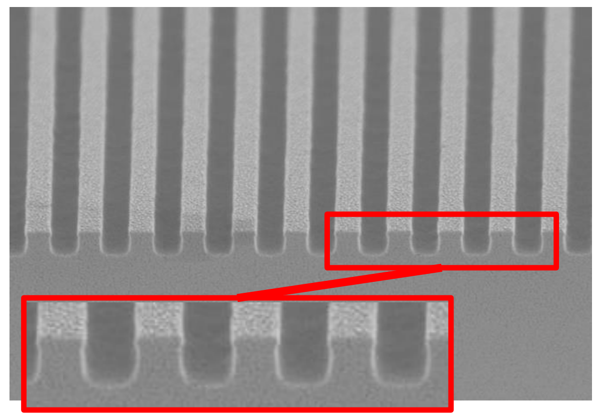
(i) Ätzen von Si

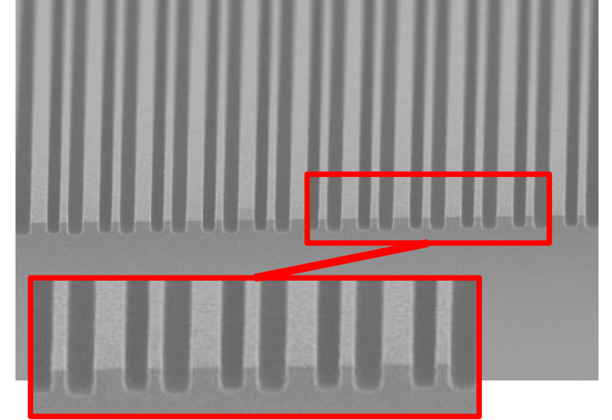
Wafer-Stepper: Double Patterning

Overlay Error leads to CD errors









Overlay-Errorin x
$\approx$ 82 nm

Wafer-Stepper: Double Patterning

60µm PA-Marke

20P-4FA AA-Marke

Ebene 2 → Ebene 1

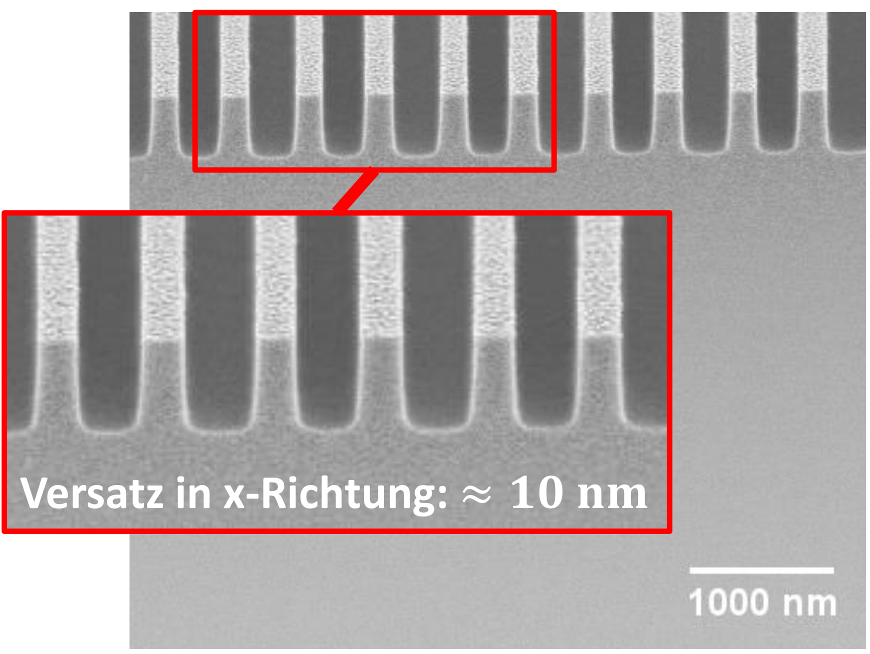
Layer-to-Layer Alignment

Ebene 1, Ebene 2 → Markeneben

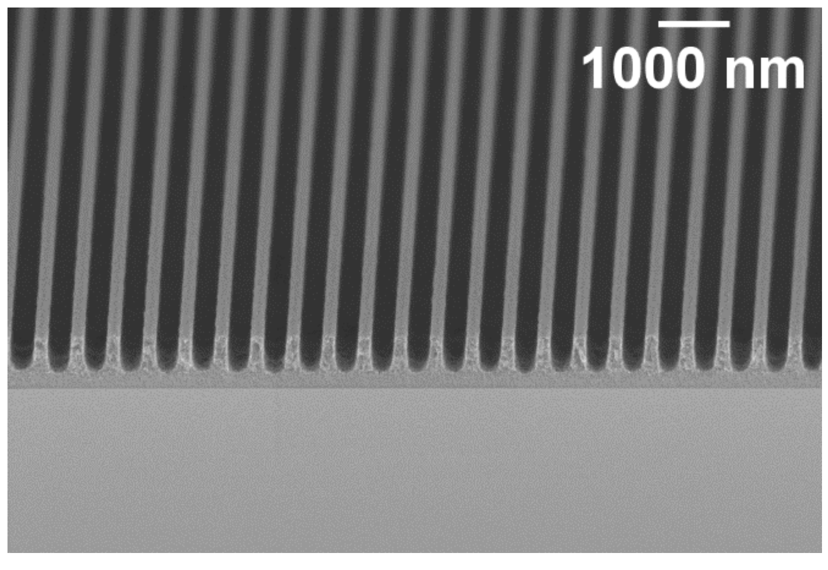
Zero Layer Alignment

- **Introduction of Zero Mask Layer with depper etched alignment marks to increase contrast**

Wafer-Stepper: Double Patterning



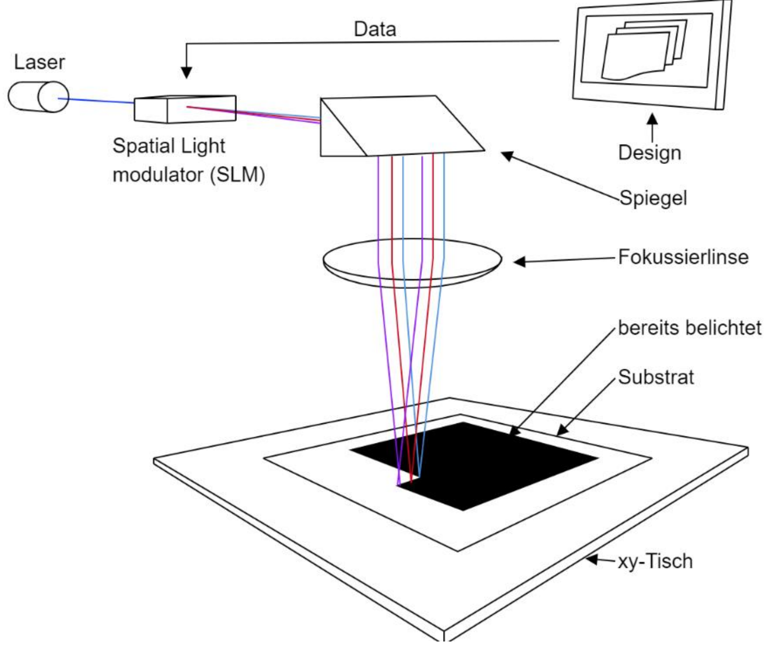
Double Patterning with two masks
half pitch ≈ 250 nm



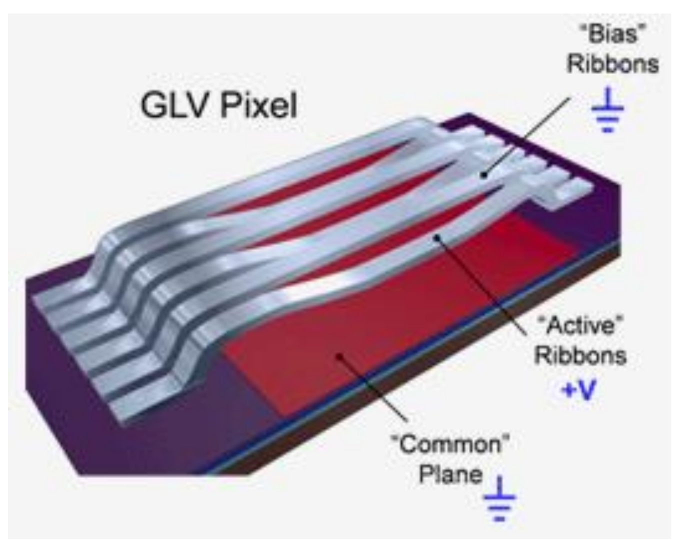
Single Patterning resist exposure
half pitch ≈ 250 nm

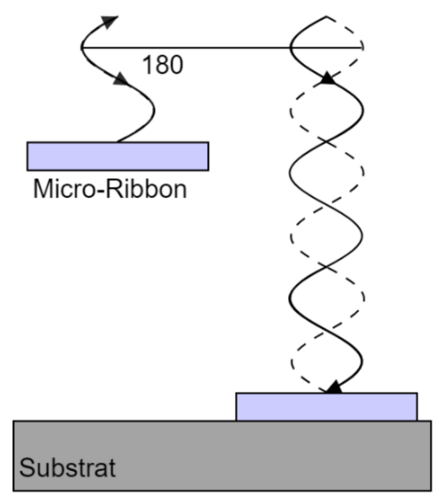
Laser Writer: Write Strategy

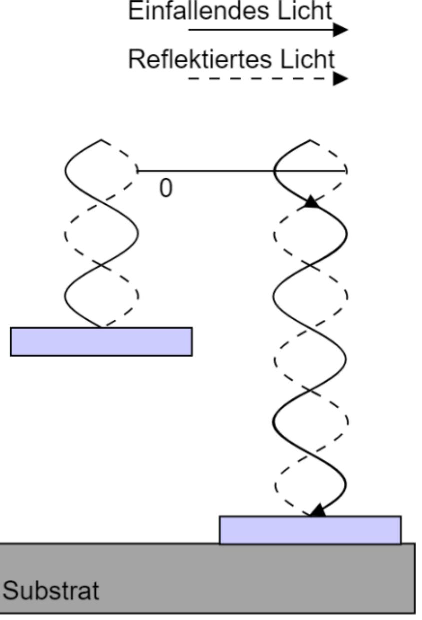
- Instead of Masks: Modulation of Light Intansity within one Write Stripe using Spatial Light Modulators (SLM)
- Use of Grating Light Valves (GLV)
- Instead of Hg Lamp (365nm) use of DPSS Laser (355nm)



GLV Principle



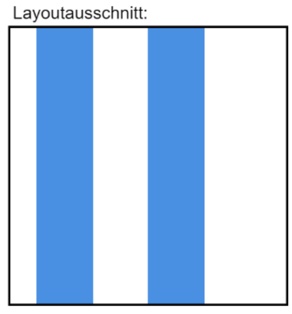


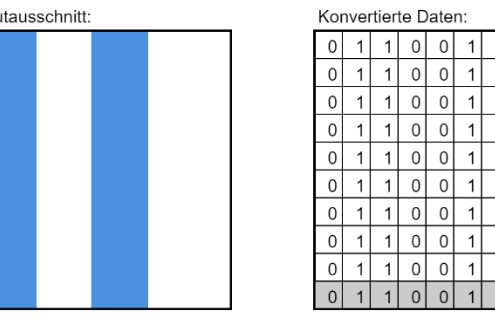


Resolution Limit: Laser writer

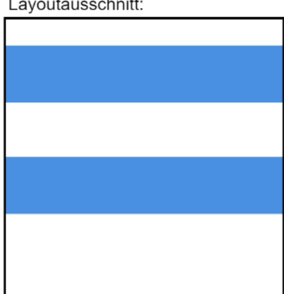
- Write stripe is created by two pixel array writing in parallel
- Size of 1 pixel depending und write lens. In this case 400nm
- Finer adress grid and resolution by interpolation and grayscaling of pixels

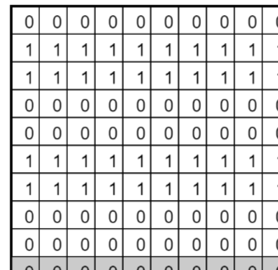
- Resolution Limit is influenced by
  - Diffraction
  - Interaction of neighboring pixels due to coherent light
  - Pixel size





0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0
0	1	1	0	0	1	1	0	0	0

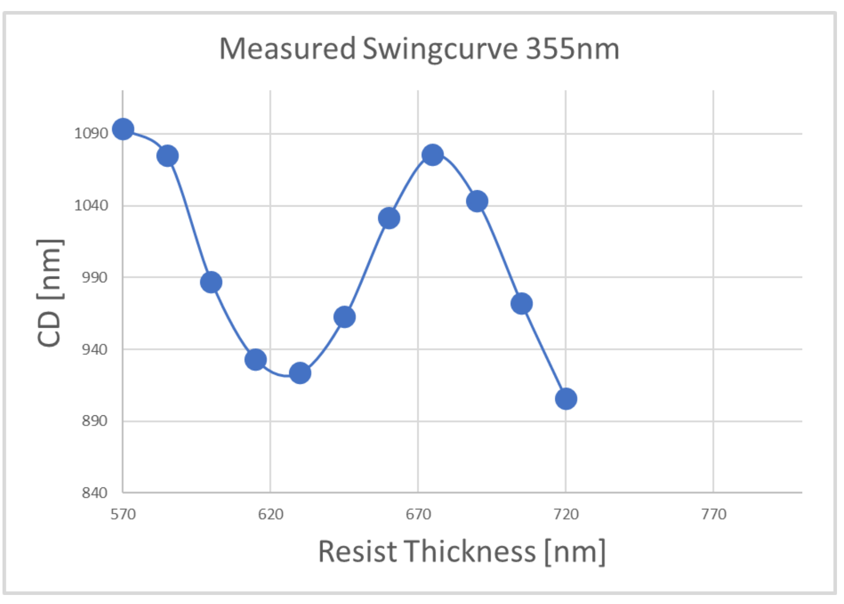




0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

HEIDELBERG INSTRUMENTS

Simulated and measured Swing Curves



Optimization of Resist Thickness

Resist thickness: 640nm

600nm halfpitch

550nm halfpitch

500nm halfpitch

Resist thickness: 1067nm

600nm halfpitch

550nm halfpitch

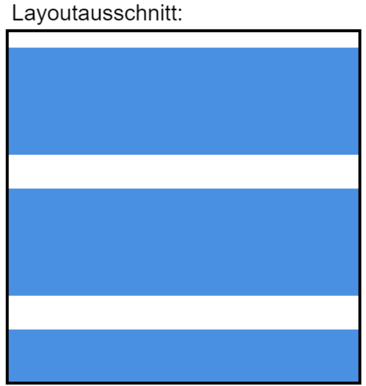
500nm halfpitch

HEIDELBERG INSTRUMENTS

Laser Writer: Double Exposure

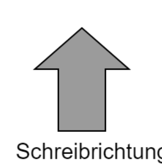
- **For high pattern densities, resolution is limited by pixel size**
- => no areas with 0% intensities

Layoutausschnitt:



Konvertierte Daten:

0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1	1	1	1	1	1	1	1	1	1

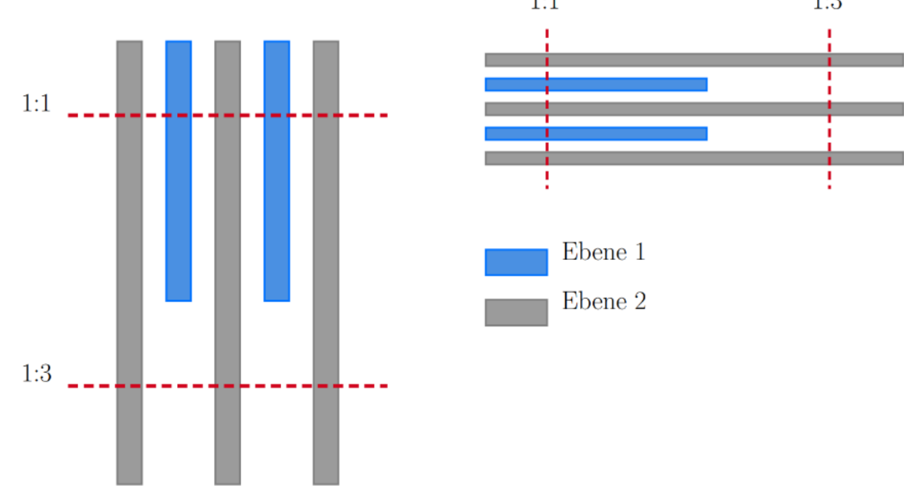


Schreibrichtung

Laser Writer: Double Exposure

- Reducing Pattern density by separatin design into two separate exposures
- No wafer unload between the two exposures, no alignment necessary

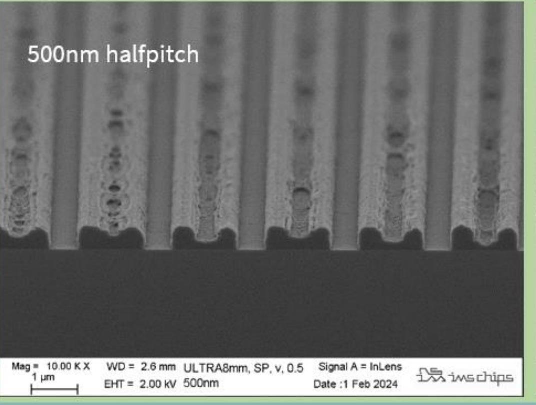
  => Almost no Overlay error, defined by stage repeatebility, <10nm

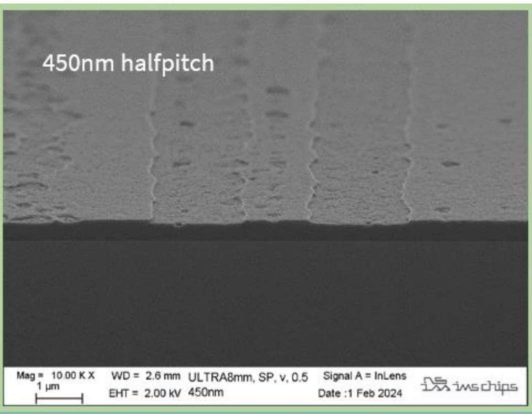


HEIDELBERG INSTRUMENTS

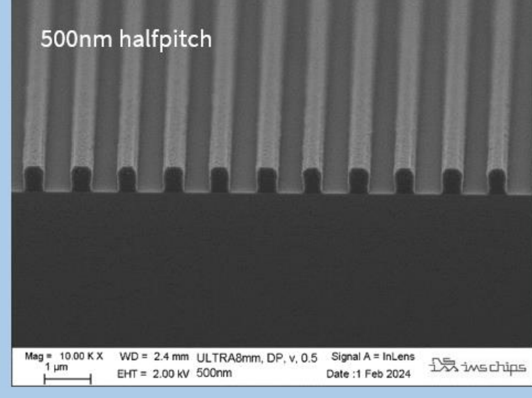
Vertical Structures

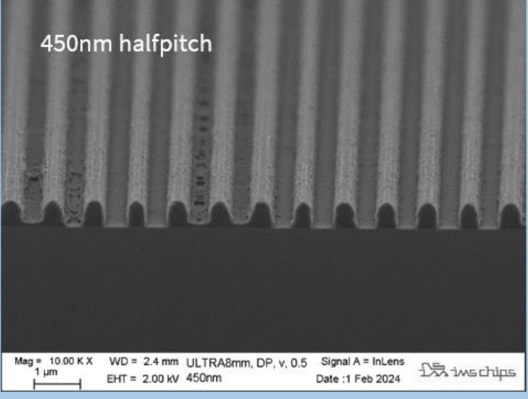
1:1 pattern
(single exposure)





2x 1:3 pattern
(overlay exposure)

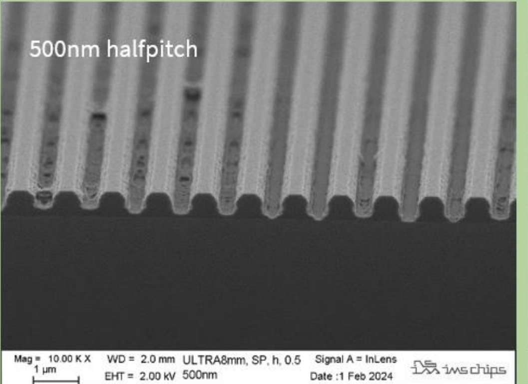


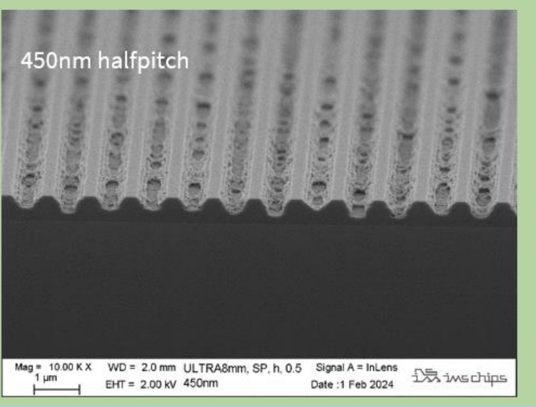


HEIDELBERG INSTRUMENTS

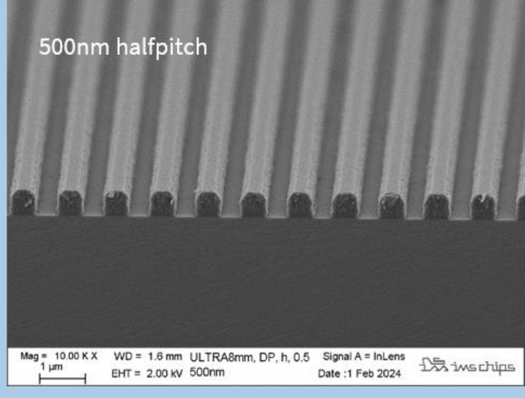
Horizontal structures

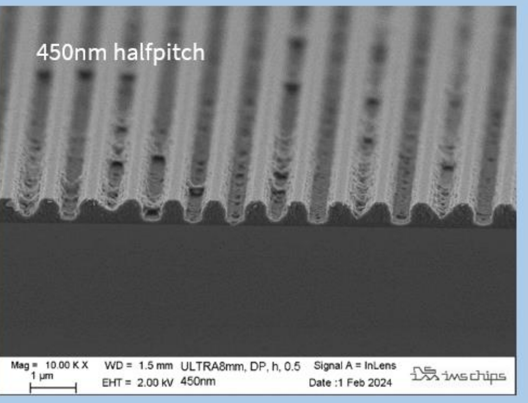
1:1 pattern
(single exposure)





2x 1:3 pattern
(overlay exposure)





Conclusion

- Optimization of optical litho processes for stepper and laser
  - Resist thickness
  - Exposure strategy
- LAB gives accurate results for swing curve and bossung plot simulations
- Litho-Etch-Litho-Etch approach enables patterns smaller than diffraction resolution limit
- Resolution of Laser direct writer can be improved by separation of exposure into two steps: 500nm Lines Spaces 400nm pixel size!