SYNOPSYS®

Challenges for stochastic EUV lithography simulation

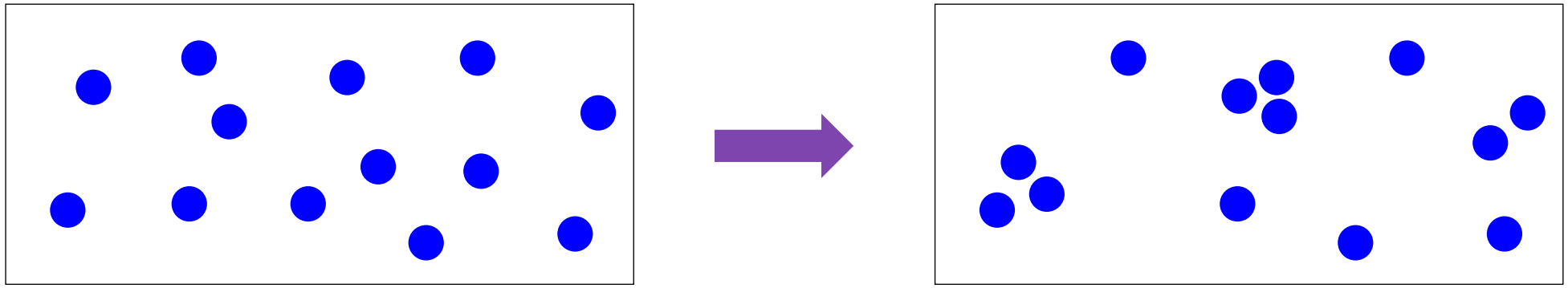
EUVL Workshop

Ulrich Welling, Lawrence Melvin III, Hans-Jürgen Stock

Leuven, June 6th 23

Starting from a Question

How does aggregation of PAG or Quencher in PR affect the lithographic process?



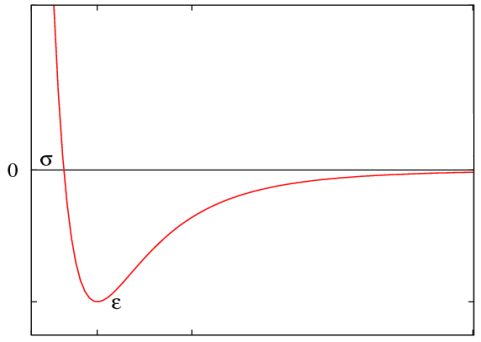
Attempt to give an informed in-silico answer based on:
particle simulations
lithographic process simulation

Aggregation

Aggregation is caused by PAG molecule interaction in the PR Matrix.

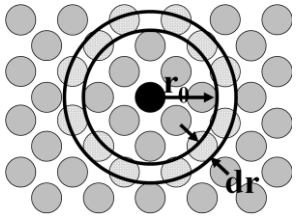
Characterized by the radial distribution function (RDF)
(probability of finding another particle at distance r of a central particle)

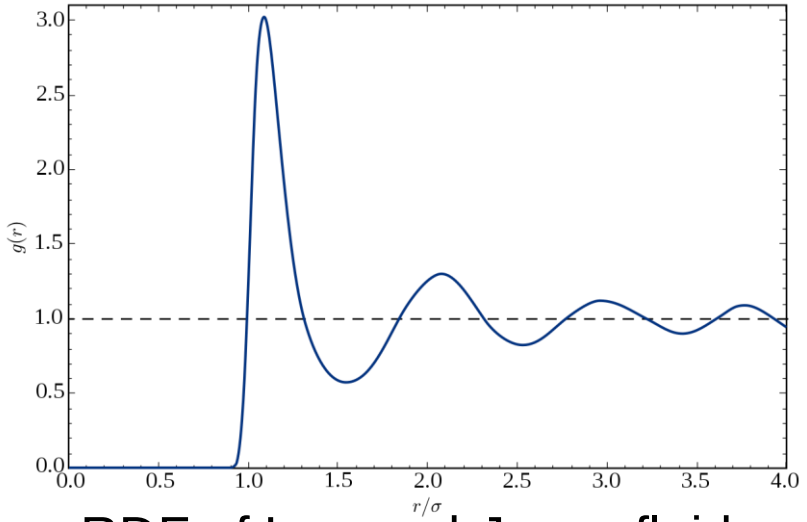
$$\Phi_{12}(r) = 4\epsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right]$$



Lennard-Jones 12/6 potential

$$g(\mathbf{r}) = \frac{1}{\rho}\langle\sum_{i\neq 0}\delta(\mathbf{r}-\mathbf{r}_i)\rangle$$



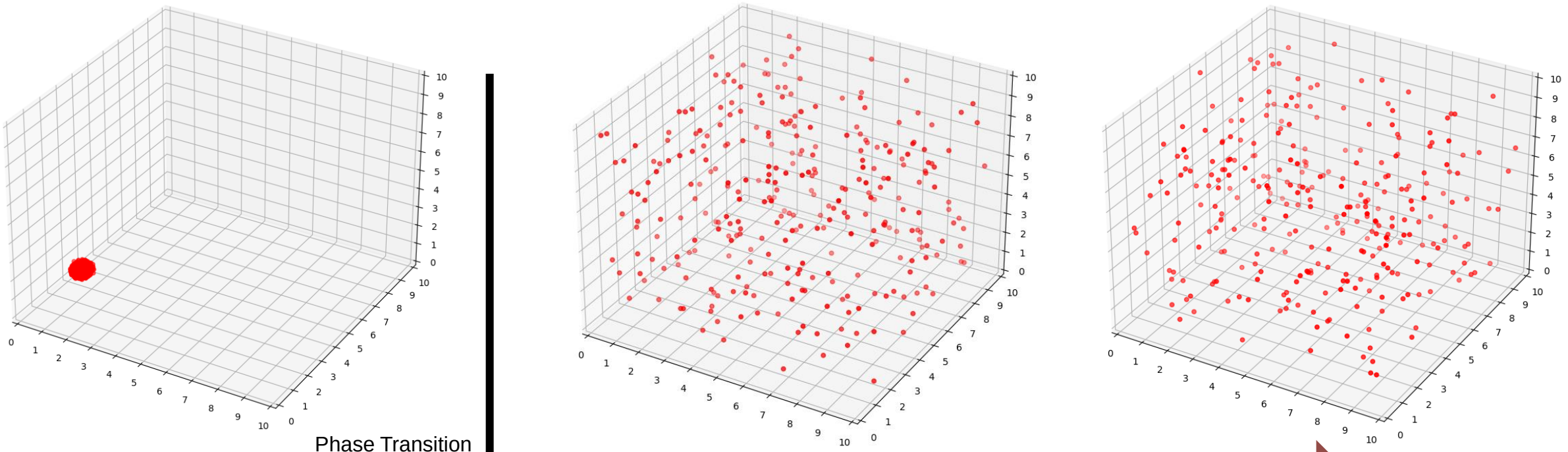


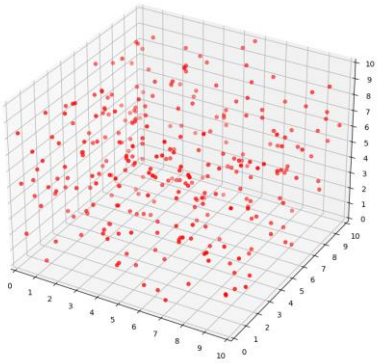
RDF of Lennard-Jones fluid

PAG Model System

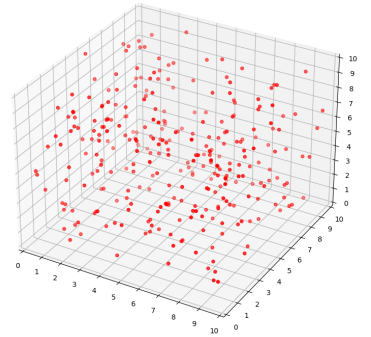
Brownian Motion simulation of LJ fluid, based on ref. PR quantities as model for PAG distribution

$c(PAG) = 0.3/nm\text{^}3 \quad \epsilon_{\{min\}} = 0.5nm$



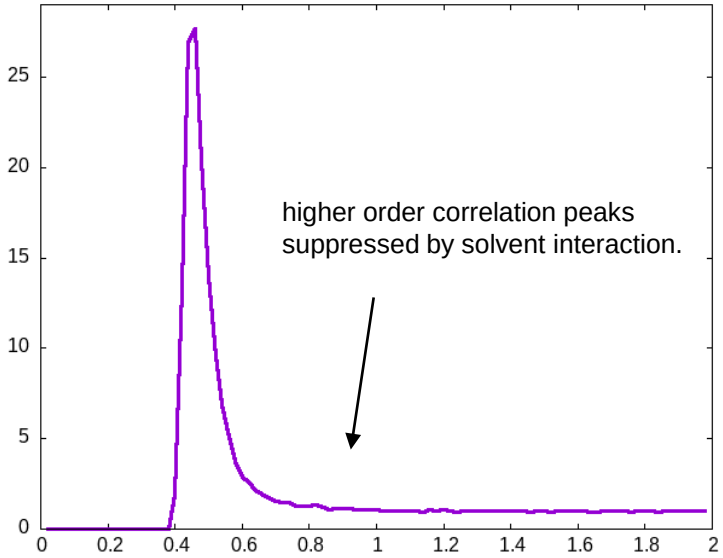


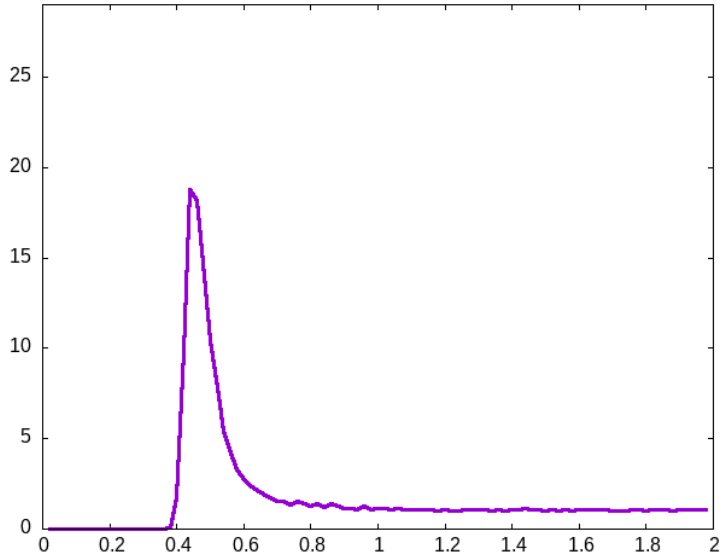
Microscopic Structure

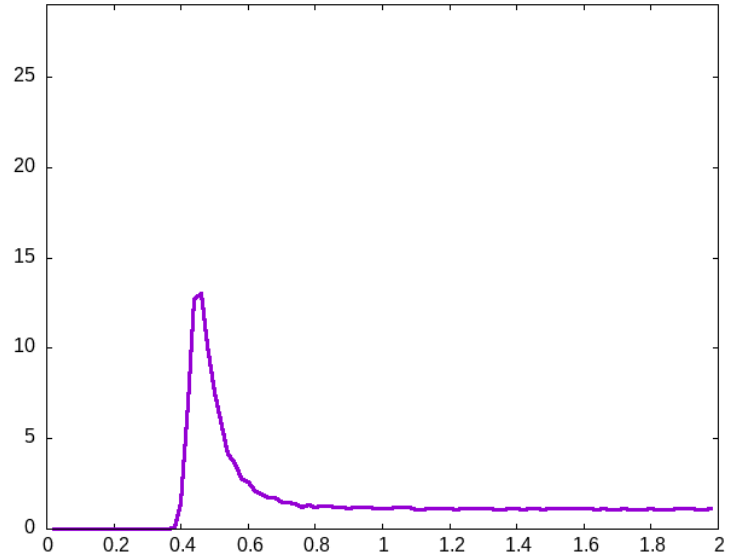


model temperature + interaction modifies local aggregation

RDF







Temperature

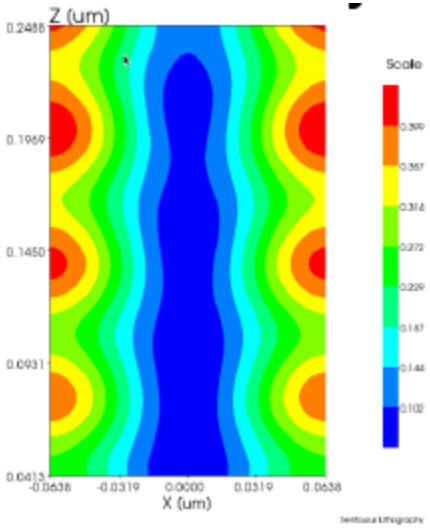
Interaction Strength

Stochastic Lithography Simulation

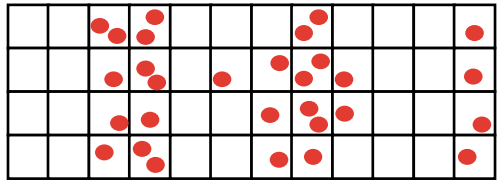
Conceptual Flow

Influence from Aggregation

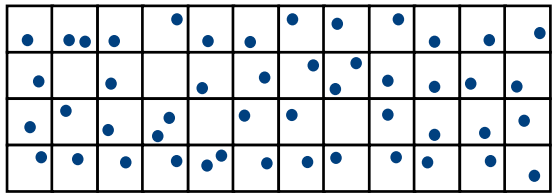
Aerial Image



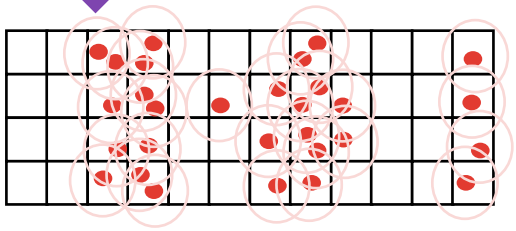
Discrete photon absorption

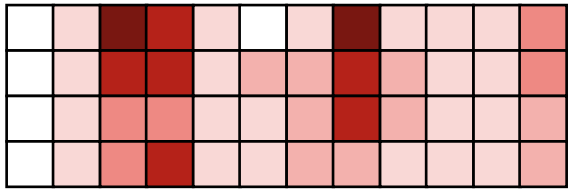


PAG Distribution



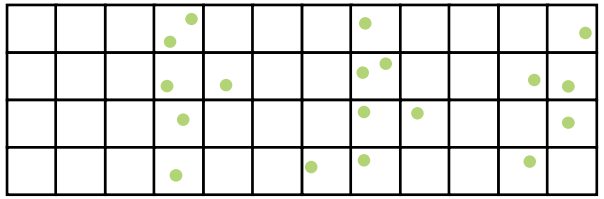
2nd electron blur



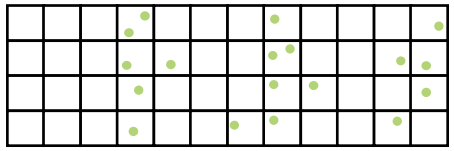


Energy Deposition

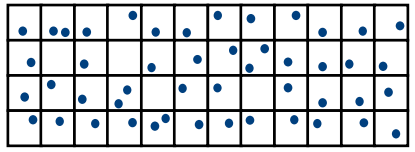
Acid Distribution



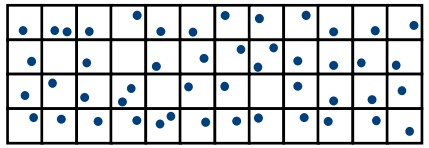
Acid Distribution



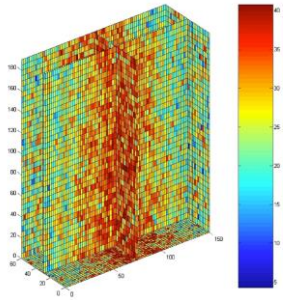
Quencher Distribution



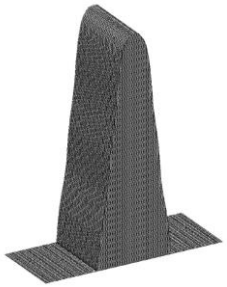
Inhibitor Distribution



Gillespie Algorithm to solve CME



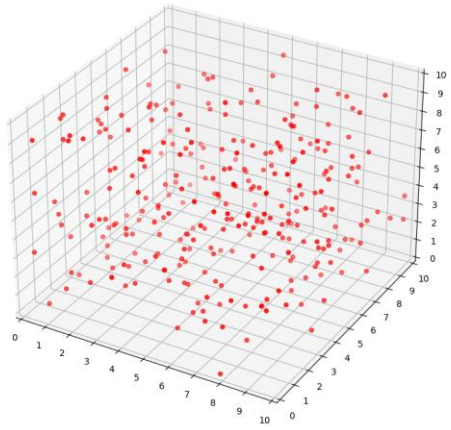
Development



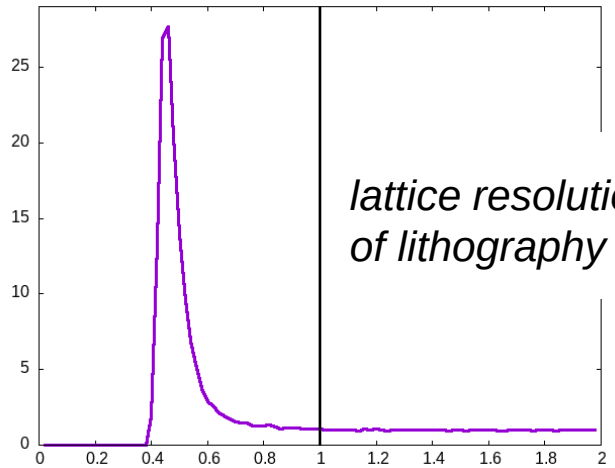
Relating microscopic structure and lattice-based distribution

particle based model system gives access to required information

Particle Distribution

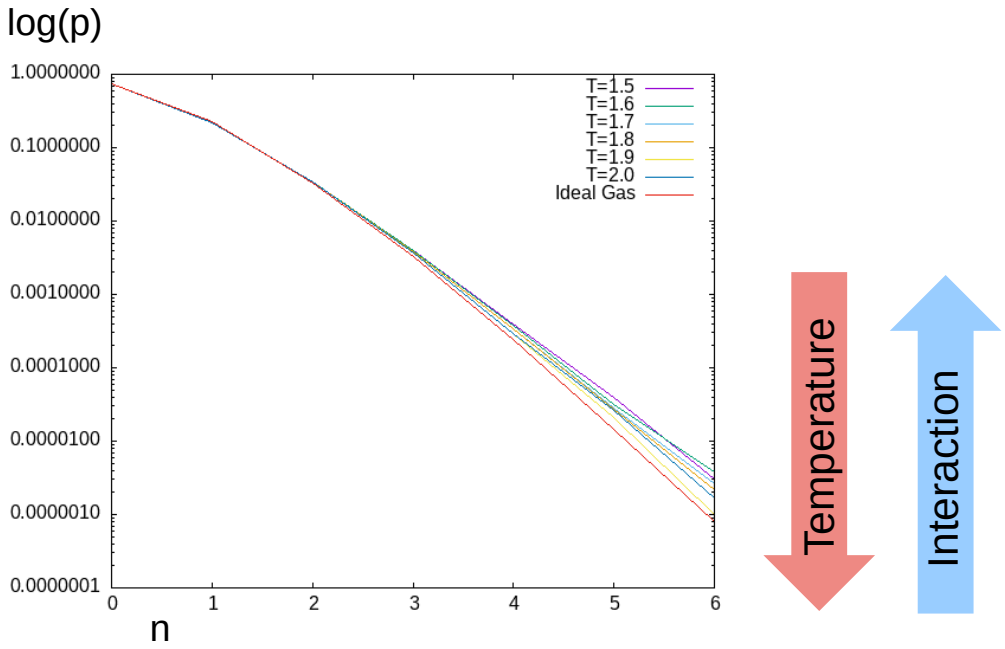


RDF



lattice resolution of lithography model

Histogram of particle count in 1nm^3 lattice cells



the impact is small, difference is in the weight of tails

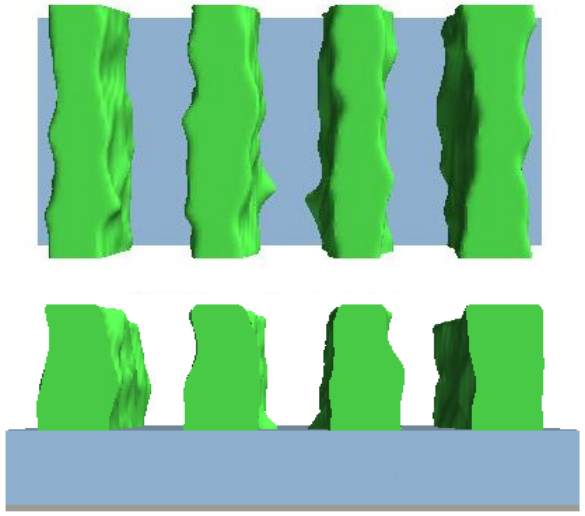
cluster size generated from binomial distribution matching observed particle number histograms

Impact on Lithography Simulation

Modified initial PAG distribution leads to very small changes in roughness

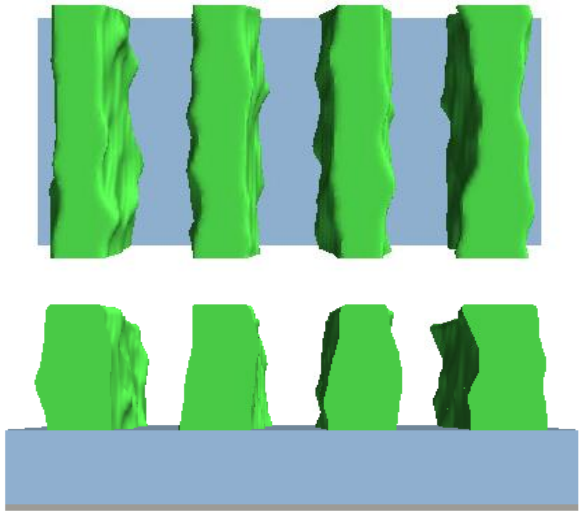
EUV PTD resist, P36 L/S, NXE:3300, IMEC PR

No Interaction



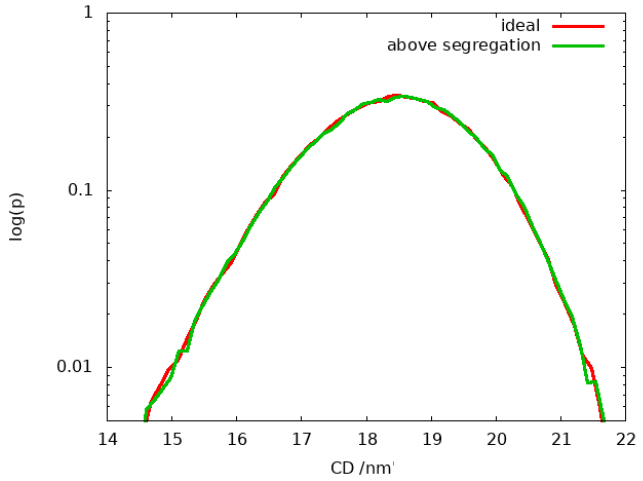
CD: 18.450nm
LWR: 3.462nm

T close to segregation

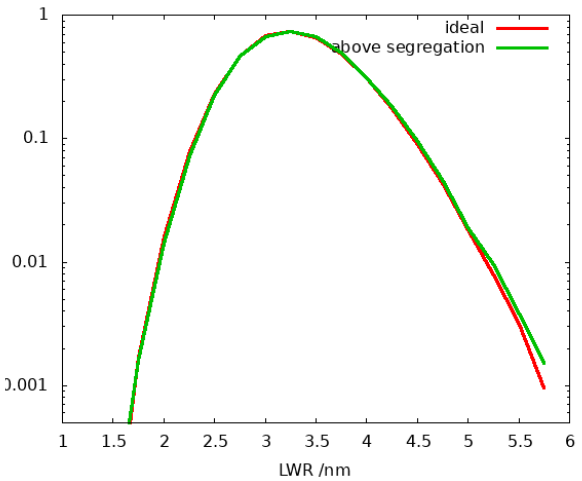


CD: 18.439nm
LWR: 3.473nm

CD



LWR



no difference in CD,
slightly increased chance of higher LWR

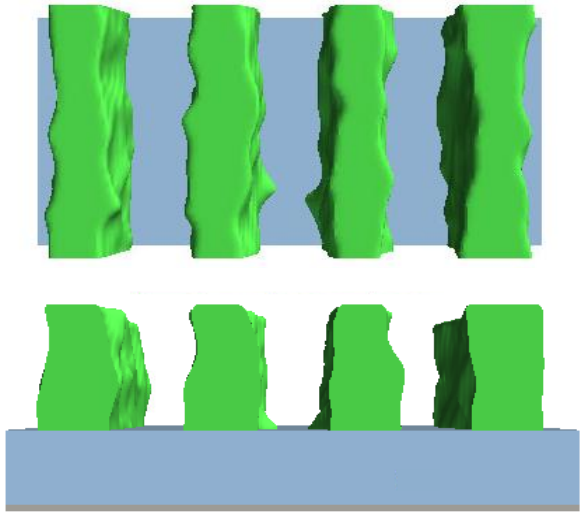
Is this an effect or noise?

Impact on Lithography Simulation

Modified initial PAG distribution leads to very small changes in roughness

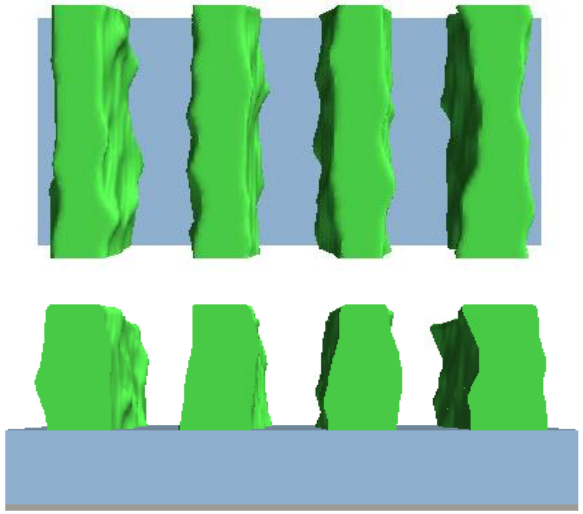
EUV PTD resist, P36 L/S, NXE:3300, IMEC PR

No Interaction



CD: 18.450nm
LWR: 3.462nm

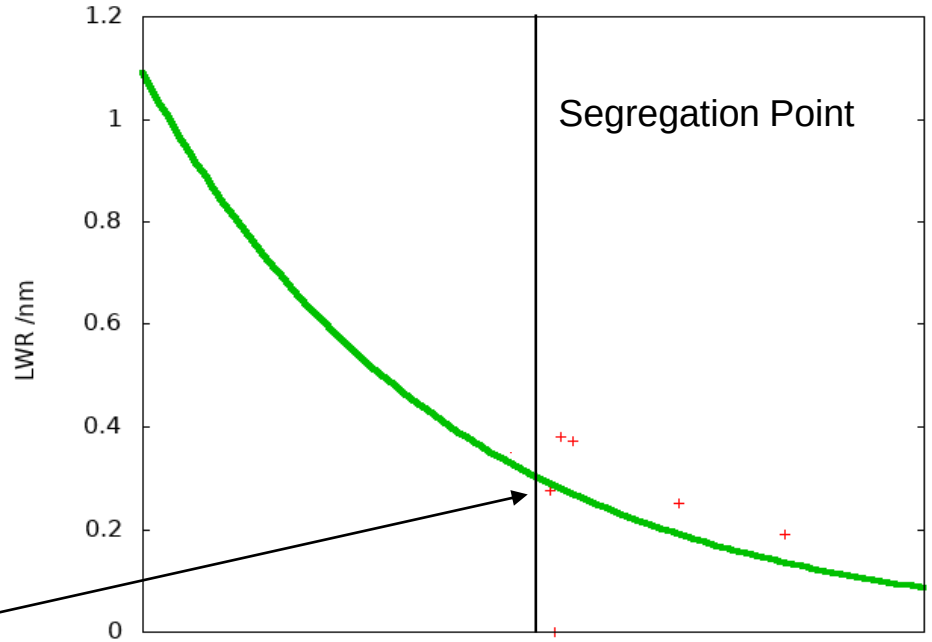
T close to segregation



CD: 18.439nm
LWR: 3.473nm

Added LWR: 0.36nm
(assuming added LWR to be uncorrelated noise)

LWR contribution from Aggregation



Modified Cluster Size Distribution (N,p)

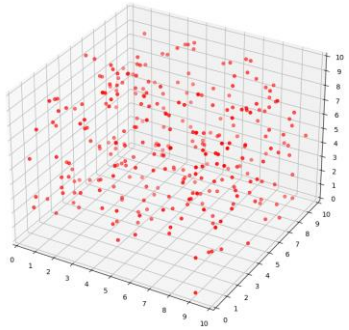
Temperature

Interaction Strength

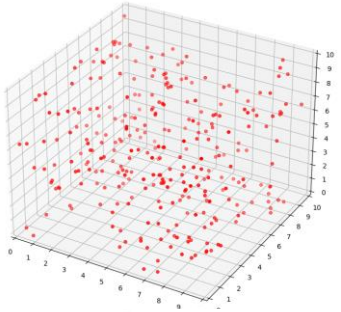
Impact of Solvent Evaporation Process

Assumption: PAG solubility switches below Segregation Point during Post Apply Bake

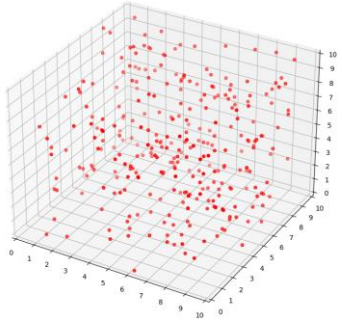
$t = 0\tau$



$t = 25\tau$

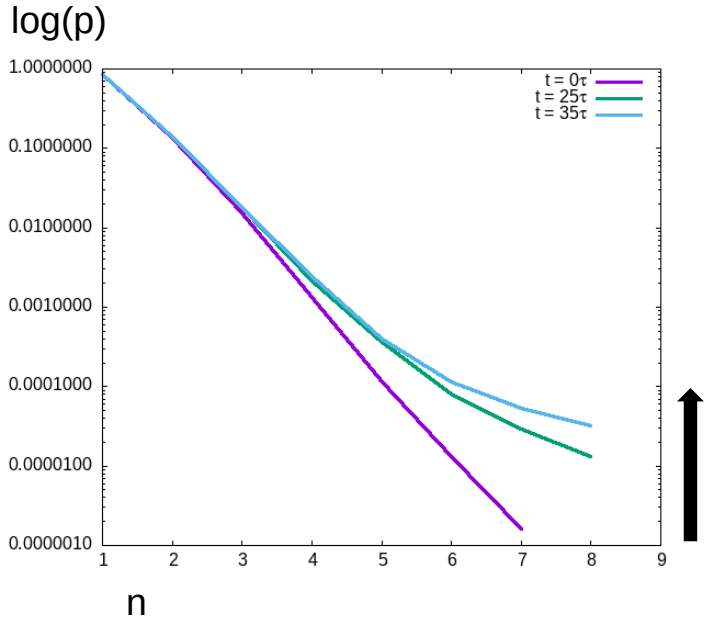


$t = 35\tau$

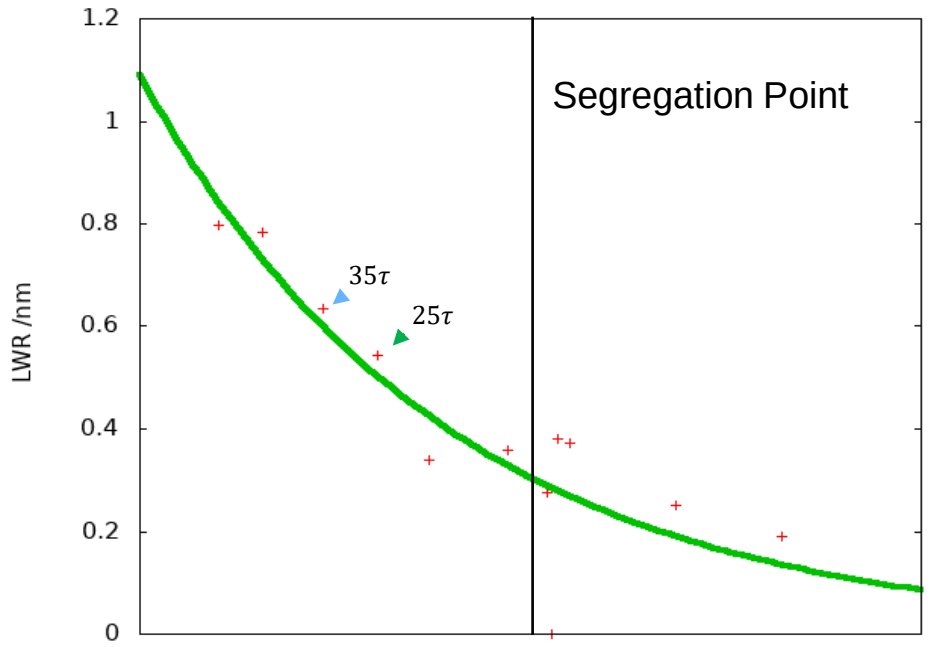


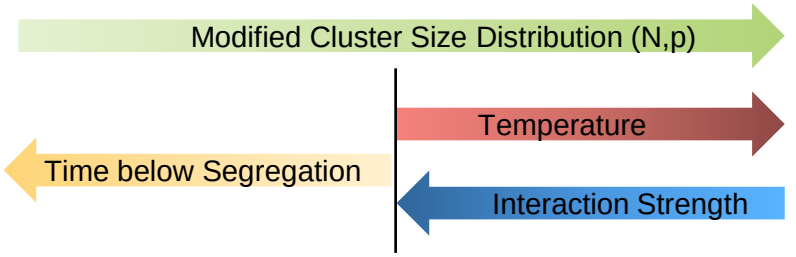
τ corresponds to 1-10s for typical PAG diffusion rates

Quenching a system leads to increased probabilities of larger aggregations.



LWR contribution from Aggregation

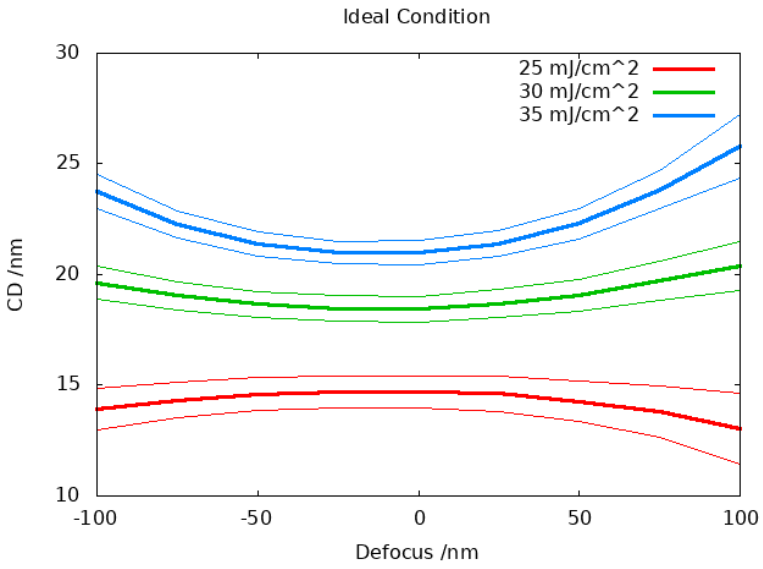


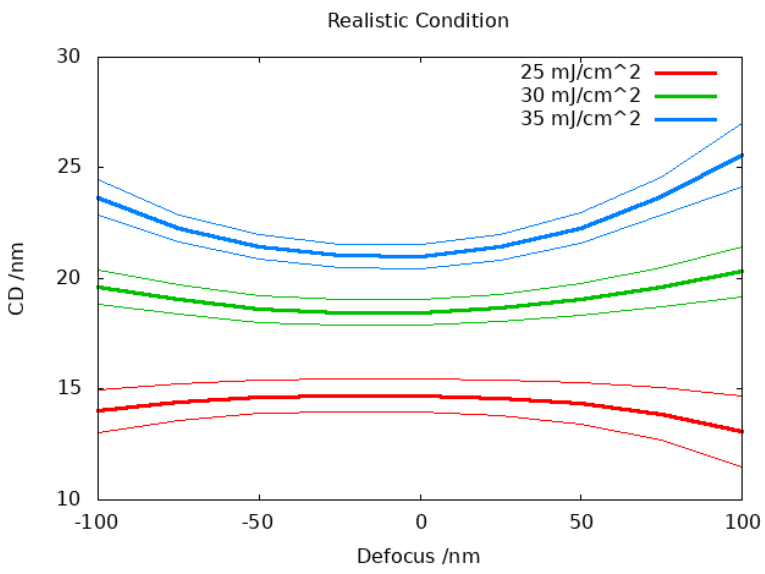


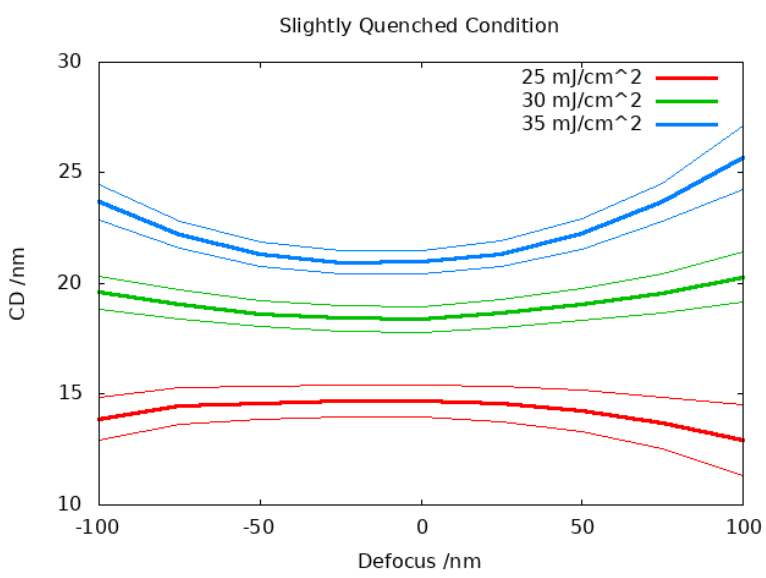
The initial stage of a quenching process has an impact on LWR before the particle distributions vary substantially

Process Window Impact

36P18 L/S PW for ideal, realistic and slightly quenched PAG distribution







No visible impact on process window for the considered cases.

Conclusions

- Demonstration of a pathway to include Aggregation Effects to lattice-based stochastic lithography simulations

- LJ model implies aggregation *does not affect* the process above the segregation point: short-range pair correlations do not affect process quality

- PAG molecule segregation due to solvent evaporation / slow cooling after Post Apply Bake could have severe impact on PR performance : *experiments needed*

diffraction experiments + detailed atomistic simulations could provide insight in distributions needed to inform litho-process simulations

Acknowledgements

imec

Peter de Bisshop

UCL

Guido Germano

SYNOPSYS®

Sentaurus Lithography

Thomas Mülders
Balint Meliorisz
Wolfgang Demmerle
Ulrich Klostermann

Mask Solutions

Zac Levinson

Quantum-ATK

Julian Schneider