Organic Antireflective Coatings for Photomask Fabrication using Optical Pattern Generators

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High Resolution Resist Optimization

Goal: Improve **resolution** and **process latitude** for photomask fabrication

Method: Line-edge optimization of exposure image and resist development response

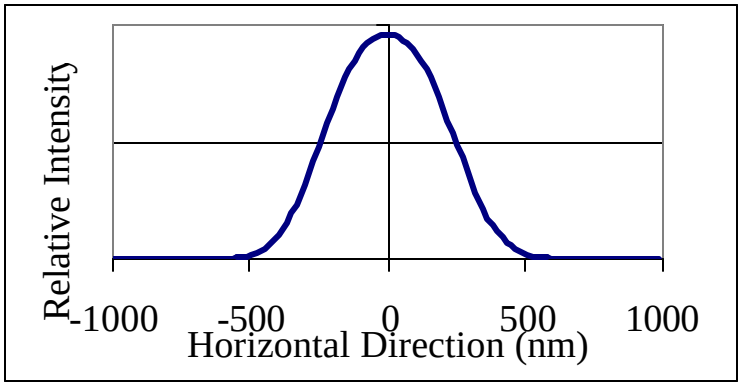
Challenge: Standing waves impact resist performance

Solution: PEB and/or organic antireflection coatings (ARCs)

Basis of Line Edge Optimization

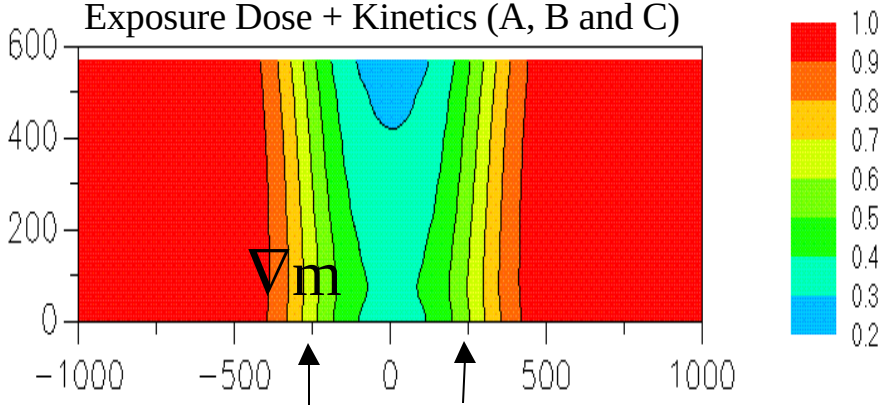
(0.5 µm Space in Resist)

Aerial Image

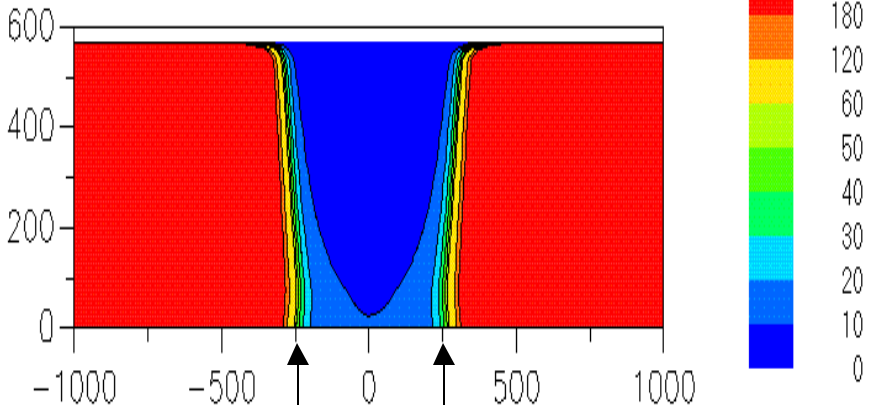


Relative PAC (m)

Exposure Dose + Kinetics (A, B and C)

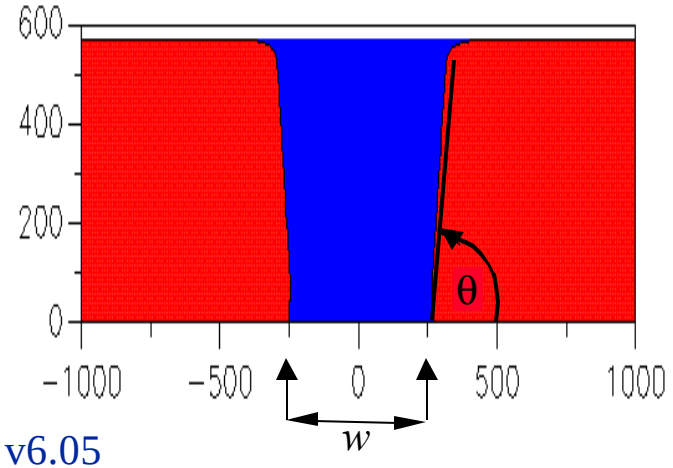


Develop Time Contours



Output: Resist Profile

Sidewall angle θ and feature size *w*



PROLITH 2 v6.05

Lithographic Imaging Equation

High Resolution Imaging

1. Image Transfer
Position steepest slope (inflection point) of the aerial image at the feature edge

2. Dissolution contrast (γ_R)
Maximize dissolution change with dose through R(m) analysis

3. Dissolution Threshold
Position dissolution threshold at the inflection point of the image

1-Dimensional Analysis

$$\left.\frac{dR}{dx}\right|_{x^*} = g_R \frac{dm}{dx}$$

$$g_R = \frac{dR}{dm}$$

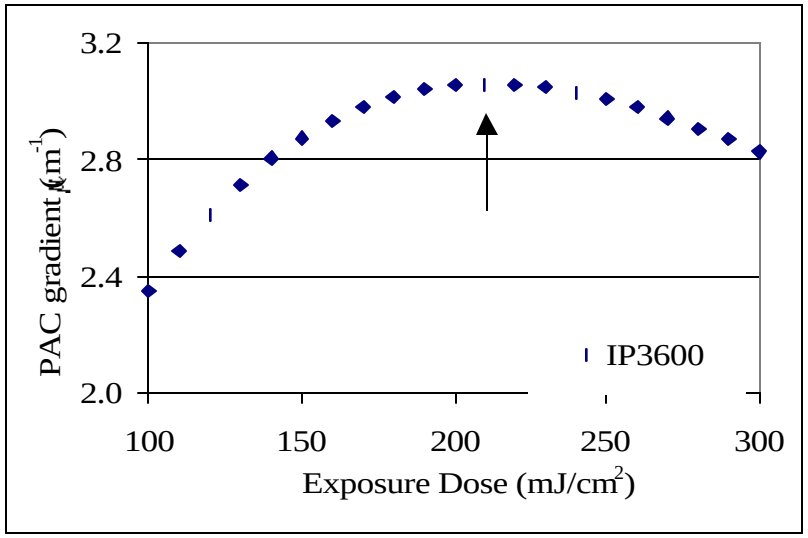
R = Dissolution rate
x = Horizontal position
m = Relative PAC Concentration
g_R = Resist contrast
x^* = Nominal edge of resist feature

Simulated Optimum Exposure Dose for Photomask Lithography

Determined exposure dose that resulted in the **maximum Ñm**

Best Doses

IP3600 ≅ 210 mJ/cm^2

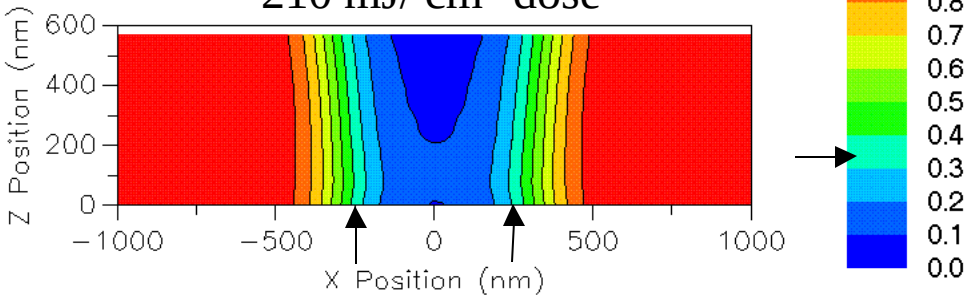


Determined m at the edge of the resist feature at the dose giving maximum ∇m

Target m

IP3600 = 0.3

m(x,z) of IP3600 with a 210 mJ/ cm^2 dose

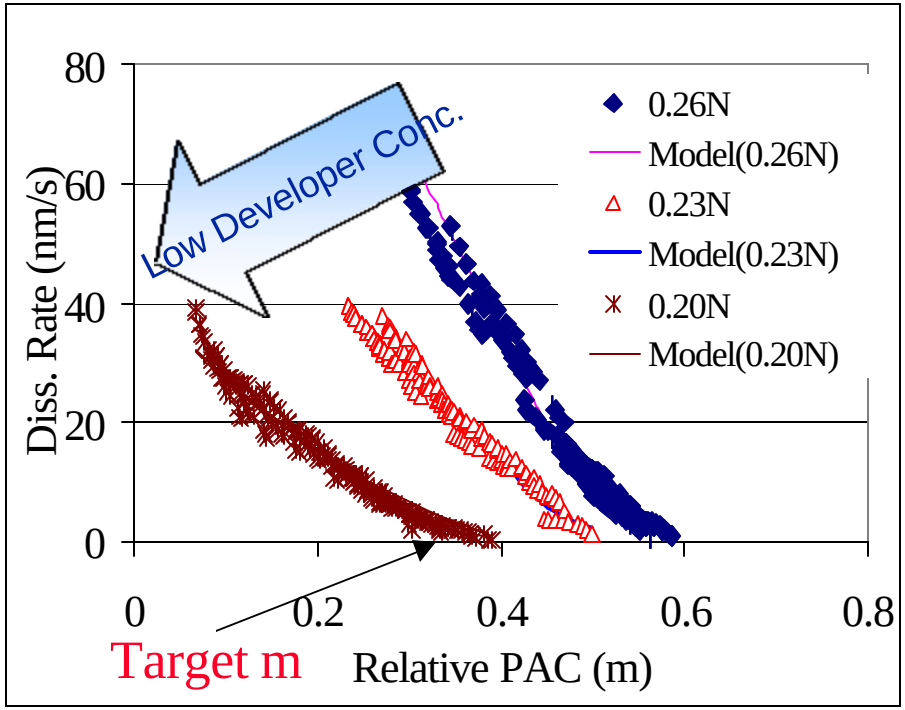


Optimal Dissolution Notch Location

<u>Lower</u> developer concentration shifts notch toward the target m

Optimal resist for mask lithography has…

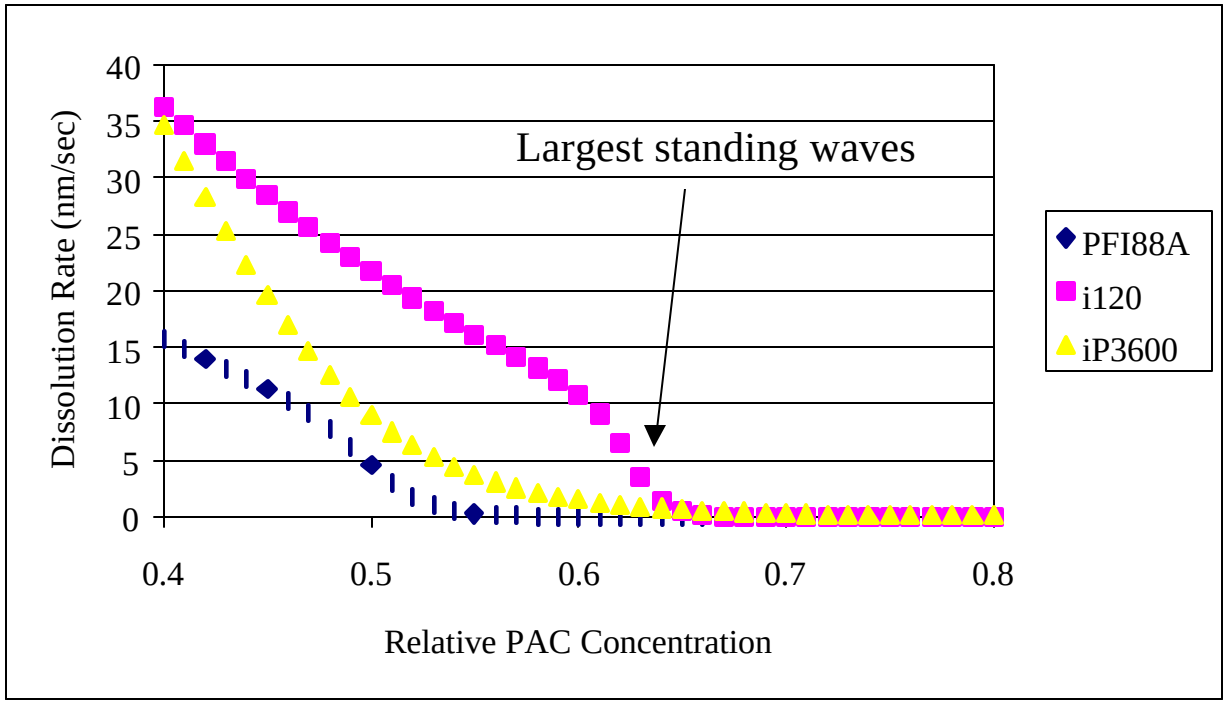
Large dissolution
Notch near Target m



IP3600 Notch Location
m ≅ 0.35
(developed w/ 0.20 N TMAH)

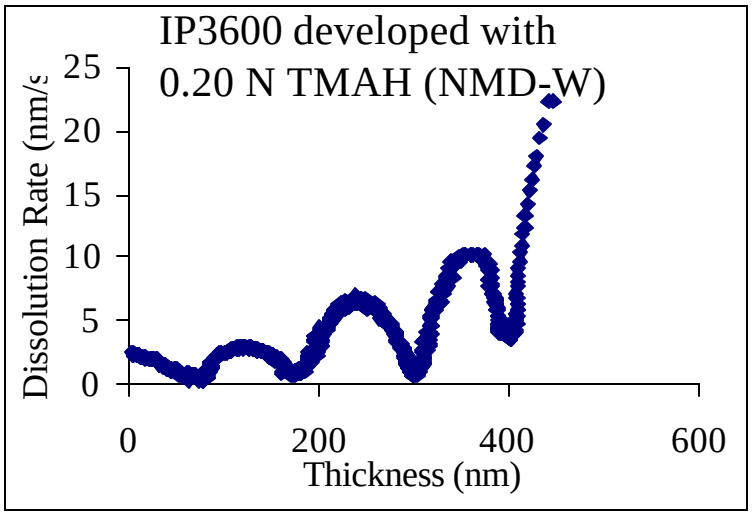
Optimal Development Rate Function (R(m))

- High contrast resists have a large dissolution notch that resolves standing waves



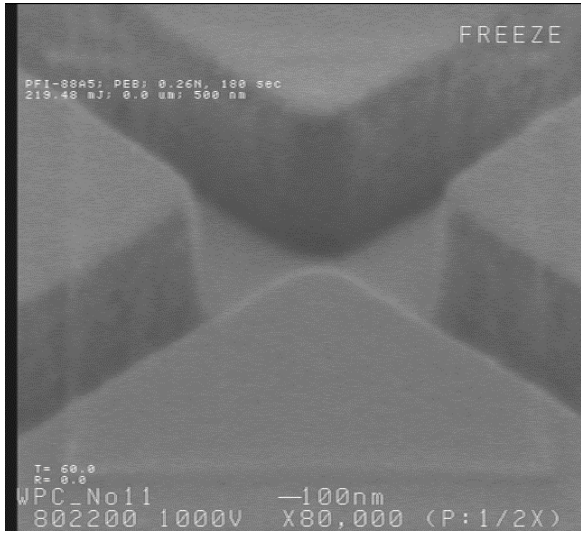
Standing Waves in Photomask Resists

- Measured oscillation in dissolution rate shows clear evidence of interference
- Lower developer concentration increases influence of standing waves

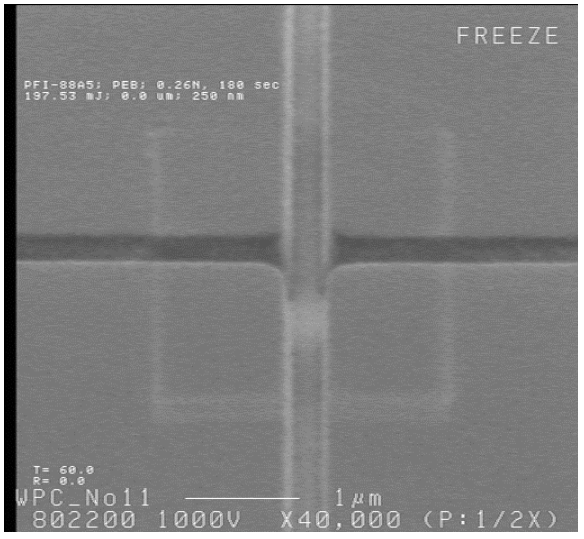


High Resolution Resists Resolve Standing Waves

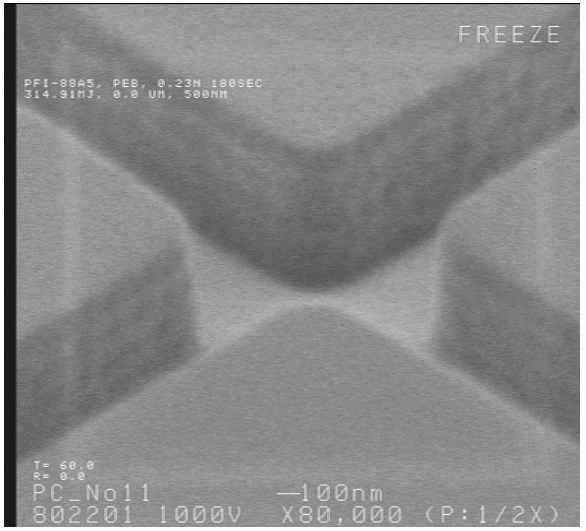
No Standing Waves → High Resolution 0.27 micron space → Lower Developer Concentration → Standing Waves



PFI88A3/ 0.26N TMAH/
300 sec. 120 C PEB

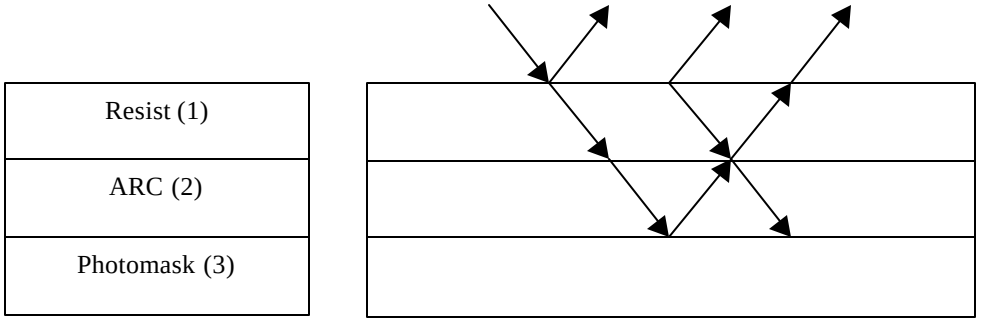


PFI88A3/ 0.26N TMAH/
300 sec. 120 C PEB



PFI88A3/ 0.23N TMAH/
300 sec. 120 C PEB

Organic Antireflection Coatings (ARCs) for Laser Photomask Fabrication



$$R_{total} = \left| r_{total} \right|^2 = \left| \frac{r_{12} + r_{23} t_D^{\,2}}{1 + r_{12} r_{23} t_D^{\,2}} \right|^2$$

Where $r_{ij} = \dfrac{\tilde{n}_i - \tilde{n}_j}{\tilde{n}_i + \tilde{n}_j}$

and $\tilde{n}_j$ is the complex index of refraction

$$r_{12} + r_{23} t_D^{\,2} = 0$$

$$t_D = e^{-i 2 \pi \tilde{n}_2 D / \lambda}$$

- Minimize reflectivity (R_{total})
  - ARC index of refraction (n_2)
  - ARC thickness (D)

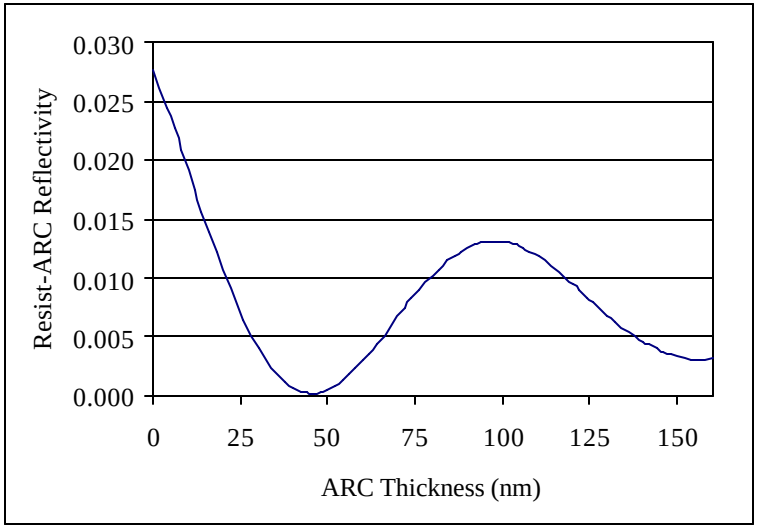
ARCs on Photomasks

- Coating Process
  - Spin coat diluted Barli II at 2000 rpm
  - Bake 15 minutes at hot plate set point of 200 C
  - Successfully coated 55 nm ARC thickness

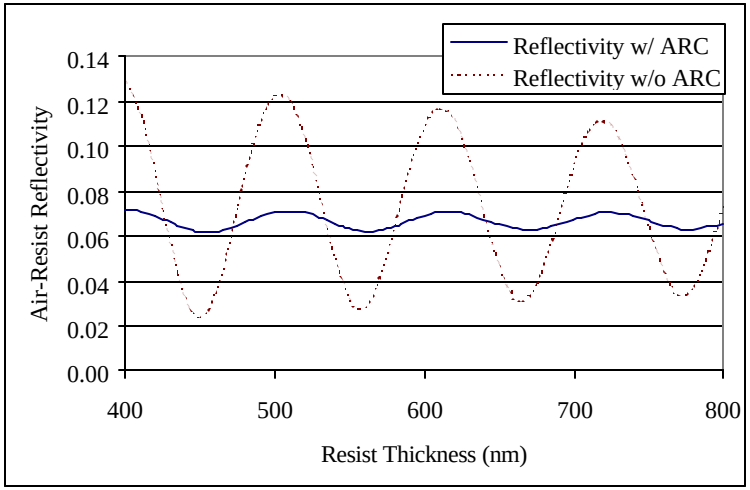
- ARC Evaluations
  - No gross defects at 55 nm
  - Gross defects at 35 nm
  - No resist beading or intermixing

Simulated Organic ARC for Iline

- Simulated Optimal ARC thickness is 46nm

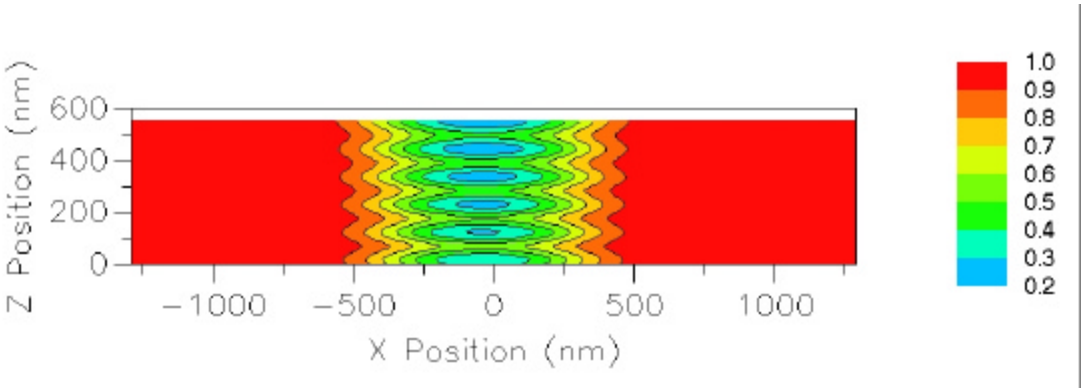


- Resist swing curve dramatically reduced with an ARC

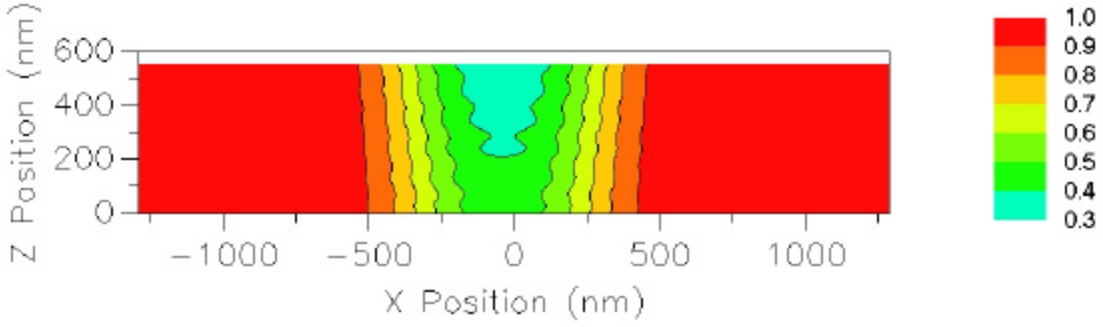


Simulated PAC distributions

- PAC distribution in resist (IP3600) without ARC

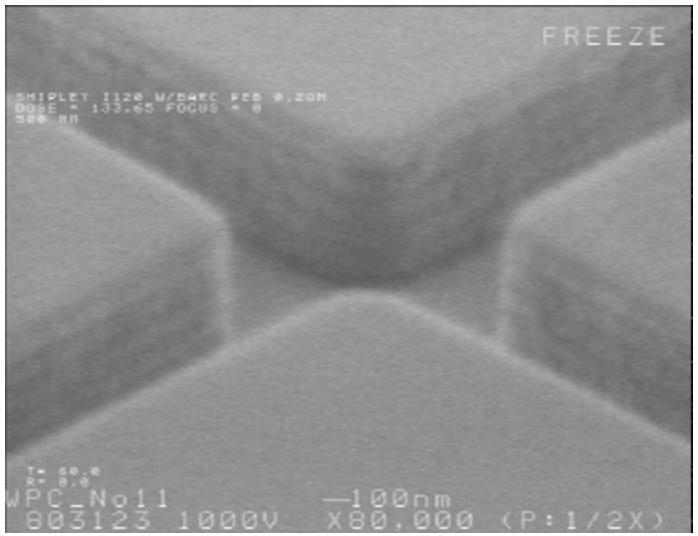


- PAC distribution in resist ARC (46 nm)
  - Minimize standing waves

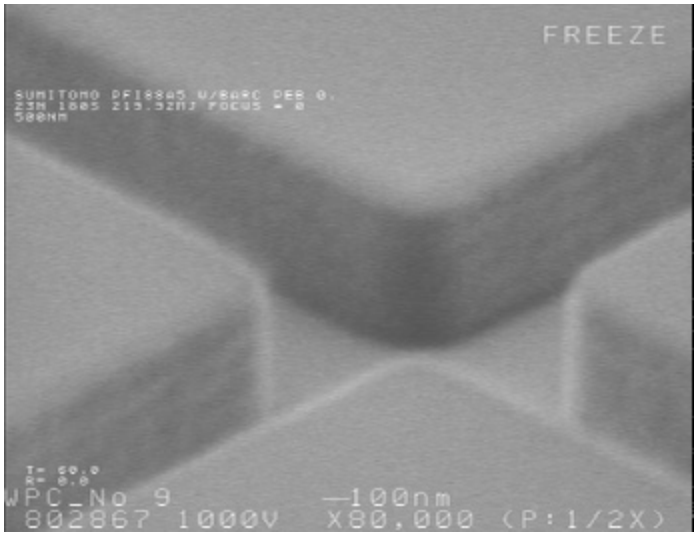


Photomask Resist Profiles on an Organic ARC

- Standing waves are reduced
- ARC film thickness needs to be optimized to remove more of the reflections



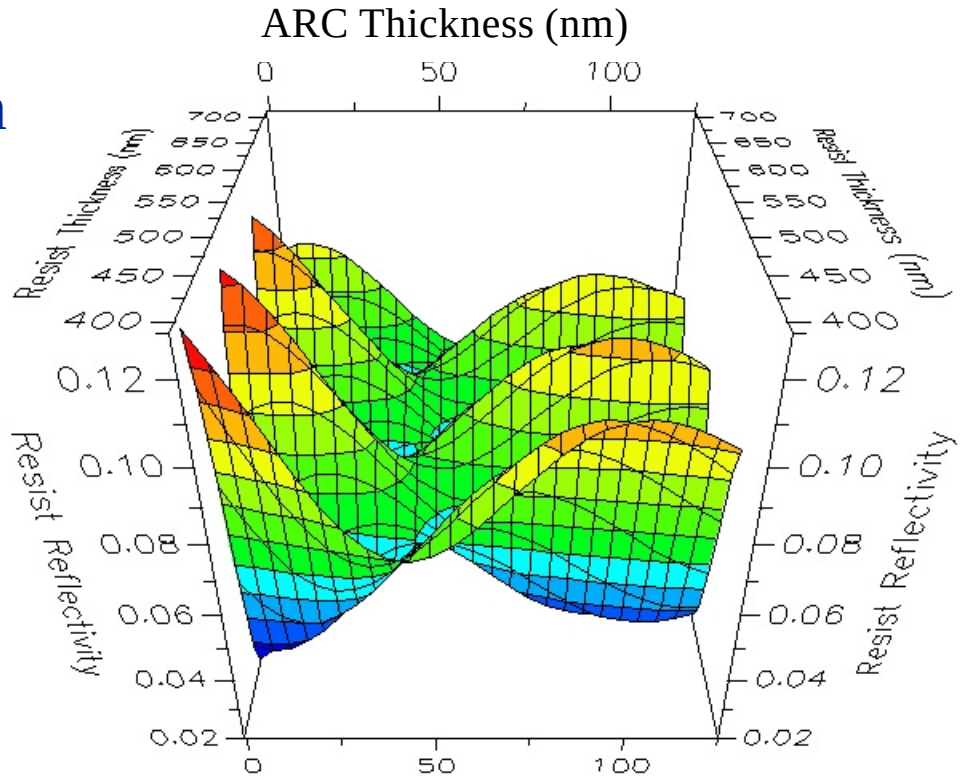
i120/ 0.20 N/ ARC/ PEB



PFI88A3/ 0.23 N/ ARC/ PEB

I-line ARC and Resist Thickness Optimization

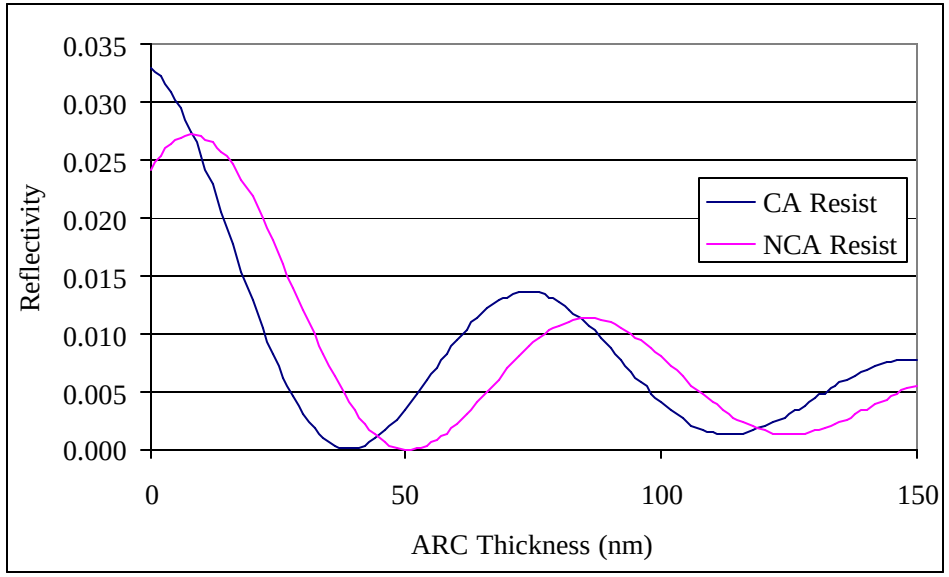
- Simultaneous optimization of both ARC and resist thickness is required



Organic ARCs for 257 nm Laser Photomask Fabrication

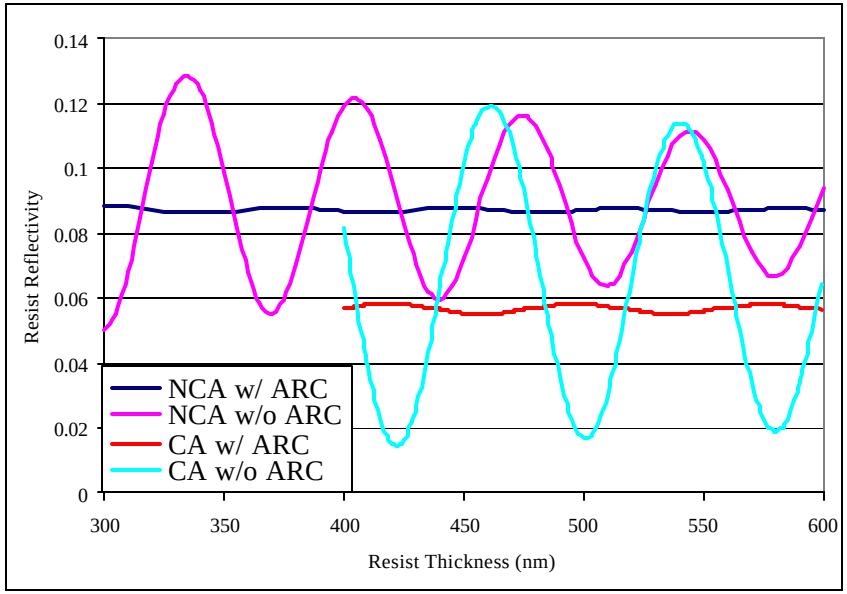
- NCA resist shows similar substrate reflectivity to I-line resists

- CA resist shows more reflectivity at substrate interface than NCA resist
  - High contrast of CA resists will increase impact of standing waves

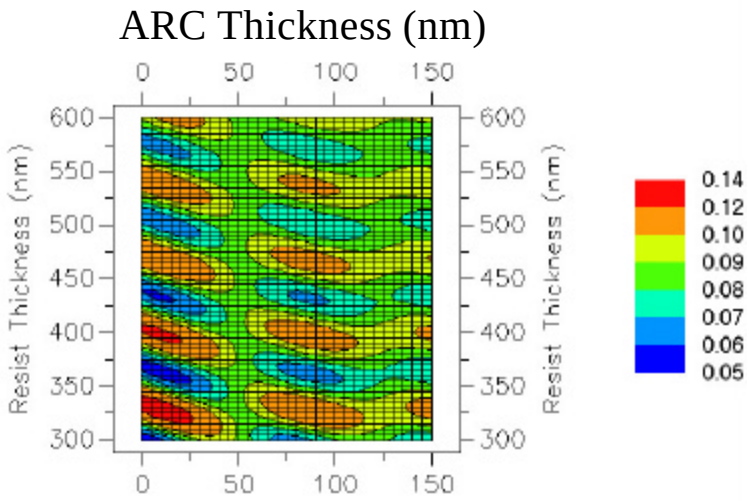


ARC Thickness and Swing Curves at 257 nm

- CA resists display more severe swing ratio without an ARC



- Simultaneous ARC and resist thickness optimization required



Conclusions

- High resolution I-line resists resolve larger standing waves
- Photomask resist profiles have been successfully imaged on organic ARCs to minimize reflections
- High contrast resists (CA resists) for 257 nm optical pattern generators may require ARCs
- ARC and resist thickness need to be simultaneously optimized to reduce reflections

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