Process Model Guided Photoresist Formulation Optimization

工艺模型指引下的光刻胶配方优化

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Outline

- Target setting for photolithography processes
- Opitcal imaging characteristics and limits
- Principles and properties of photoresists
- Types of imaging conditions
- Moldeling of imaging with photoresists, examples
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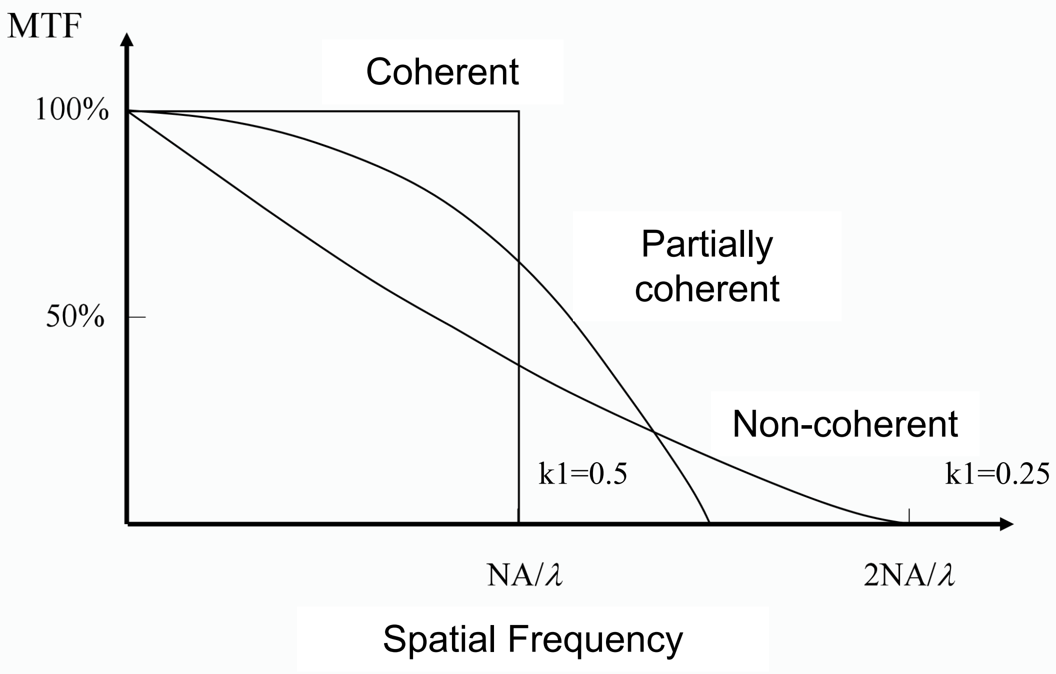
Target setting for photolithography processes

How to define an appropriate photolithographic process windows?

- Opitcal imaging characteristics and limits
  - Modulation Transfer Function (EL, MEF)
  - Depth of Focus
  - Any residual aberration and distortion
- Principles and properties of photoresists
  - Thickness and absorption
  - Sensitivity
  - Activation energy for Chemically Amplified Resist (CAR)
  - Chemical Amplification
  - Response linearity and saturation
  - All kinds of uniformities (chemical uniformity, MW uniformity, etc.)

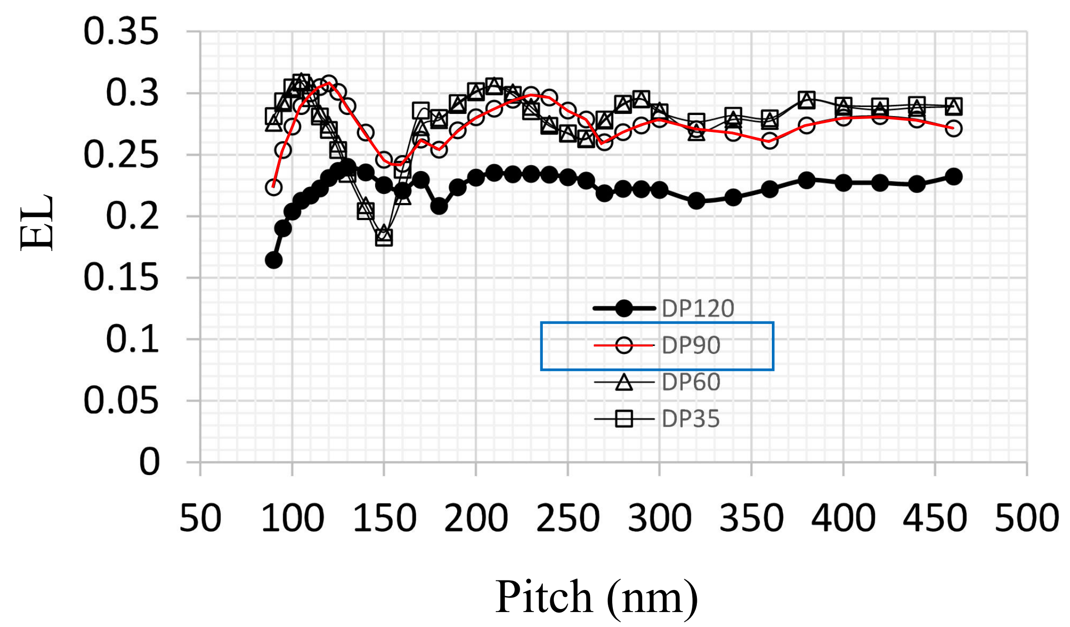
Opitcal imaging characteristics and limits

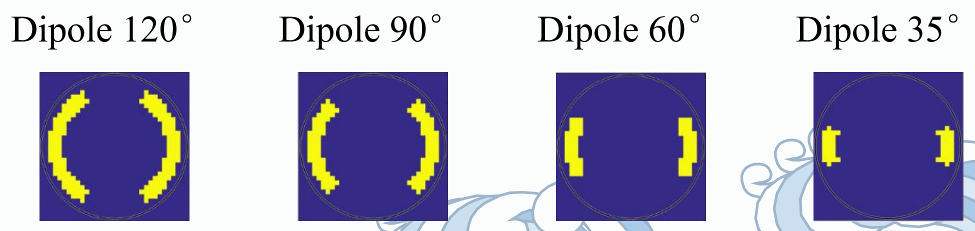


- For all processes with k1<0.5， it is impossible for all pitches to have good imaging contrast
- Generally speaking, it is not so easy to make the contrast to be above 40~60% for all pitches that are allowed by the design rules
- There is a trade-off between being able to imaging with the smallest minimum pitch and being able to accommodate all pitches with the highest possible contrast

Opitcal imaging characteristics and limits

- This is an example with a 90 nm minimum pitch imaging case with NA1.35 and k1=0.314.
- With Dipole 90° illumination condition, it is possible to provide a high Exposure Latitude (EL) of >22% for all pitches
- The cost is common Depth of Focus (DoF)



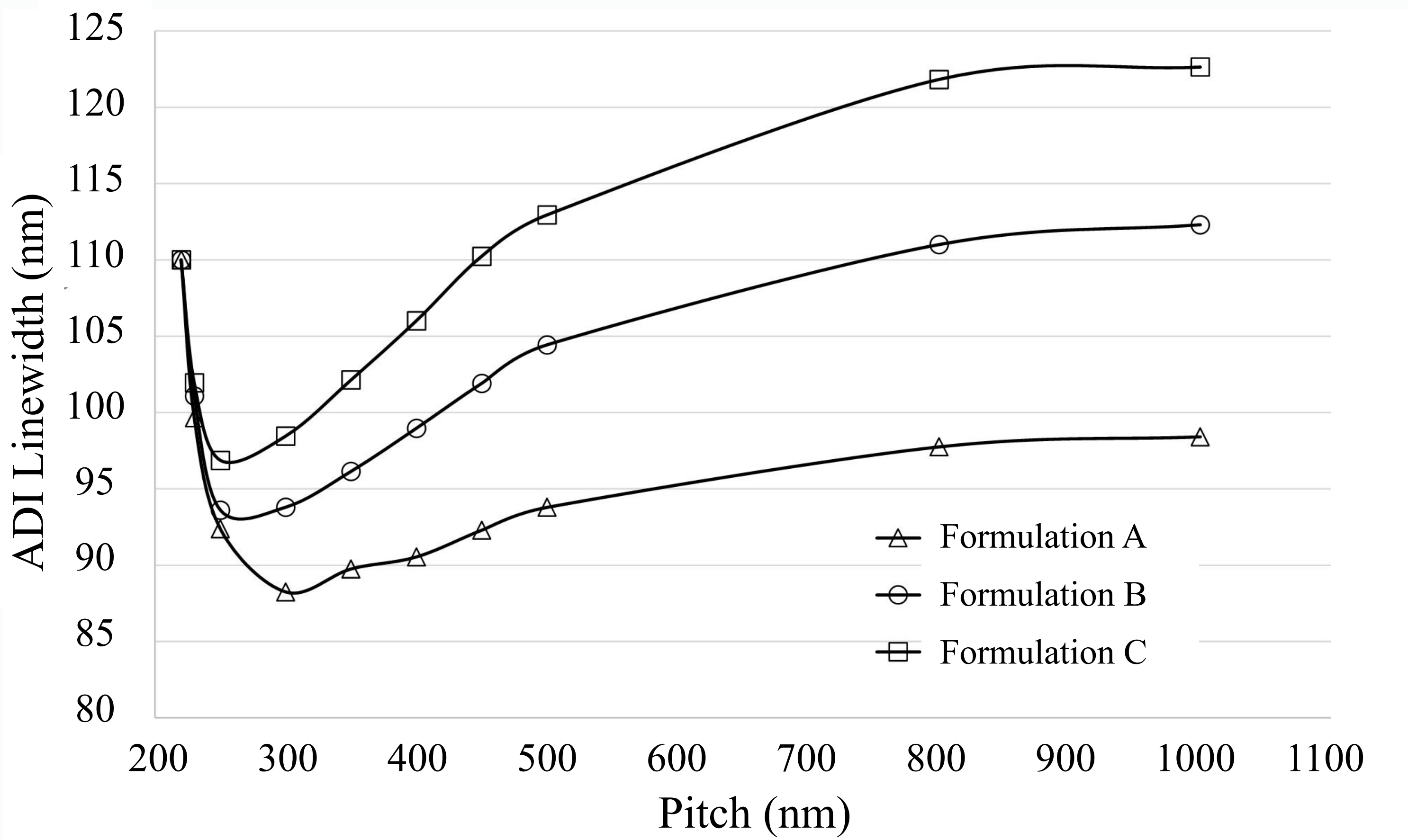


DoF	67.6 nm	54.7 nm	53.2 nm	39.9 nm

* Qiang Wu, CSTIC 2020, 3-11

Moldeling of imaging with photoresists, examples

Activating energy versus CD through pitch



Principles and properties of photoresists

- Thickness and light absorption:
  - Profile
- Sensitivity, activiation energy (E_a), chemical amplification:
  - Low E_a → high sensitivity
  - Chemical amplification will damage contrast
- Response linearity and saturation:
  - Facing bright field (BF) and dark field (DF),
    - DF needs high sensitivity (otherwise → residual)
    - BF needs low sensitivity (otherwise → thickness loss or pattern missing)
    - Linearity is good, but we need guarantee on low defectivity (~ppT, usually beyond metrology)
- Photoacid, Base quencher, all uniformities:
  - PAG and quencher blending uniformities
    - → CD uniformities,
    - → pattern edge roughness (circularity for hole layers)
  - Developing dosage uniformities
    - → CD uniformity, developing residual defect
  - Molecular weight distribution
    - → pattern edge roughness (circularity for hole layers)
- Dissolution contrast
  - High dissolution contrast can support high imaging contrast (EL), but smaller DoF

Types of imaging conditions

- Choice of process platform and performance level
  - 193 nm dry, 193 nm water immersion, 248 nm, EUV, etc

- Choice of target process
  - Positive Toned Developing (PTD) or Negatively Toned Developing (NTD)
  - BEOL metal and vias, aka. Dark Field (DF) types
  - FEOL gate and Active Area (AA), aka. Bright Field (BF) types
  - FEOL and BEOL accomodating type: has high demand on the uniformity: PAG and quencher blending, MW distribution, and high dissolution contrast, etc.

- Determining parameters that affect process performance
  - Effective Photoacid Diffusion Length (EPDL)
  - PAG and base quencher loading
  - Dissolution contrast

Moldeling of imaging with photoresists, examples

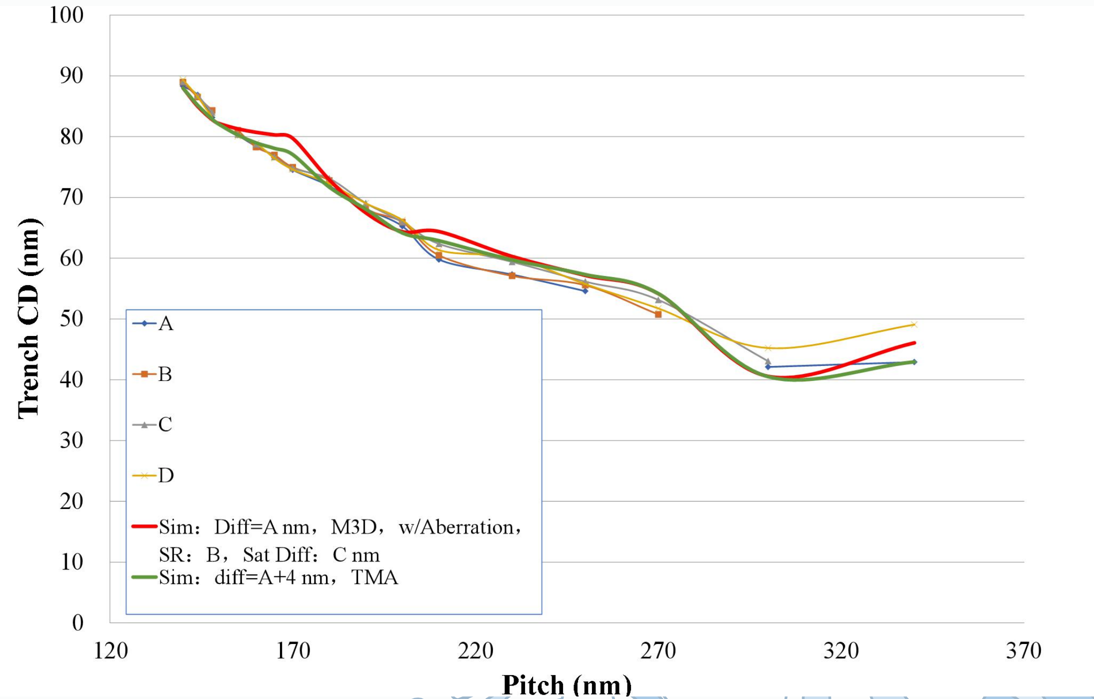
Peformance of formulations A-D in trench lithography (DF)

EL and MEF

Formulation	EL (simulation=100%)	MEF (simulation=100%)
A	0.98	0.94
B	0.90	0.92
C	0.98	1.00
D	0.90	0.81

- EPDL = A nm
- The agreement between experiment and simulation is very well in all of EL, MEF, and OPC

CD Through Pitch

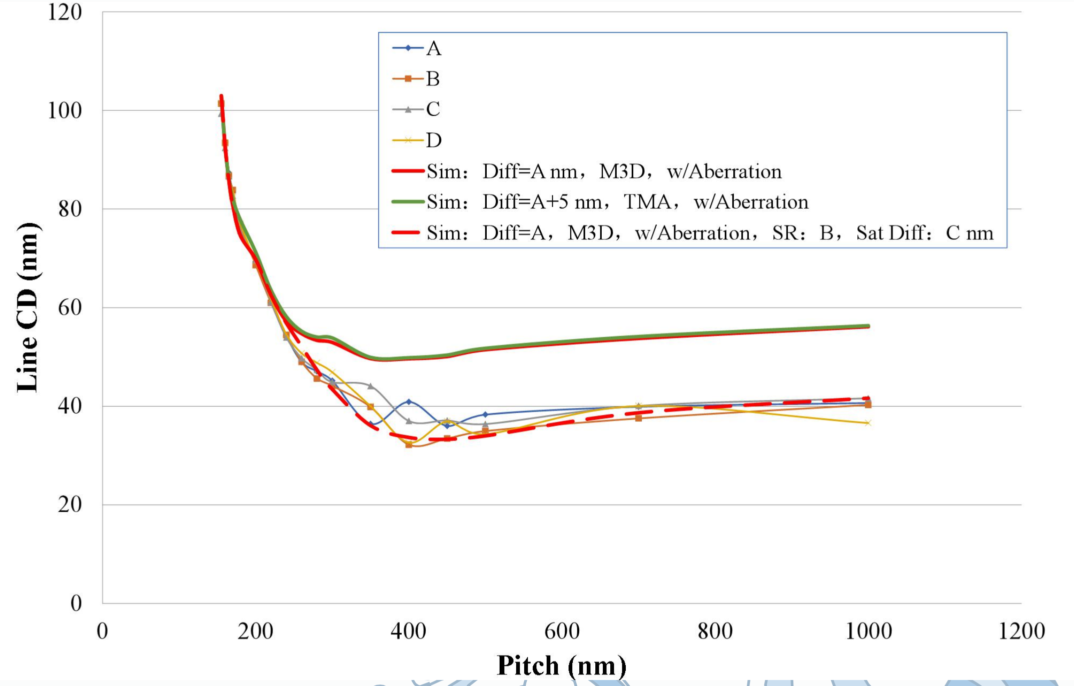


Moldeling of imaging with photoresists, examples

Peformance of formulations A-D in line lithography (BF)

- EPDL = A nm
- Formulations A-D line CD through pitch agrees with simulation (w/ linear response) only in dense pitches.
- At semi-dense to isolated pitches, it only agrees with models with non-linear response to the illumination, indicating response saturation exists in under BF conditions.
- We can extract parameters that describe the saturation: SR (=B) and Sat Diff (=C nm).
- This photoresist type is better for dark field application since the sensitivity is high so that it easily saturates under BF condition.

CD Through Pitch

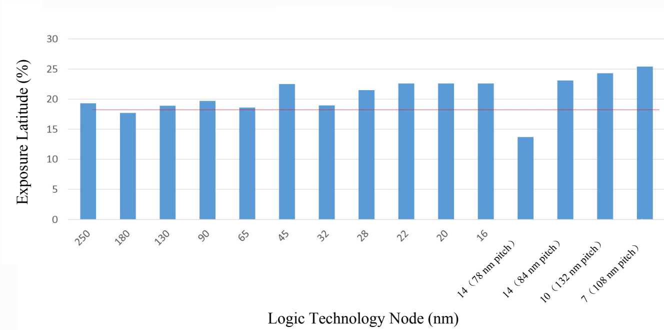


Moldeling of imaging with photoresists, examples

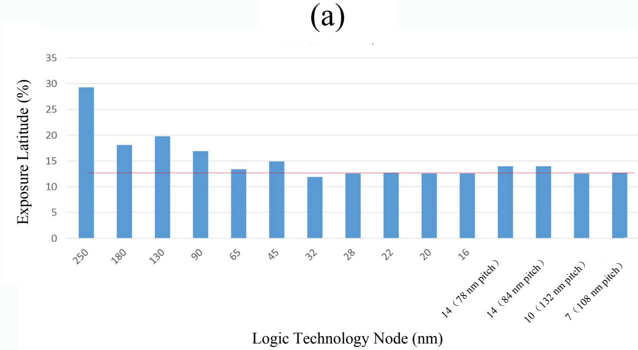
- We have a good understanding of the photolithographic process and material response,
- we will need to know how to balance the parameters, such as EL, MEF, DoF, OPC, etc.
- Recently, we have done a study on the typical process performance over the years starting from 250 nm logic technology node

Proposals and recommendations

EL

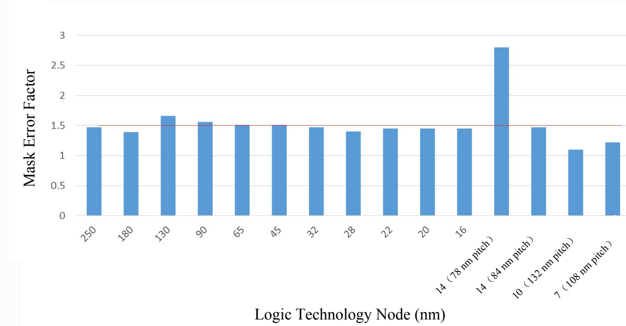


(a)

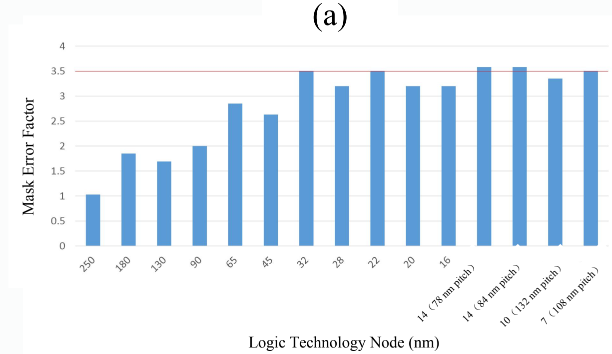


(b)

MEF



(a)



(b)

- From 250 nm technology nodes to the current 7 nm in DUV and 5 nm and beyond in EUV, the industry follows some standards in photolithography process performance
- The EL for FEOL is >18%, for BEOL is >13%
- The MEF for FEOL is <1.5 and for BEOL is <3.5 (7 for contact/vias)

* Qiang Wu, IWAPS 2018, JoMM 2019, J. Microelectron. Manuf. **2**, 19020101 (2019)

Proposals and recommendations

- We recommend that the photoresist development efforts be aware of or follow the industry guidelines and standards to speed up the process.

- Good physical simulation modeling can help to understand the behavior of photoresist performance and provide guidelines for formulation improvement and optimization. It can also save a lot of exposure work and data analysis in matching EL, MEF, OPC to a given set of specifications.

* Qiang Wu, IWAPS 2018, JoMM 2019, J. Microelectron. Manuf. **2**, 19020101 (2019)

Summary

- We have done an analysis on the photoresist performance under 193 nm immersion photolithography with physical modeling support (made possible by CF Litho)

- We found that our complete physical model can describe the photoresist exposure data very well and extract parameters that are useful for formulation improvement and optimization.

- We recommend the method: "Process Model Guided Photoresist Formulation Optimization" to all who need to develop or optimize a photoresist formulation.

- We also recommend this physical modeling (made possible by the **CF Litho** software) to whom has a need to optimize a photoresist process.


谢谢！
我们的目标是星辰大海，诗和远方。。。。。。