Non-Chemically Amplified Resists for Mask Fabrication using 257 nm Optical Pattern Generation: Part II

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257 nm Optical Pattern Generation

- Resolution
  - OPC
  - Pattern fidelity
  - Phase shifting
- Non-chemically amplified resist
  - Post coat delay
  - Post exposure delay
  - No PEB facilities
  - Cluster tool mini environment

Non Chemically Amplified Resist Development at 257 nm

Goal: Determine the optimum 2,1,4 DNQ/ novolak resist formulation for 257 nm

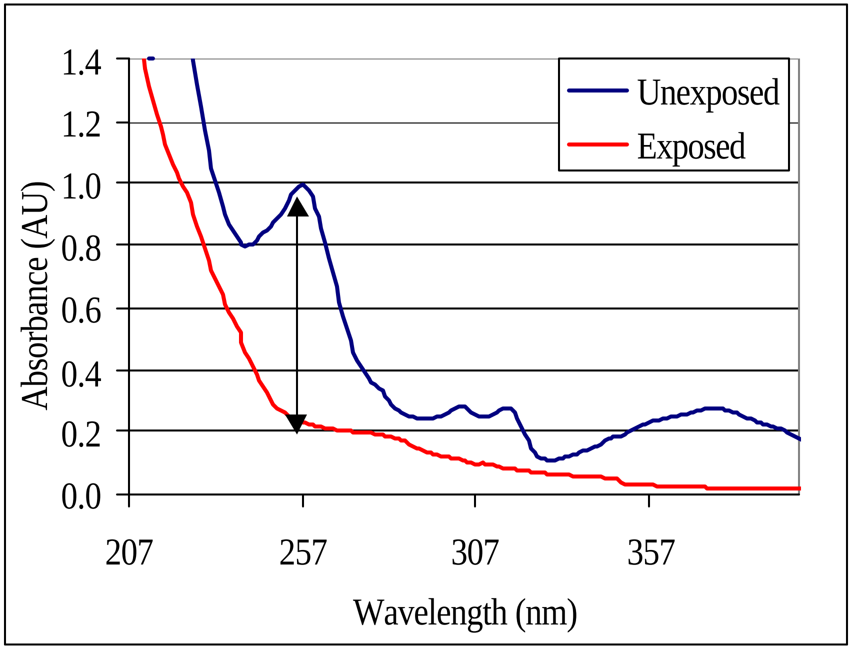
Method: Model exposure and dissolution parameters as a function of PAC and developer concentration

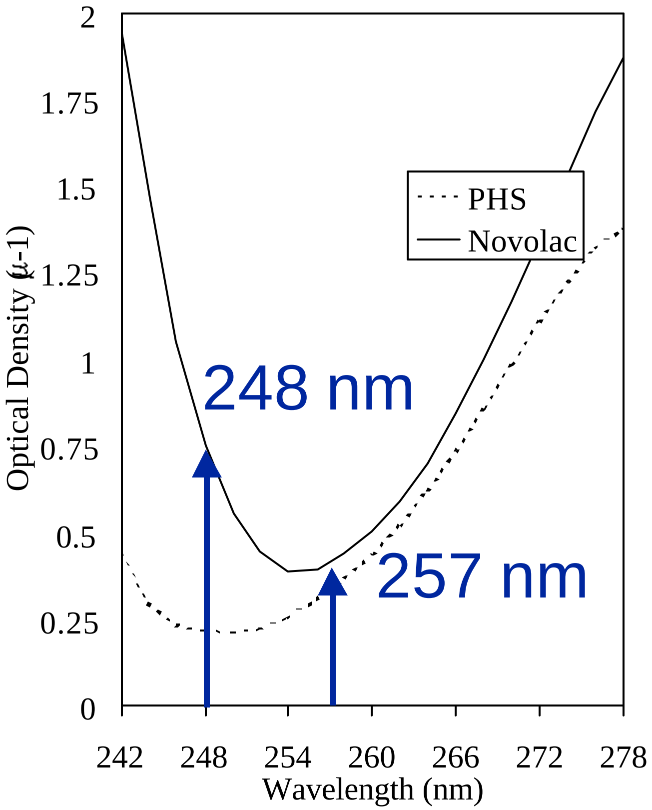
Verification: Compare simulated and imaged profiles

257 nm Resist Materials

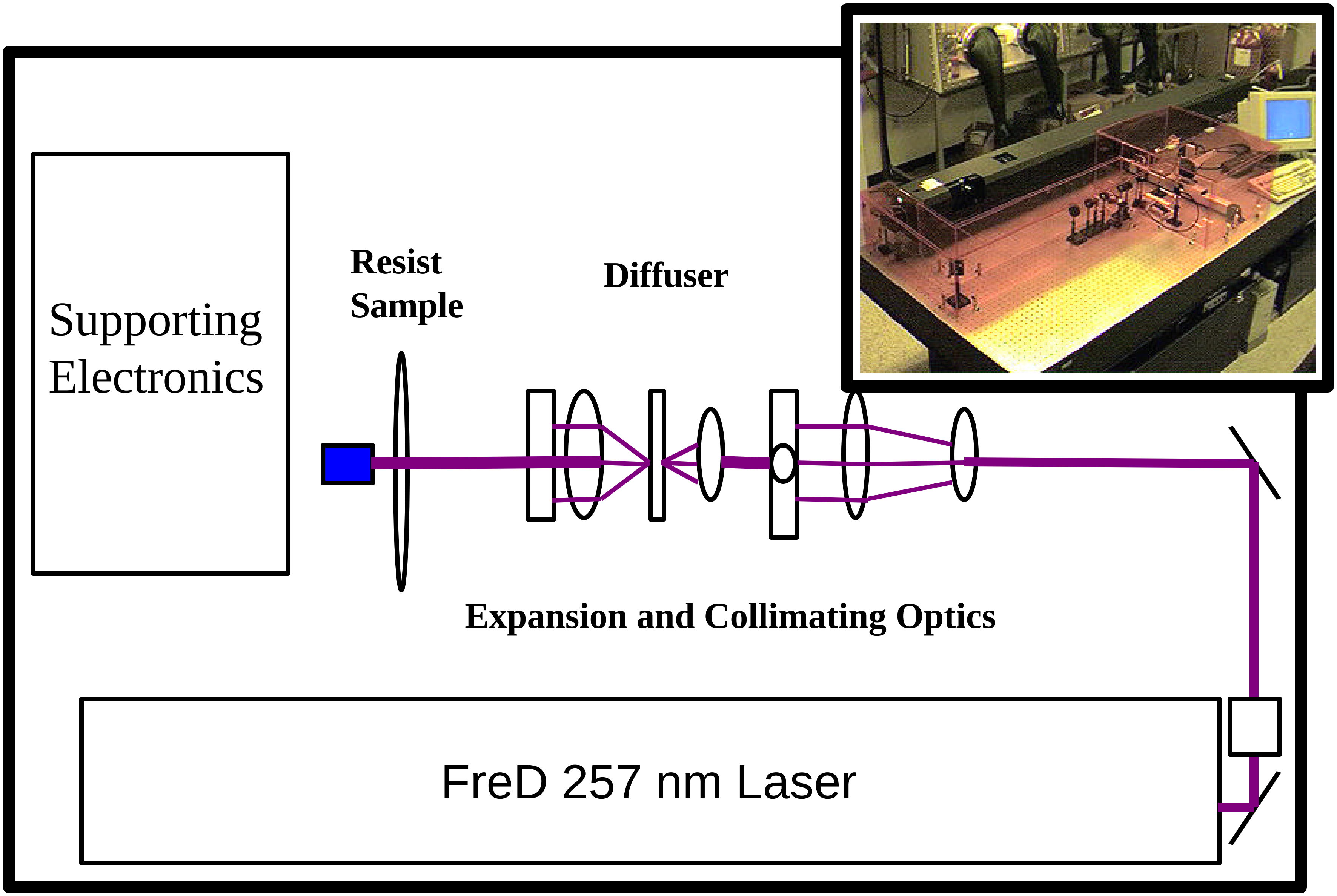
Optimum bleaching of 2,1,4 DNQ occurs at 257 nm

Novolak has a transparency maximum at 257 nm





Photoresist Exposure Tool



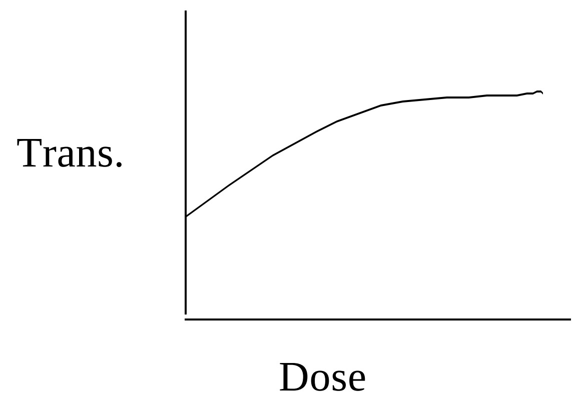
Exposure Parameters at 257 nm

- A = bleachable absorbance (μm^{-1})

$$A = \frac{4p(k_2 - k_1)}{l}$$

- B = unbleachable absorbance (μm^{-1})

$$B = \frac{4pk_1}{l}$$



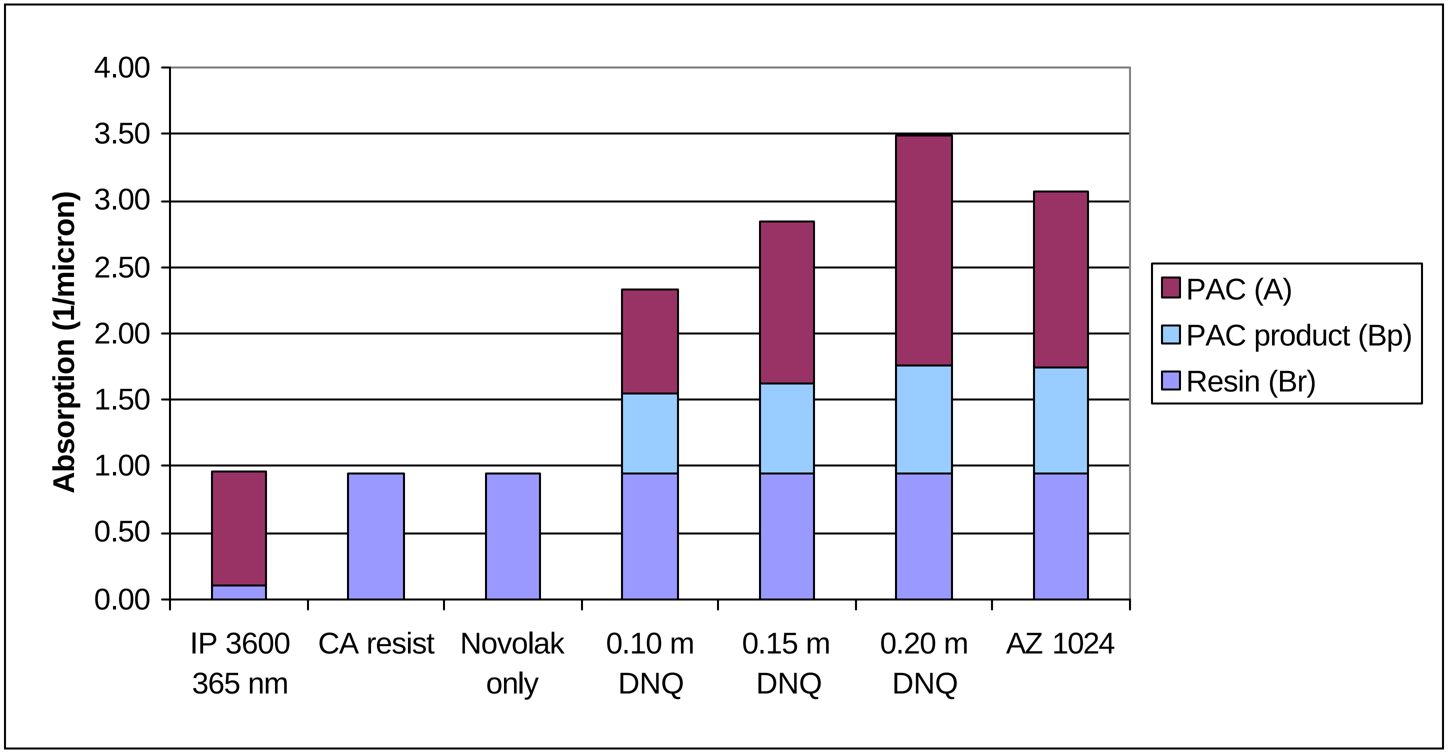
- C = rate constant of PAC conversion (cm^2/mJ)

$$C = \left(\frac{A+B}{A}\right)\left(\frac{1}{T(0)\{1-T(0)\}}\right)\left(\frac{dT(0)}{dE}\right)$$

k_1 = exposed complex index of refraction
k_2 = unexposed complex index of refraction

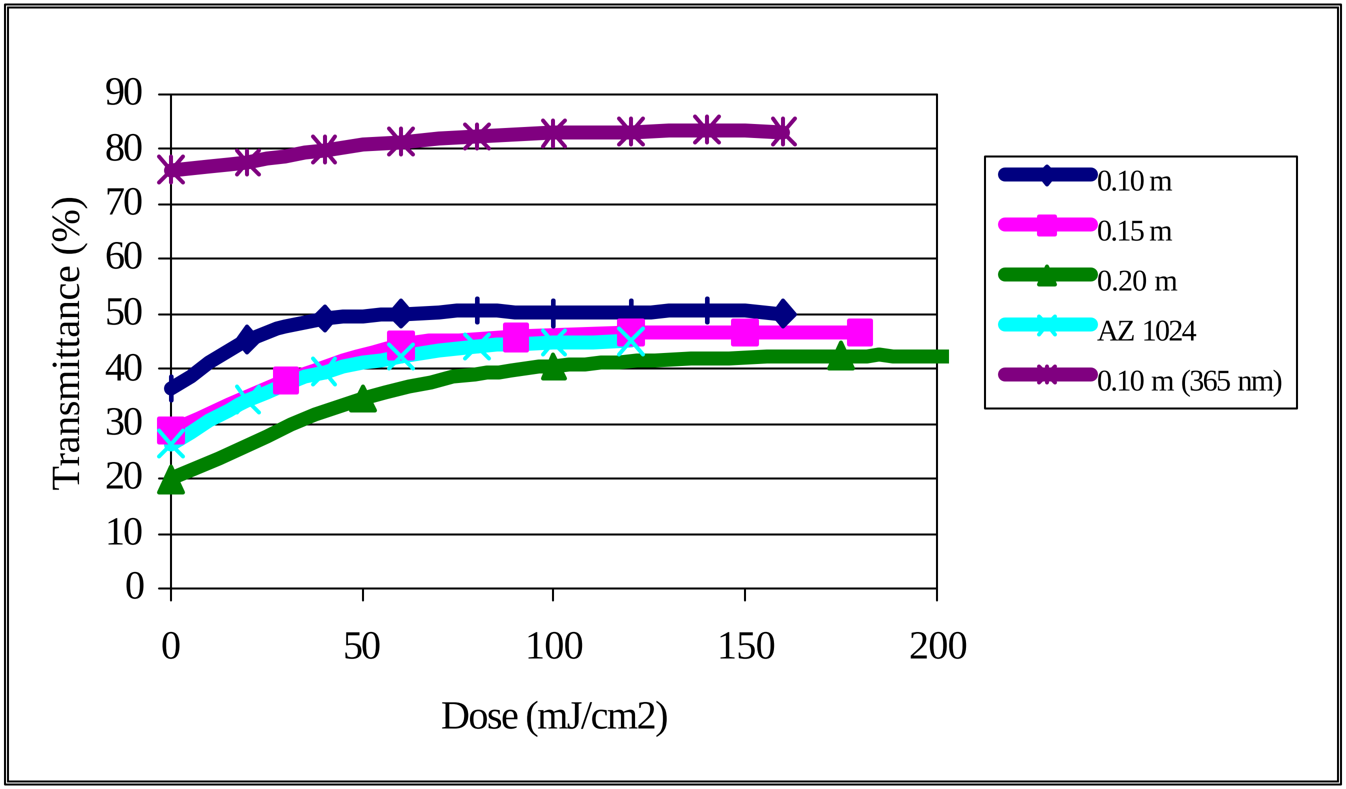
Dill Exposure Parameters

- Higher PAC concentration increases the absorbance as well as increases the level of bleaching at 257 nm
- CA resists have less absorbance than NCA resists at 257 nm



PAC Bleaching Kinetics

- 2,1,4 DNQ bleaches with a high photospeed
- Exposure rate constant (C) equals 0.048 cm^2/mJ at 257 nm and 0.02 cm^2/mJ at 365 nm



Photospeed/ Quantum Efficiency Analysis

Photospeed is 2.7 x greater at 257 nm than 365 nm due to the 2.7 x increase in the molar absorptivity

$$C(\lambda) = \frac{\phi_T a_m(\lambda)\lambda}{N_A hc}$$

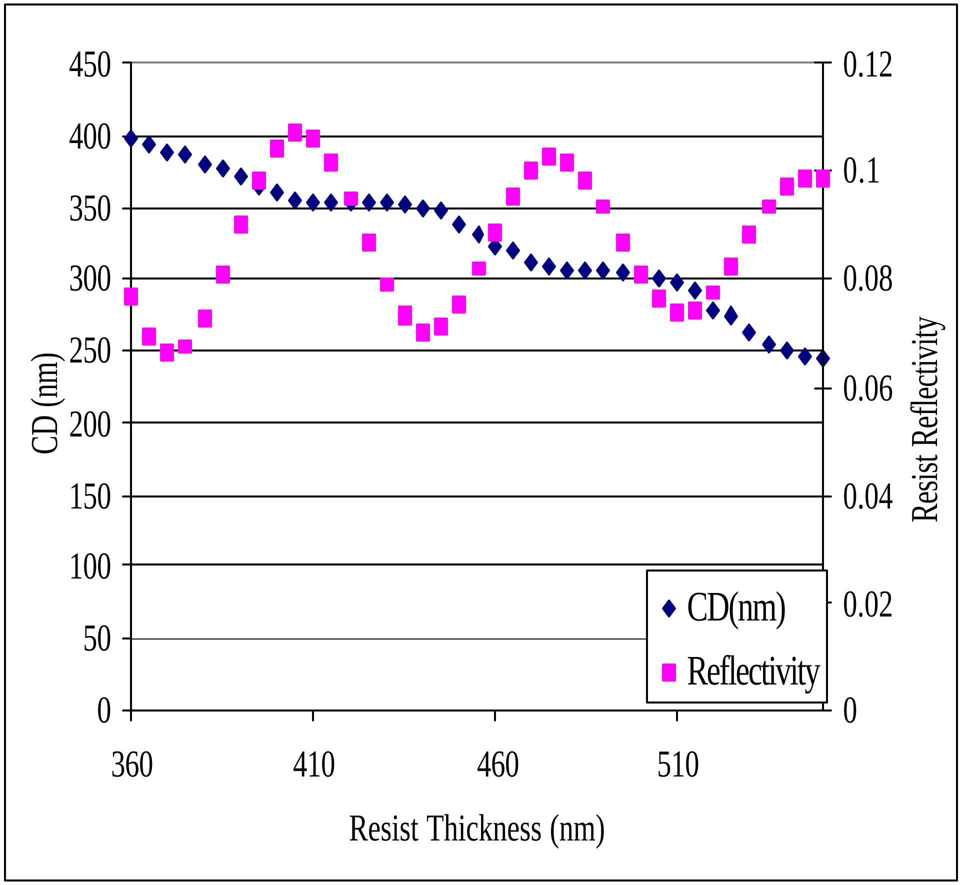
wavelength (nm)	**Dill C (1/μm)**	**Molar Absorptivity (m2/mole)**	**Quantum Efficiency**
257	0.056	5513	0.47
365	0.021	2010	0.34

C = kinetic rate constant (J/m^2)
ϕ_T = quantum efficiency
a_m = molar absorptivity (m^2/mole)
λ = wavelength of light (m)

N_A = Avogadro's number (6.02 x 10^{23} molecules/mole)
h = Plank's constant (6.63 x 10^{-34} Js)
c = speed of light (3 x 10^8 m/s)

Simulated CD Swing Curve

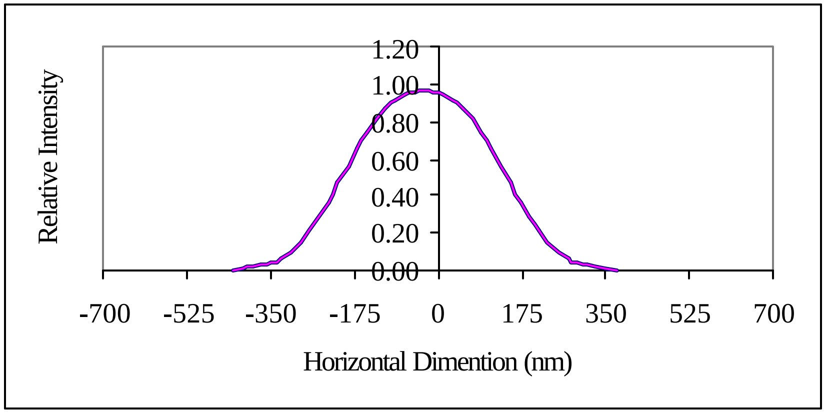
- Plateau in CD swing curve occurs for strongly absorbing resists
- Results from balance in reflectivity and thickness influence
- 30 nm thickness range of flat CD's allows increased CD uniformity



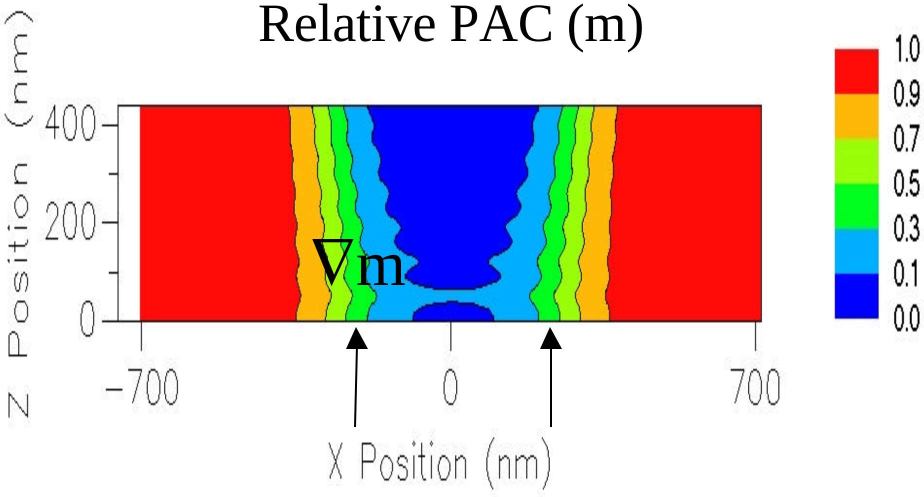
0.15m/ 0.23N/ PEB

Resist Formulation through Simulation

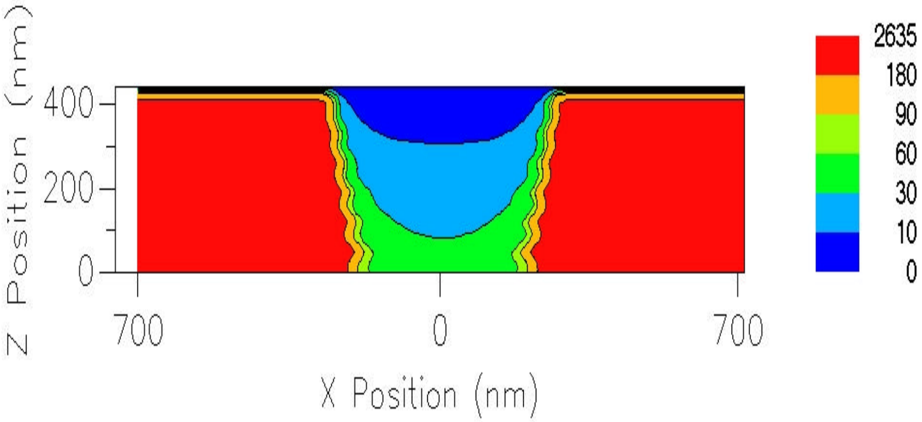
Aerial Image



Relative PAC (m)

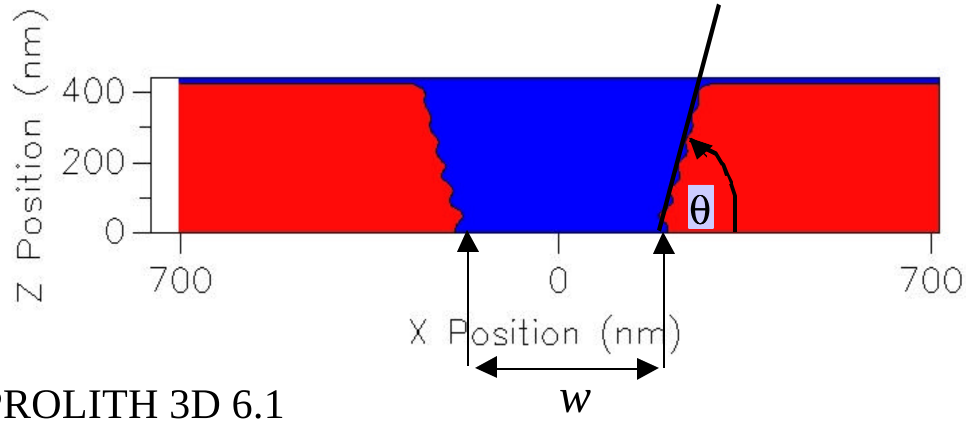


Develop Time Contours



Output: Resist Profile

Sidewall angle θ and feature size *w*



Simulation with PROLITH 3D 6.1

Lithographic Imaging Equation

High Resolution Imaging

1. Image Transfer
Maximize the PAC gradient 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

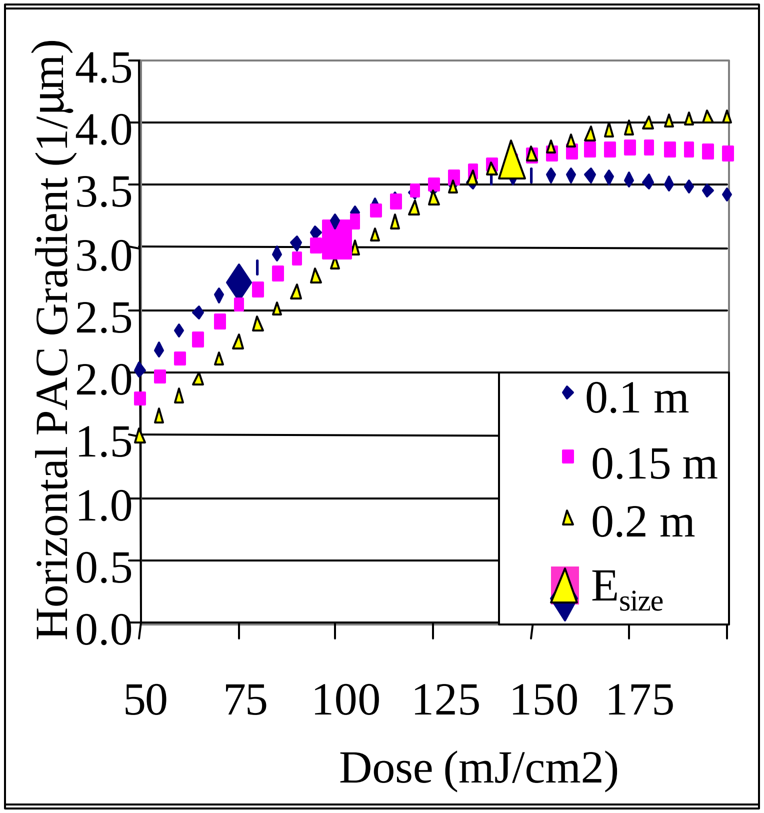
$$\left.\frac{dR}{dx}\right|_{x^*} = g_R \frac{dm}{dx}$$

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

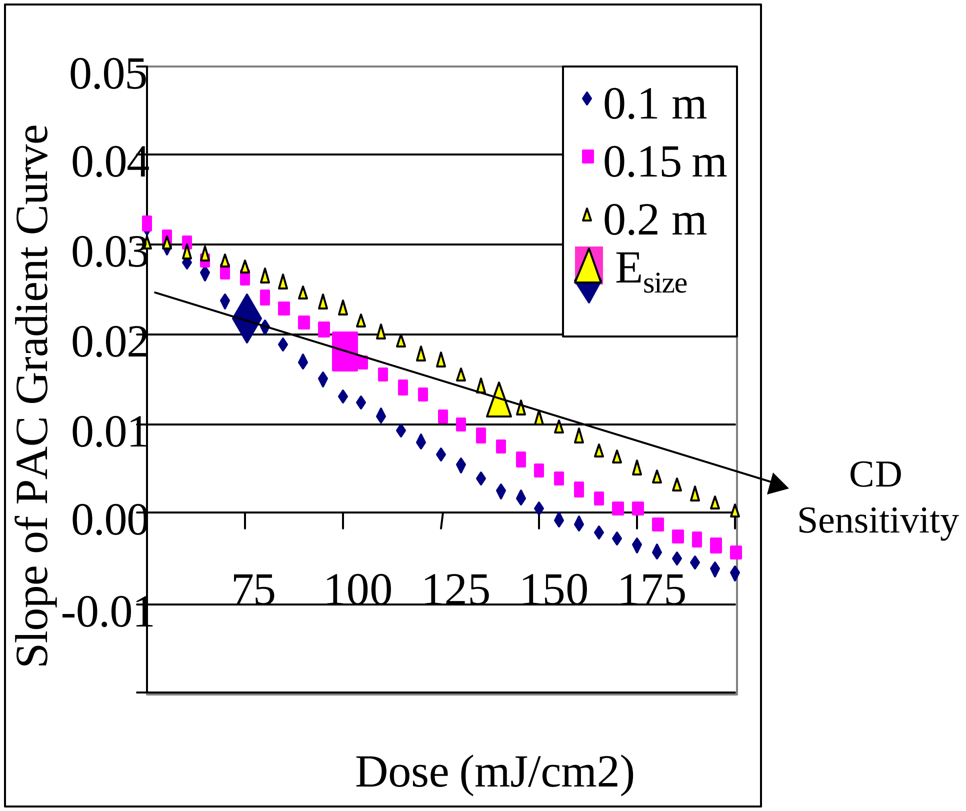
R = Dissolution rate
x = Horizontal position
m = Relative PAC Concentration
g_R = Resist contrast
x^* = Nominal edge of resist feature

Image Transfer Analysis Through Formulation Space

Horizontal PAC Gradient at dose to size increases with PAC loading



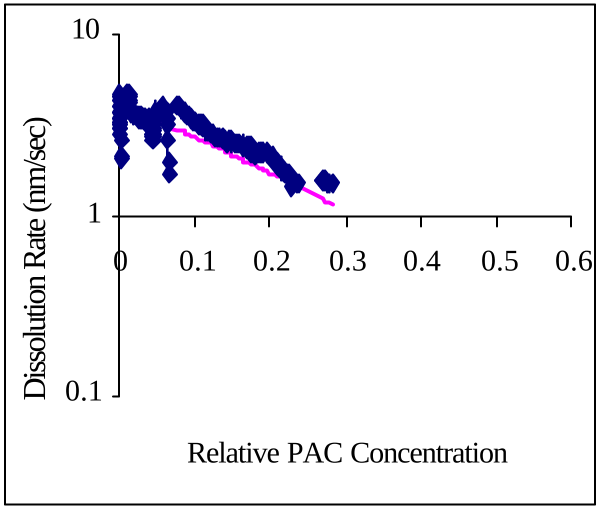
CD Sensitivity is proportional to the slope of the horizontal PAC gradient w.r.t. dose



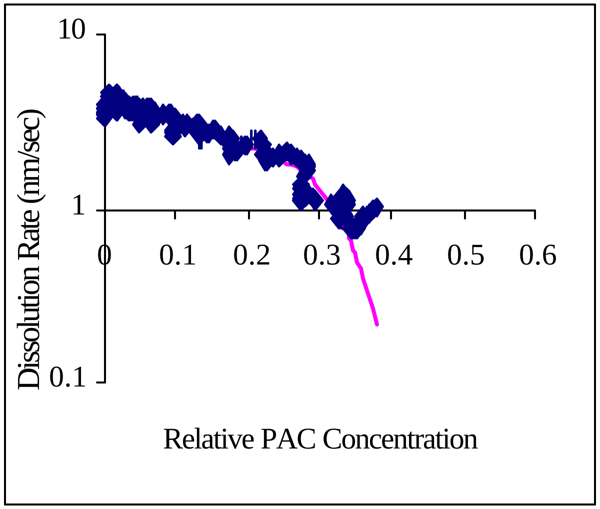
Contrast Increases with PAC Concentration

Low contrast **High contrast**

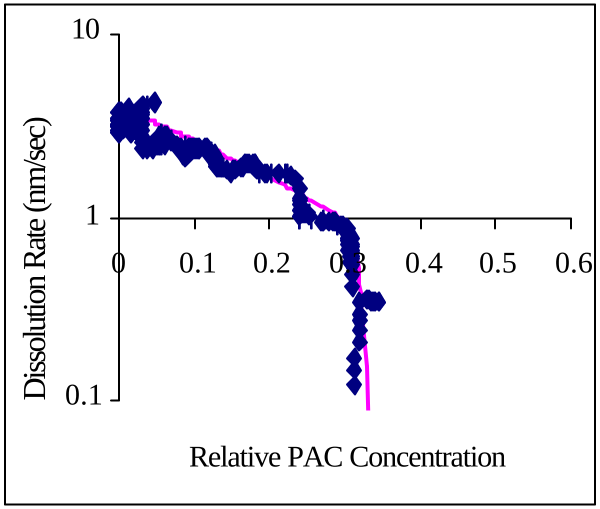
0.10 m 0.23N TMAH



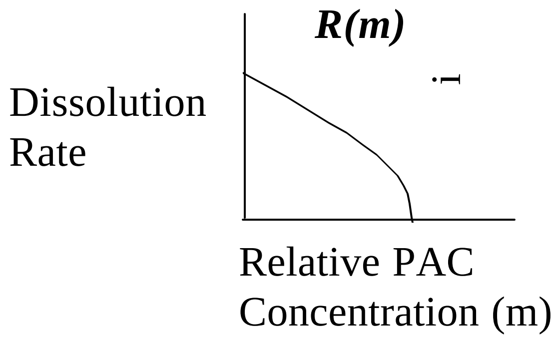
0.15 m 0.23N TMAH

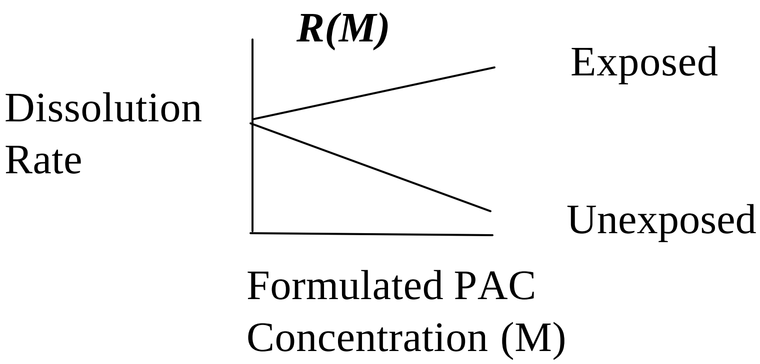


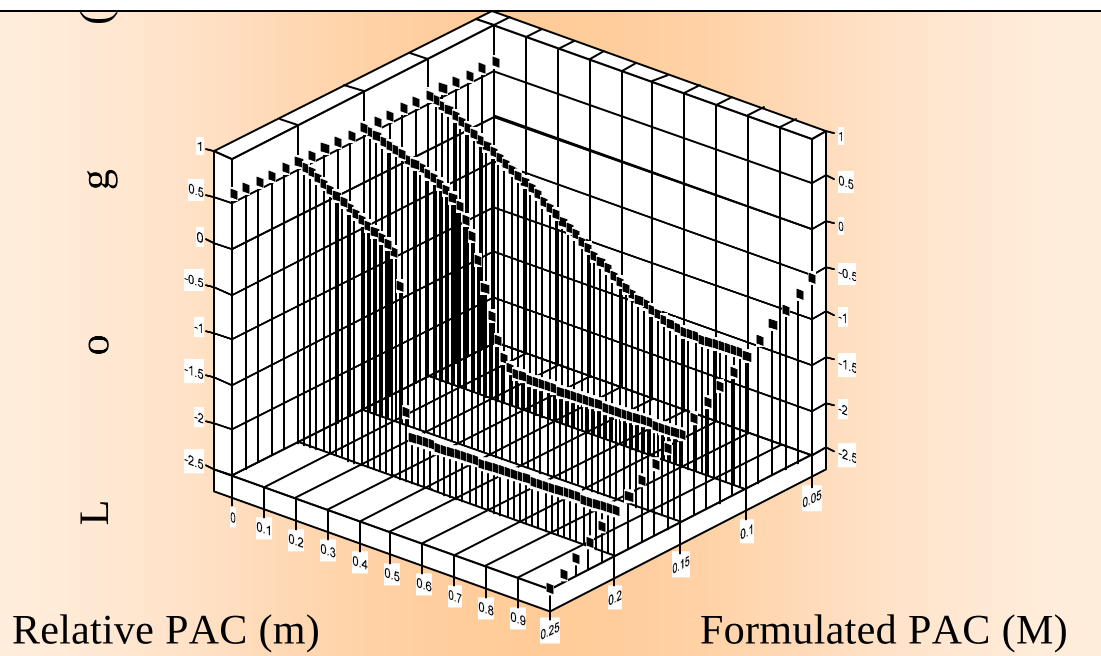
0.20 m 0.23N TMAH



Dissolution Model through Formulation Space R(m, M)

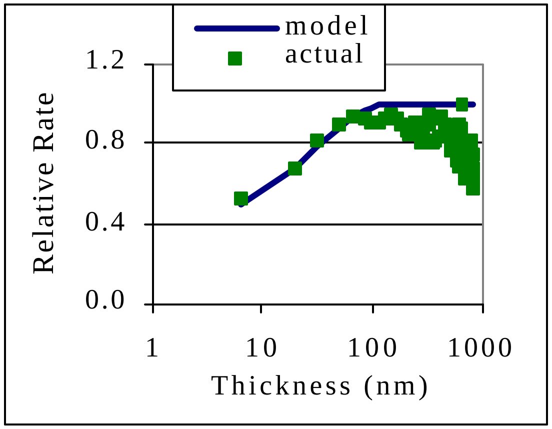




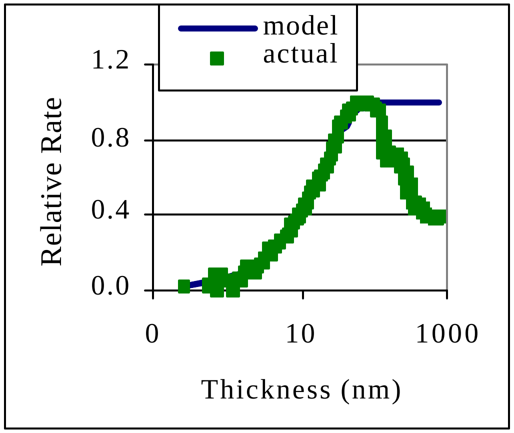


Surface Inhibition

Lower developer concentration increases surface inhibition

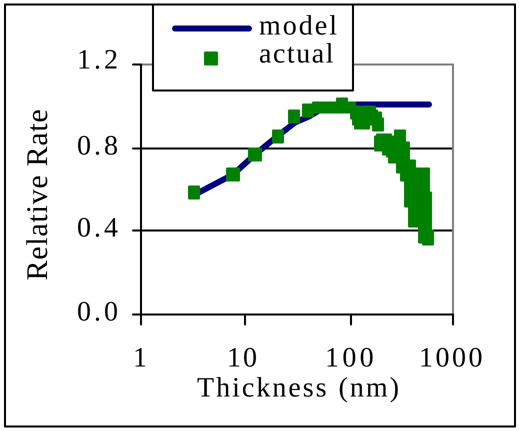


Resin/ 0.26N/ No PEB

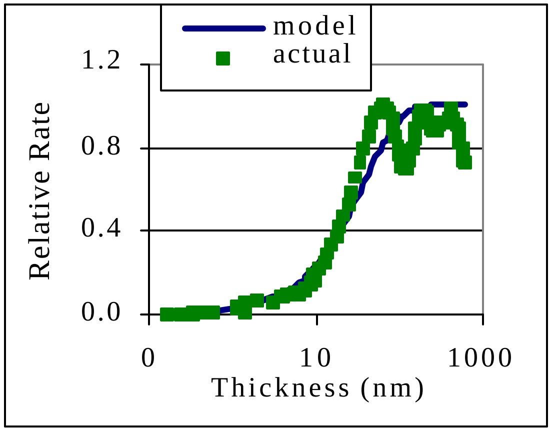


Resin/ 0.23N/ No PEB

Post-exposure bake increases surface inhibition



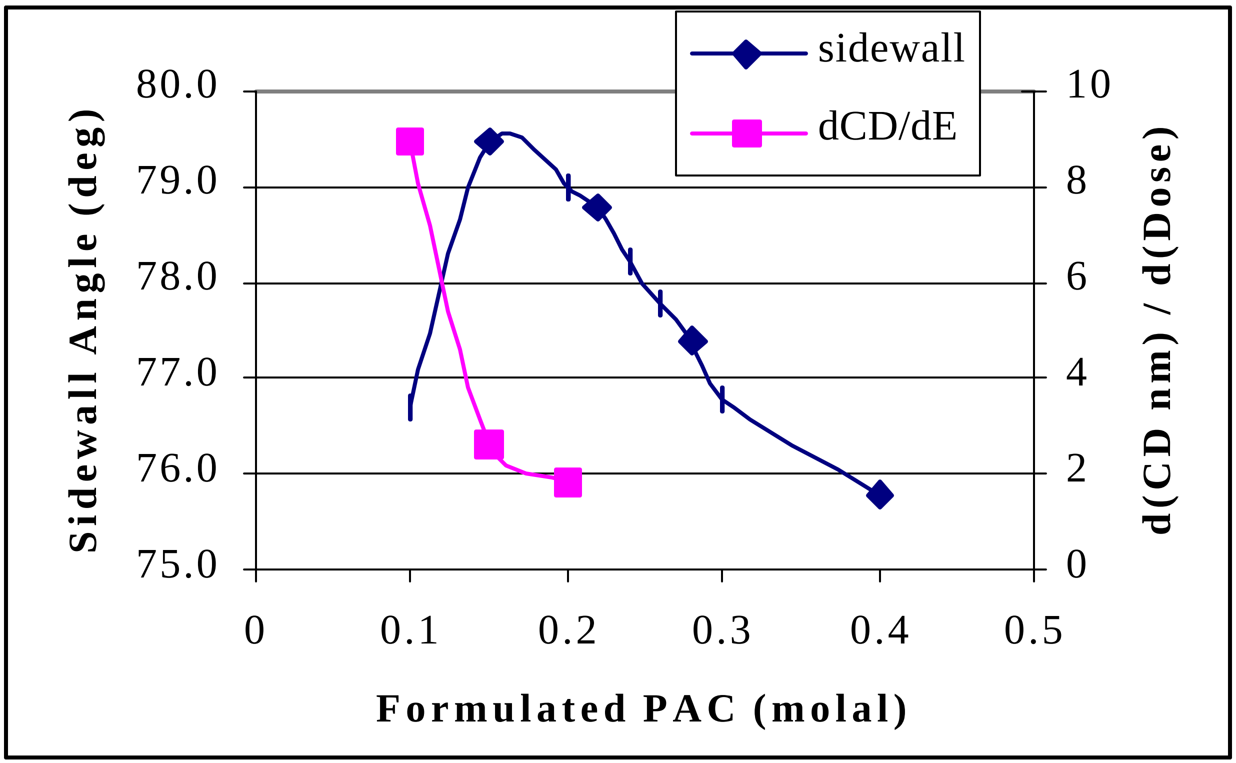
0.1 m/ 0.26N/ No PEB



0.1 m/ 0.26N/ PEB

Simulation based Formulation

Sidewall angle increases and the CD sensitivity to dose decreases with PAC concentration

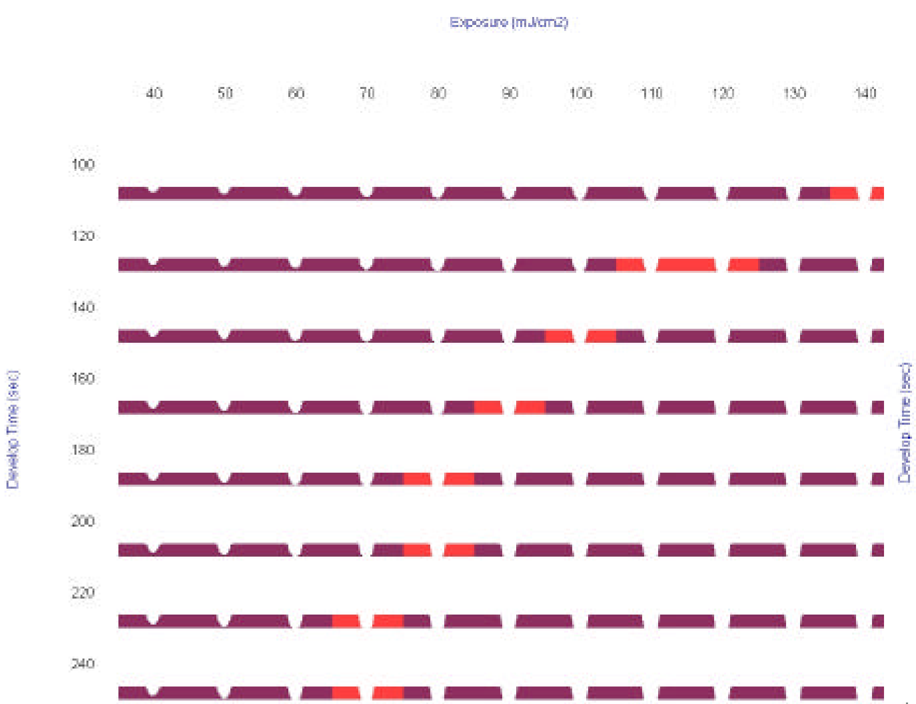


Isolated 0.35 micron spaces/ 0.15 m/ 300 second PAB at 90 C/ 240 s dev. 0.23N TMAH

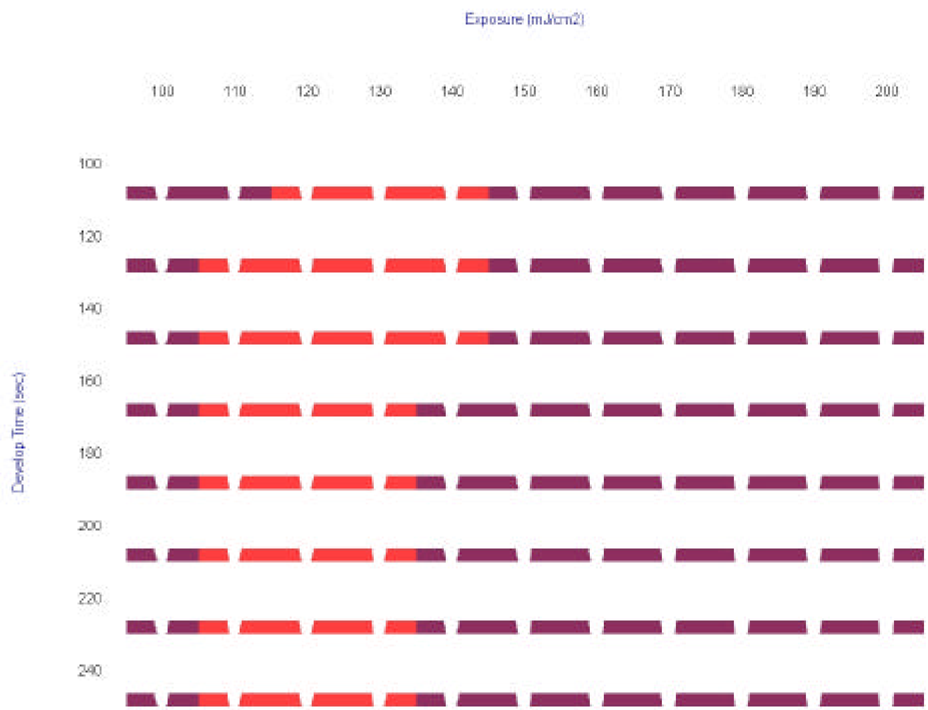
Simulated Exposure Latitude

- Increase in exposure latitude with PAC concentration

0.10 m PAC



0.20 m PAC

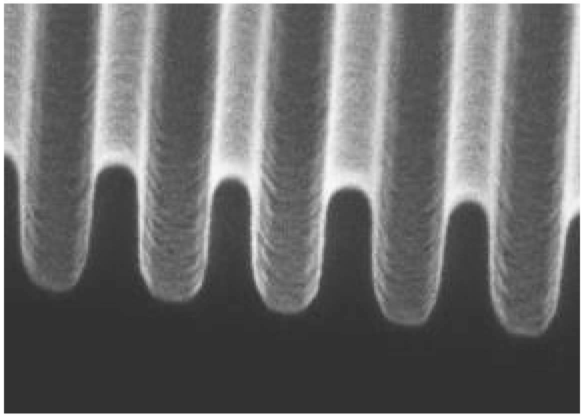
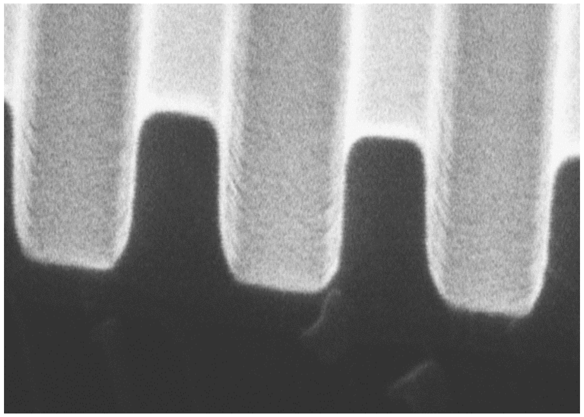


Isolated 0.35 micron spaces/ 300 second PAB at 90 C/ 240 s dev. 0.23N TMAH/ 75+ degree sidewall angle and +/- 10% linewidth range

Preliminary Manufacturing Trials

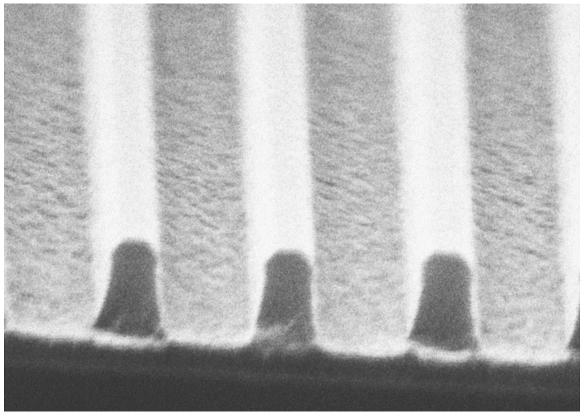
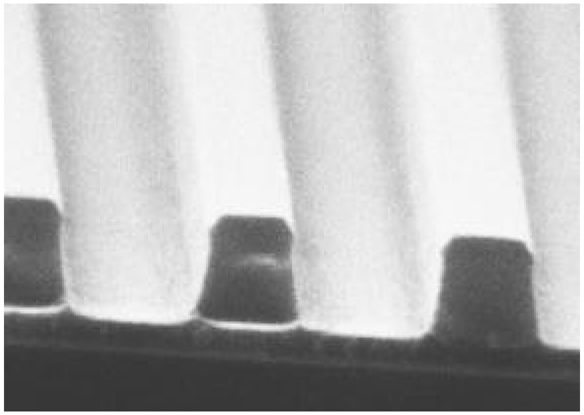
0.3 micron | 0.5 micron

0.10 m

300 s 0.26N TMAH NMD-W Developer, PEB 110°C /420 s

0.15 m

300 s 0.23N TMAH NMD-W Developer, PEB 110°C /420 s

Future

- Complete process trials with 0.1 m and 0.15 m formulations
  - Compare simulations to process trial results
  - Reformulate to maximize process latitude
  - Complete linearity, process latitude and uniformity studies

- Study CA resist in mask making environment
  - Latent image stability
  - Coated resist stability

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