Layout simulation for directed self-assembly with chemo-epitaxy methodology

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Outline

- Motivation for a rigorous simulation engine for DSA chemo-epitaxy patterning processes.
- Contact hole with EUV rectification and DUV pitch multiplication.
- Line Space with EUV rectification and DUV pitch multiplication.
- Design window discussion with simulation results.



Siemens can simulate DSA with grapho-epitaxy technology

DSA technology with grapho-epitaxy needs co-optimization among materials, design and lithography. Not mature enough by the time EUV lithography becomes prevalent.



Ma et al, Challenges and opportunities in applying grapho-epitaxy DSA lithography to metal cut and contact/via applications, SPIE 2014, 9231, 92310T Ma et al, Directed Self Assembly (DSA) compliant flow with immersion lithography – from material to design and patterning, SPIE 2016, 9777 97770N

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Industry has shown that DSA with chemo-epitaxy can improve tight pitch Line-Space and Contact Hole pattern fidelity

Logic:

LER can be improved in EUV rectification P36nm, and maintained after pitch halving to P18nm.



Singh, Continuing Moore's Law with next-gen DSA, SPIE 2023 12497-29

Memory:

9x and 12x multiplication to reach P40 nm and P35 nm contact hole with DUV lithography.

	Lo 40nm	Lo 35nm	
	9 multiplication		
SEM picture as SOC etch	Gaunas, Tokya Electron	Source, Tokyo Elearon	
CD	20.9nm	17.5nm	
LCDU (3o)	1.52nm (7.3%)	1.66nm (9.5%)	
Placement Error (3σ)	2.76nm (13.2%)	2.70nm (15.4%)	

Muramatsu et al, Pattern fidelity improvement of DSA hole patterns, SPIE 2023 12497, 124970J

Available simulation methods:

- Coarse grained molecular dynamic simulation (Cornell, Soft Matter 2018)
- Coarse grained Monte Carlo simulation (U of Chicago, Macromolecular 2008)



Calibre rDSA, SEMSuite and OPCVerify for Simulation and SEM image analysis

Calibre[®] rDSA module provides a functionality to run rigorous full physics simulations of the DSA process. Monte Carlo simulations of a coarse grain model can describe effects of patterned substrates and complex geometries with relatively modest computational

effort.



Bead-Spring representation of a block-copolymer chain

Detcheverry et al, Monte Carlo Simulations of a Coarse Grain model for Block Copolymers and Nanocomposites, **Macromolecules** 2008, 41, 4989



Calibre[®] SEMSuite[™] was utilized to extract contours from each individual SEM images. Calibre[®] OPCVerify[™] was used to analyze the statistics of the extracted contours and simulated contours for LER, LCDU, and PPE.







EUV rectification for Contact Hole patterns P34 c2c 1x

Imec mild etch flow rectification





SEM image is taken after PMMA removal, and before pattern transfer.

$\begin{array}{l} \text{CD} = 13.7 \text{ nm} \\ \text{LCDU} = 2.0 \text{ nm} (3\sigma) \\ \text{PPE} = 2.3 \text{ nm} \end{array}$

Blue: guiding pattern Yellow: DSA pattern



All track flow



CD = 13.4 nm LCDU = 2.5 nm (3σ) PPE = 2.06 nm





SEM image is taken after PMMA removal, and before pattern transfer.





CD=66 nm

Muramatsu et al, Hexagonal arrays of contact holes with chemo-epitaxial DSA, SPIE 12054, 1205402 (2022)

Blue: guiding pattern Yellow: DSA pattern

SEM image is taken after PMMA removal,

and before pattern transfer.

CD = 19.4 nm $LCDU = 3.3 \text{ nm} (3\sigma)$ PPE: 2.76 nm







Simulation of Contact Hole with hexagonal vs orthogonal arrangement



	HEX	orthogonal
CD (nm)	18.05	18.36
Circularity	0.995	0.956
LCDU (3o nm)	0.68	4.76
PPE (nm)	0.62	2.3

With the same composition and same Pitch (34 nm) and L0, orthogonal arrangement shows much worse contact hole formation in terms circularity, LCDU and PPE.

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Circularity =

 4π x Area Perimeter²



EUV rectification for Line Space patterns





SEM image is taken after PMMA removal, and before pattern transfer.

L/S Experiment: • CD = 16.6 nm

• LER= 2.43 nm (3σ)

CAR_mild etch flow P28nm





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DUV 3x pitch multiplication for Line Space patterns – SMART flow

SMART flow: L/S equivalent of M-flow Pitch 84nm on ArFi process, ideal guiding pattern CD for line/space is 42/42nm.

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1.5x L0
Image: Non-training training traini

SEM image is taken after PMMA removal, and before pattern transfer.





DUV 3x pitch multiplication for Line Space patterns – LiNe flow





Simulation shows DSA patterns are stable with varying guiding pattern CD

SMART flow: P84 $3x \rightarrow$ P28nm

Guiding Pattern CD (nm)	42	43	44
DSA CD	13.94	13.92	13.95
DSA LCDU (3σ)	1.23	0.88	0.86
DSA LER (3σ)	1.06	0.59	1.00



Guiding Pattern CD (nm)	16	18	20
DSA CD	15.01	14.95	14.99
DSA LCDU (3σ)	1.44	1.52	1.40
DSA LER (3σ)	1.35	1.48	1.37



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Pitch 28nm, CD = 14nm

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Investigation of Edge of the Array in both directions



Lines #	LER (3σ nm)
1	1.35
2	0.69
3	0.03

- Line end LCDU are ok near the array termination, and finger print grows in between
- Line-space array, outer lines have larger LER compared with inner lines

Pitch 28nm, CD = 14nm

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Summary

- Demonstrated a rigorous simulation engine for DSA chemo-epitaxy patterning processes, to predict the post-process patterns for line space and hexagonal hole layouts.
- EUV rectification and DUV pitch-split cases are simulated for both L/S and contact holes.
- Simulation with varying guiding pattern CD shows a stable process window for different DSA flows.
- Terminated array simulation also provides information in the context of design rules.

