Optical Lithography Simulation and Photoresist Optimization for Photomask Fabrication

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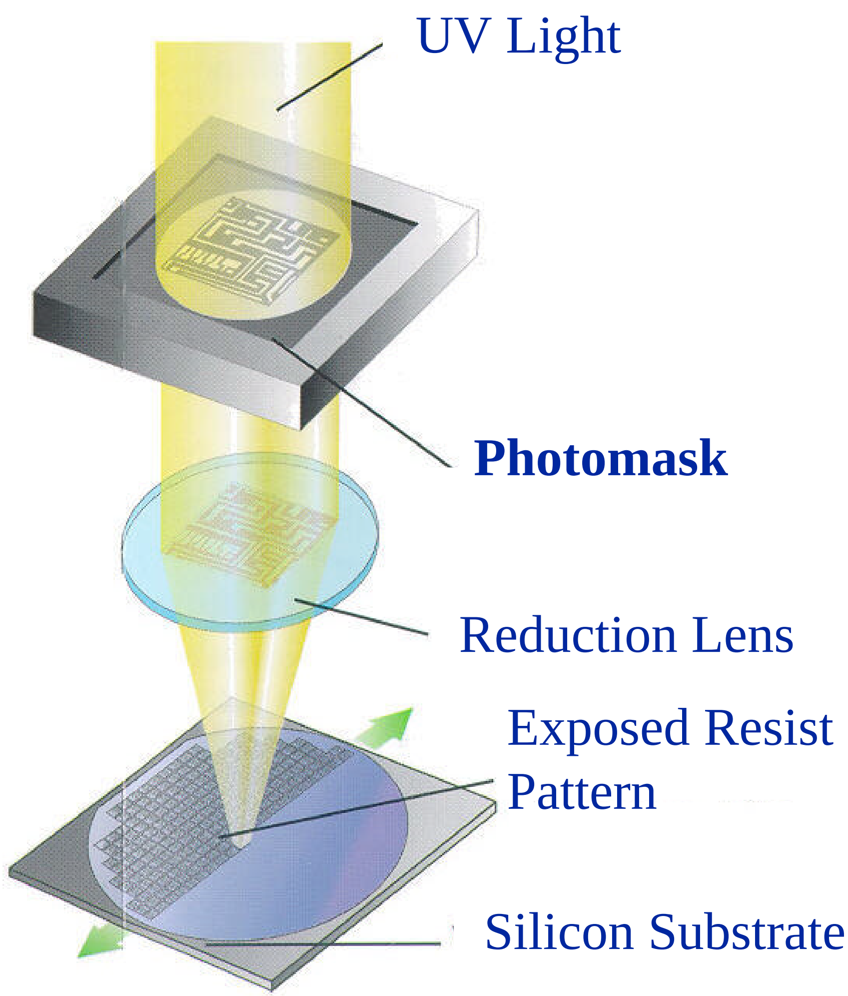
Photomask Fabrication Optimization



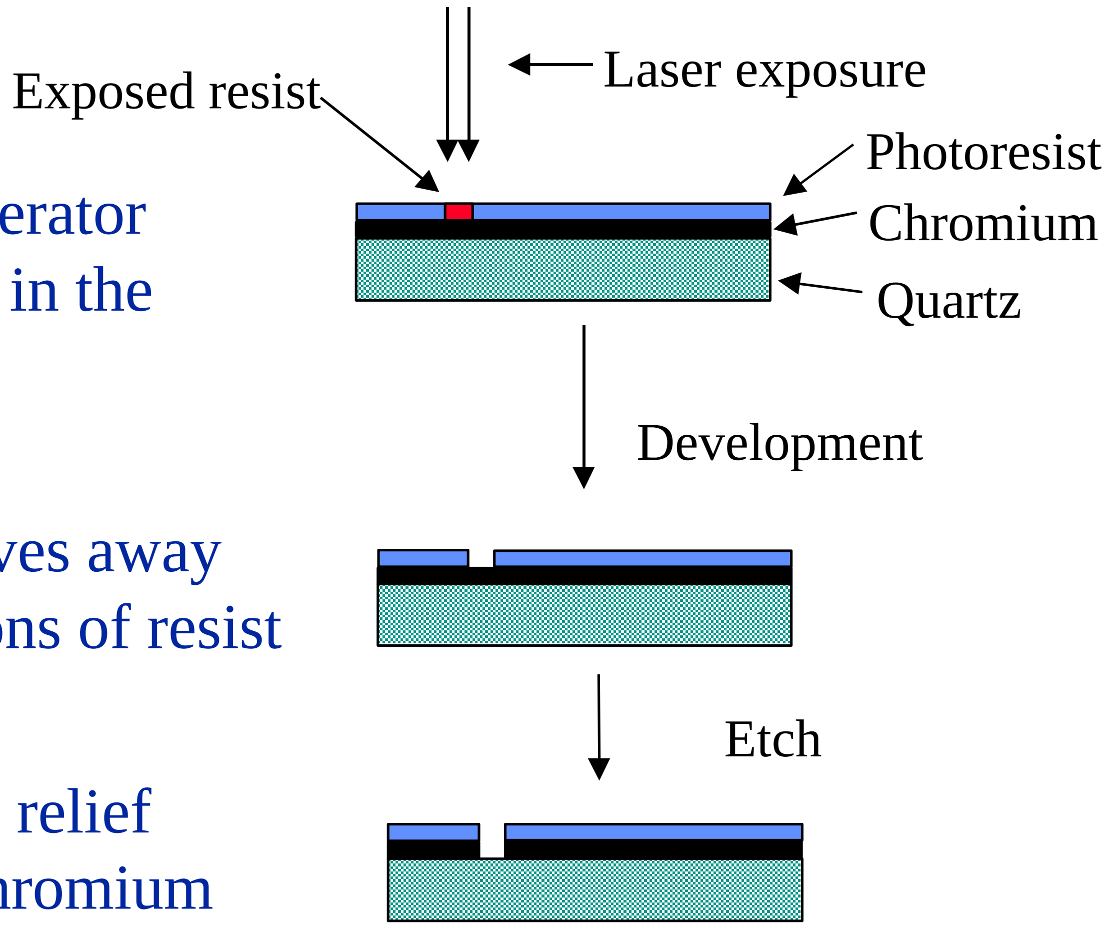
Goal: Improve resolution and process latitude for photomask fabrication using laser pattern generators

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

Results: Sub **0.30** μm resist features on photomask substrates

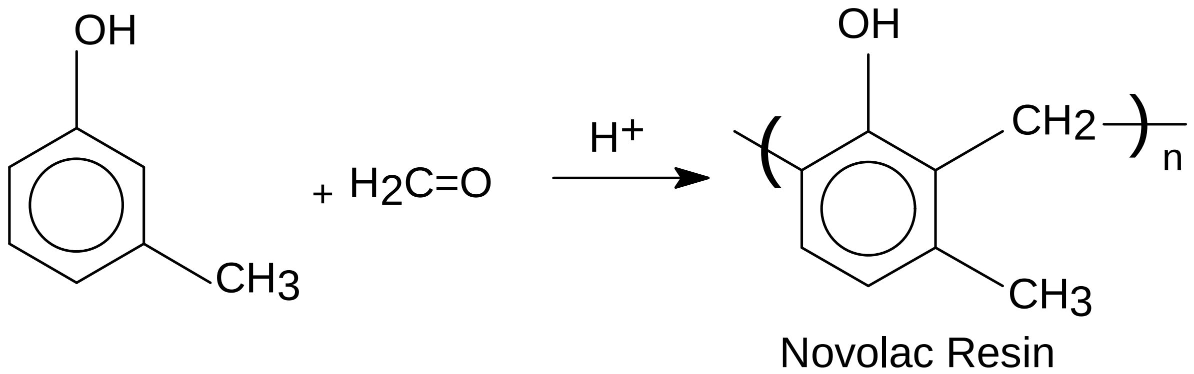
Photomask Fabrication Process

- Laser pattern generator exposes a pattern in the resist
- Developer dissolves away the exposed regions of resist
- Etch transfers the relief image into the chromium

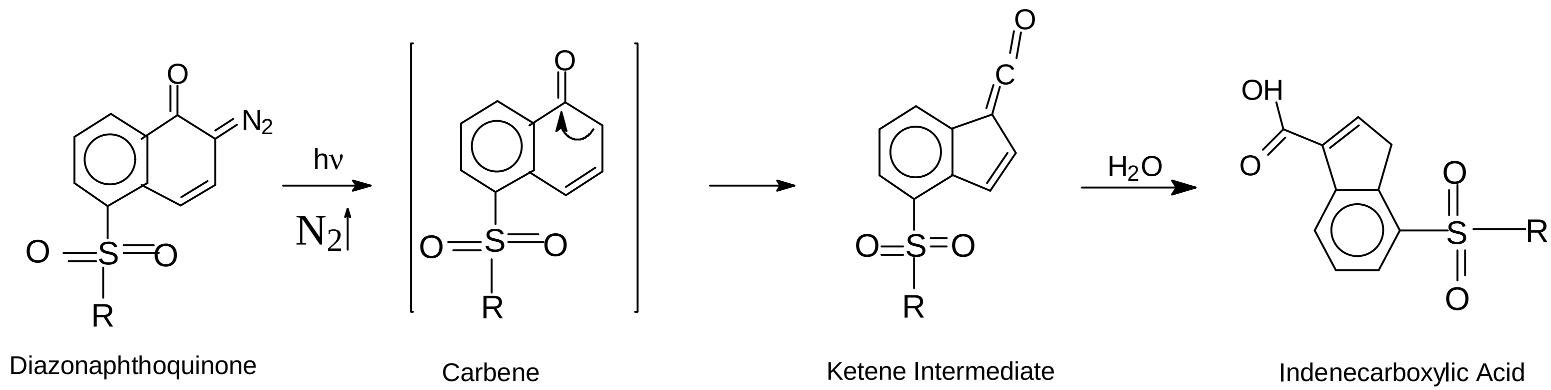


Novolac/DNQ Resist Chemistry

Photoresist polymer matrix synthesis



Photoactive Compound Photoreaction



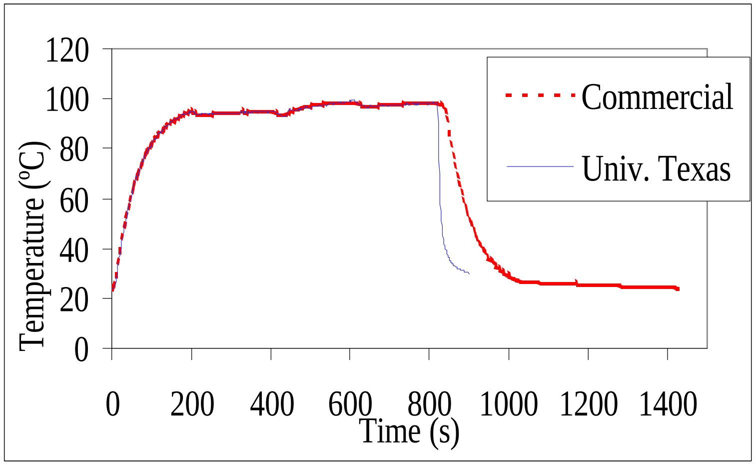
Photomask Resist Characterization

- I-line photoresists are coated on antireflective (AR3) substrates
- A hotplate was built to mimic the post application bake (PAB) of production photomasks
- Photokinetics measured through exposure parameters (Dill's A, B and C)
- Generate development rate function (R(m)) for resists

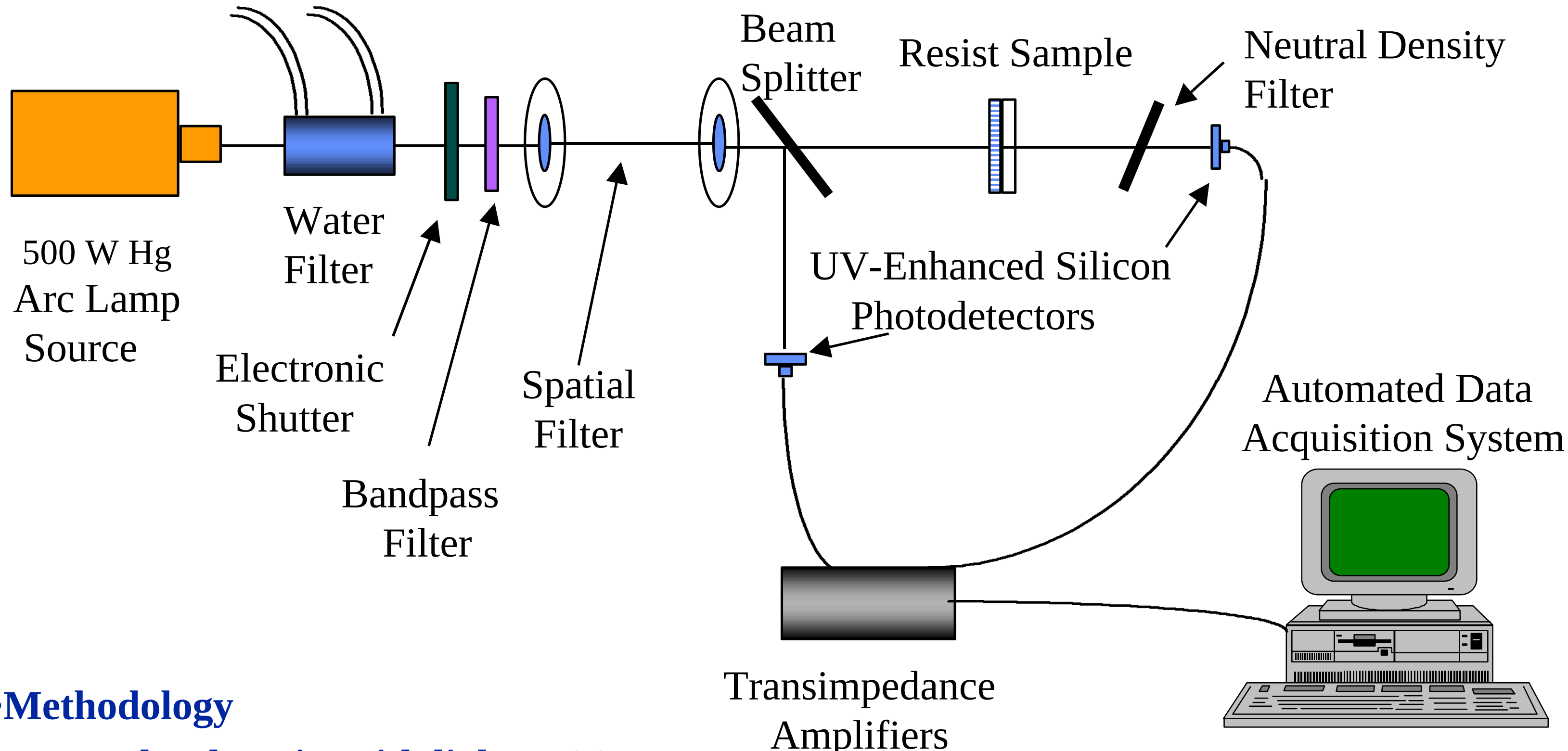
Coated Photomask Substrate

Resist	570 nm
Chromium Oxide	35 nm
Chromium	70 nm
Quartz	6.35 mm

Photomask Post Application Bake



Photokinetics Experiment



- **Methodology**
  - **Bleach resist with light at 365 nm**
  - **Photoactive compound undergoes chemical change**
  - **Photoproducts do not absorb light**
  - **Measure transmittance of resist film as a function of exposure dose**

Photoresist Reaction Kinetics

- **Dill parameters A, B and C**

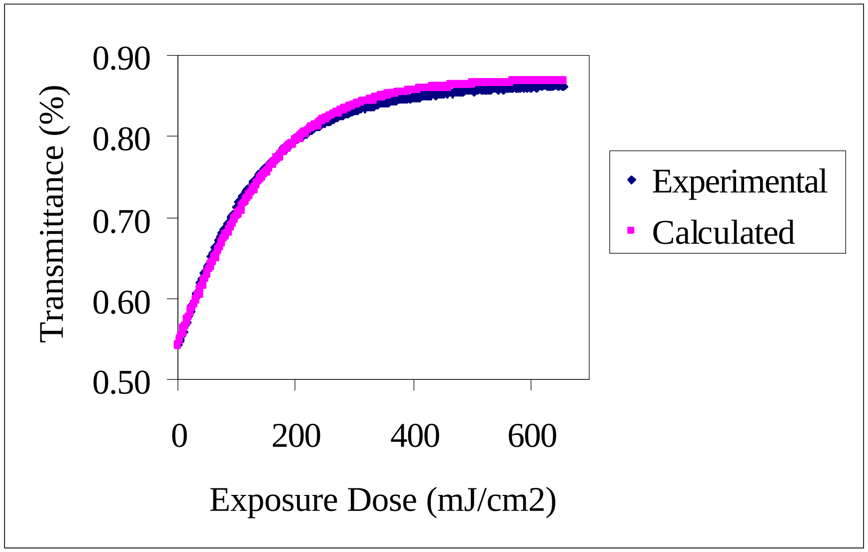
  A = bleachable component in resist

  B = non-bleachable component in resist

  C = rate of photochemical reaction in resist

- **Rigorous A,B and C Extraction**

  Simultaneous solution to the thin film optics and the Beer-Lambert equations

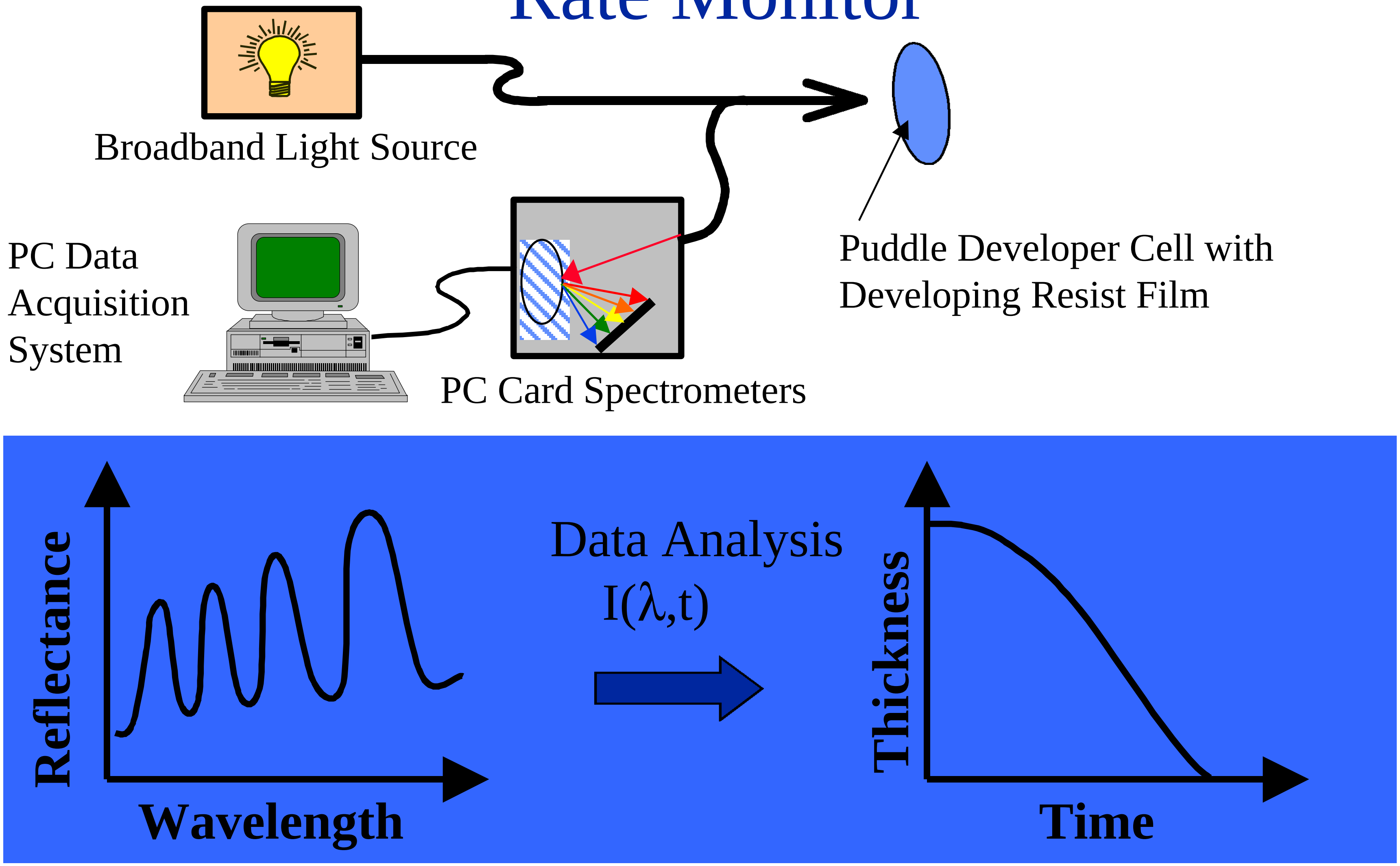


A = 0.808 1/mm

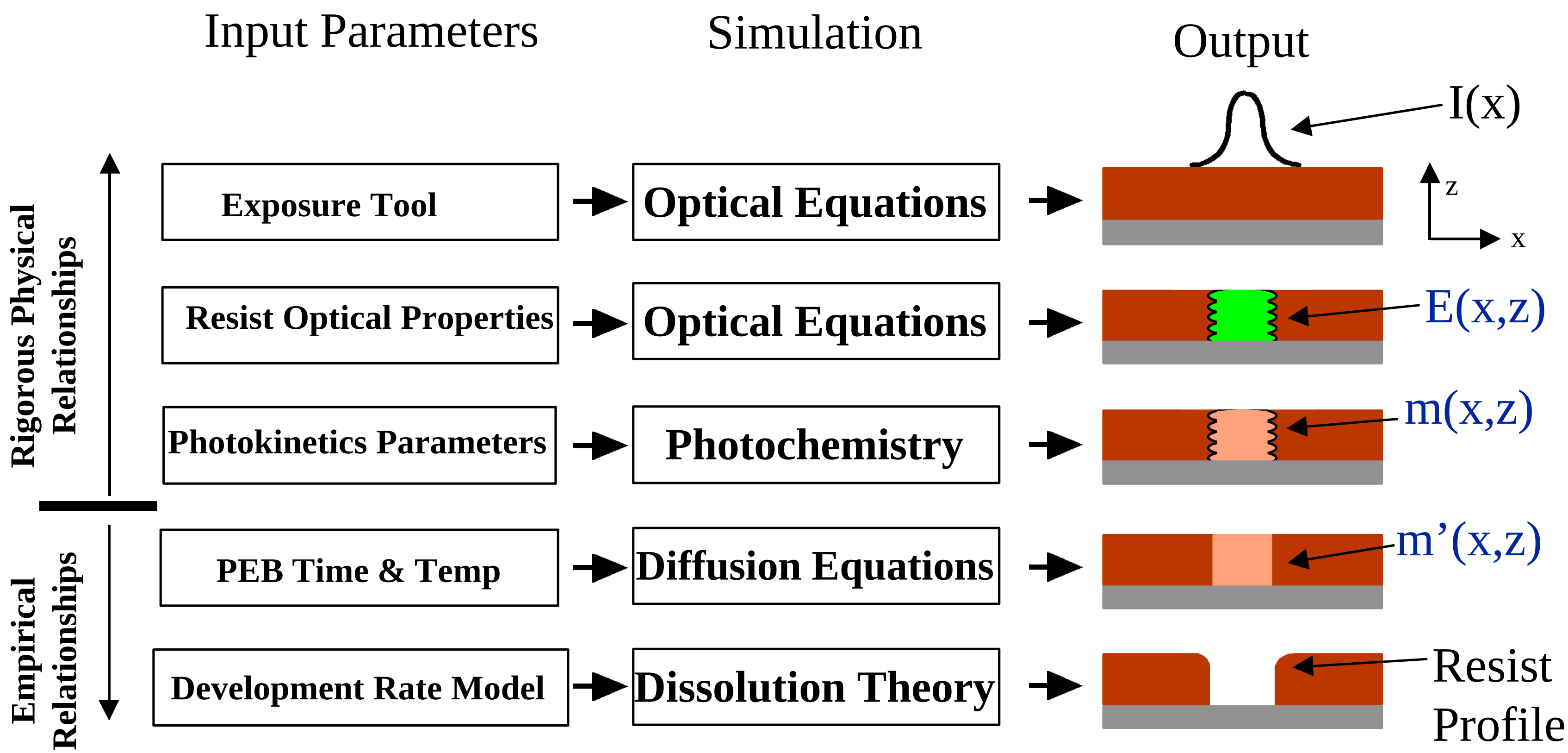
B = 0.086 1/mm

C = 0.010 cm²/mJ

Mult-Wavelength Dissolution Rate Monitor



Lithography Simulation



m(x,z) → relative photoactive compound concentration

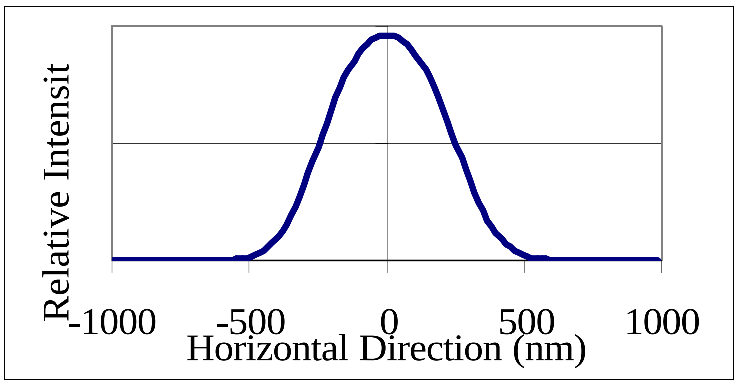
∇m → relative photoactive compound concentration gradient

E(x,z) → exposure energy distribution

Basis of Line Edge Optimization

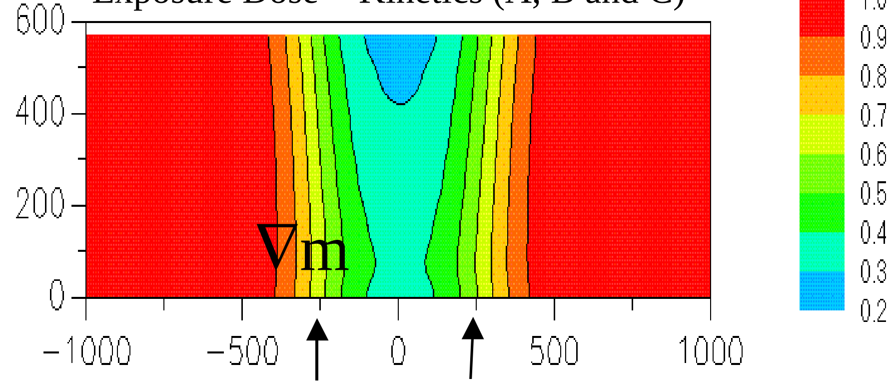
(0.5 µm Space in Resist)

Aerial Image

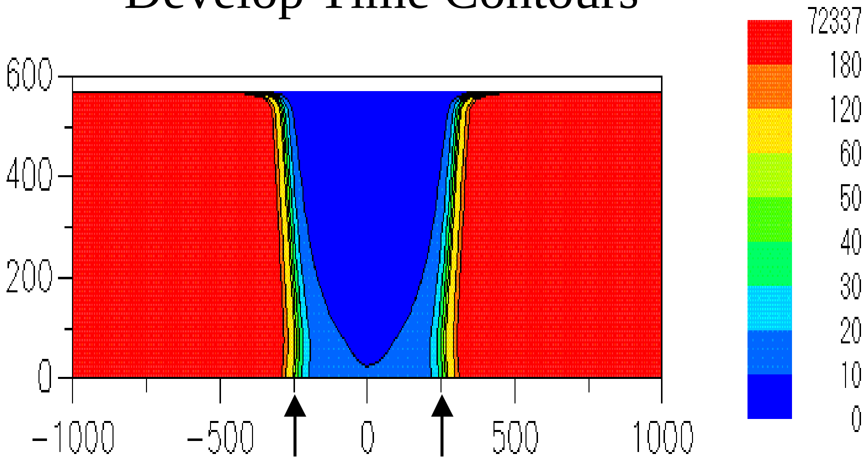


Relative PAC (m)

Exposure Dose + Kinetics (A, B and C)

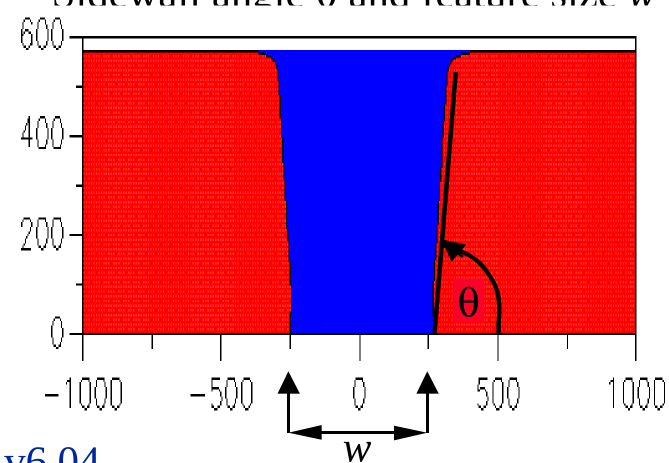


Develop Time Contours



Output: Resist Profile

Sidewall angle θ and feature size *w*



PROLITH 2 v6.04

Lithographic Imaging Equation

–Maximize the change in development rate at the edge of the resist feature

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

–Maximize ∇m = (dm/dx) through exposure dose and given aerial image

$$g_{TH} = \frac{dR}{dm}$$

–Adjust location of dissolution rate notch (g_{TH}) to the edge of the nominal resist edge (target m) with developer concentration

R = Dissolution rate
x = Horizontal position
m = Relative PAC Concentration
g_{TH} = Theoretical resist contrast
x^* = Nominal edge of resist feature

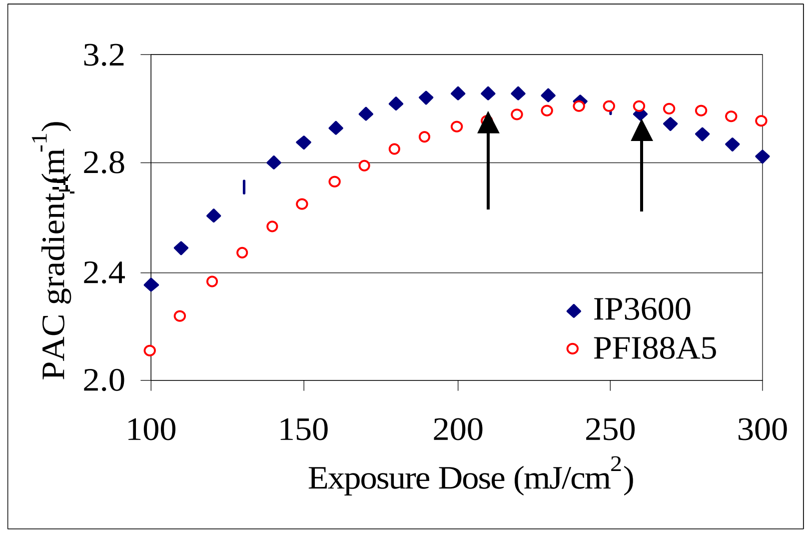
Simulated Optimum Exposure Dose for Photomask Lithography

Determined exposure dose that resulted in the **maximum ∇m**

Best Doses

IP3600 ≅ 210 mJ/cm^2

PFI88A5 ≅ 260 mJ/cm^2



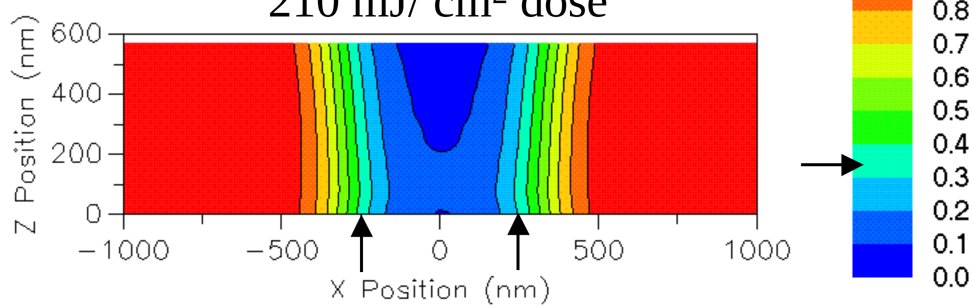
Determined m at the edge of the resist feature at the dose giving maximum ∇m

Target m

IP3600 = 0.3

PFI88A5 = 0.3

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



Optimal Development Rate Function (R(m))

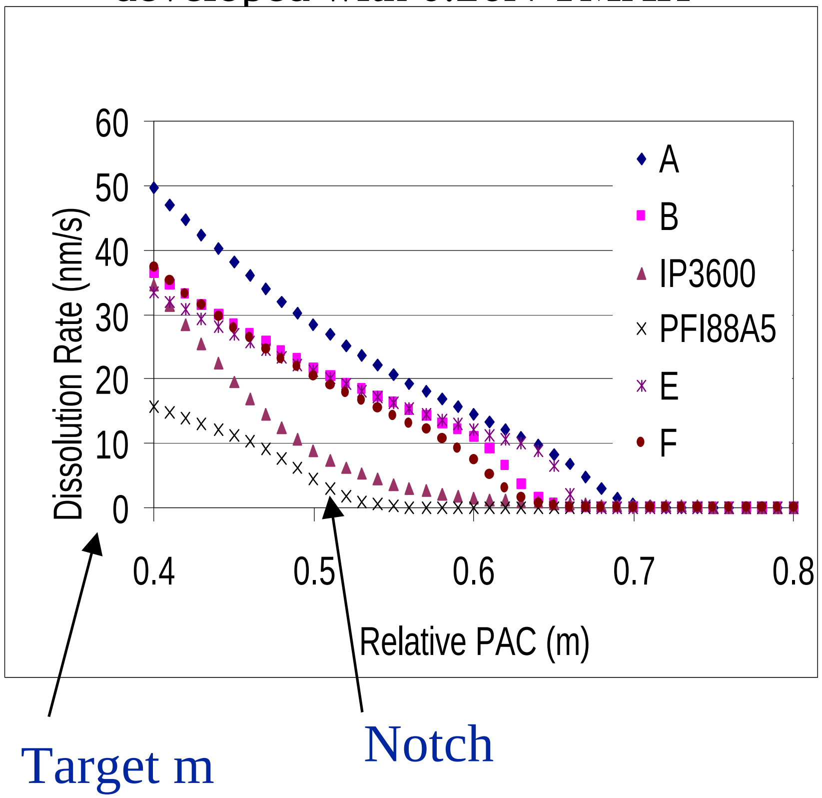
Optimal resist for mask lithography has…

Large dissolution Notch near Target m

Note:

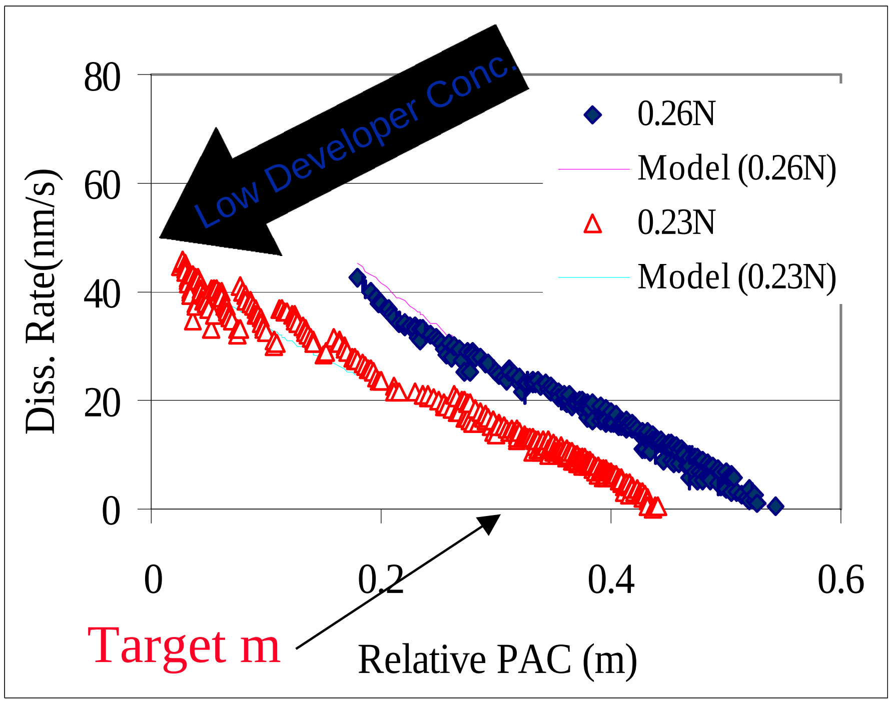
Resists A, B, PFI88A, E and F have large dissolution rate notches, however, the notches occur at high m. These resist have been optimized for high throughput on Si (high m ~ low dose).

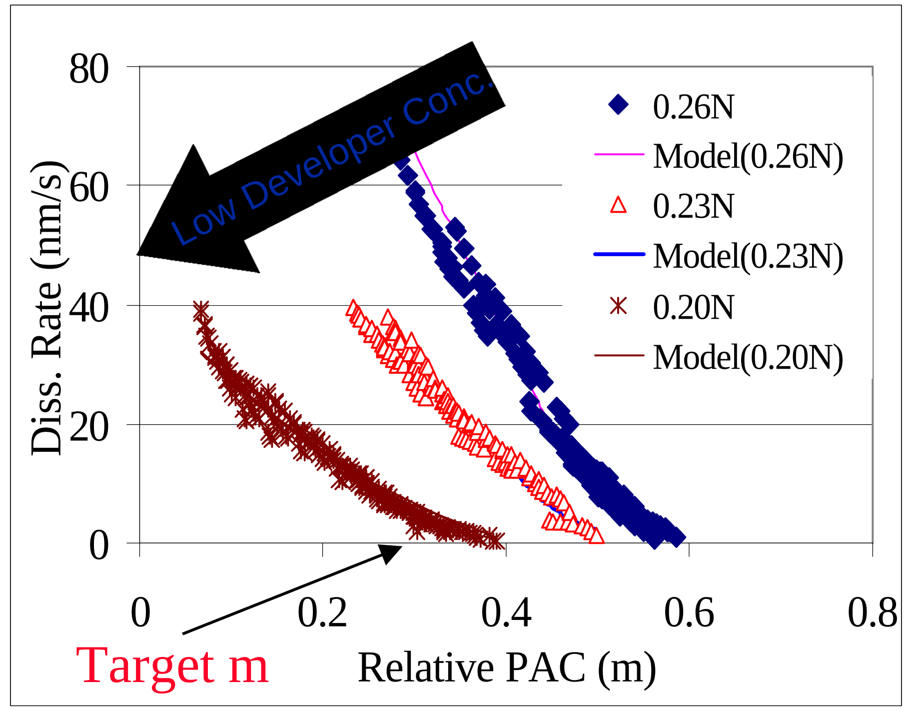
R(m) response of six I-line resists developed with 0.26N TMAH



Optimal Dissolution Notch Location

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



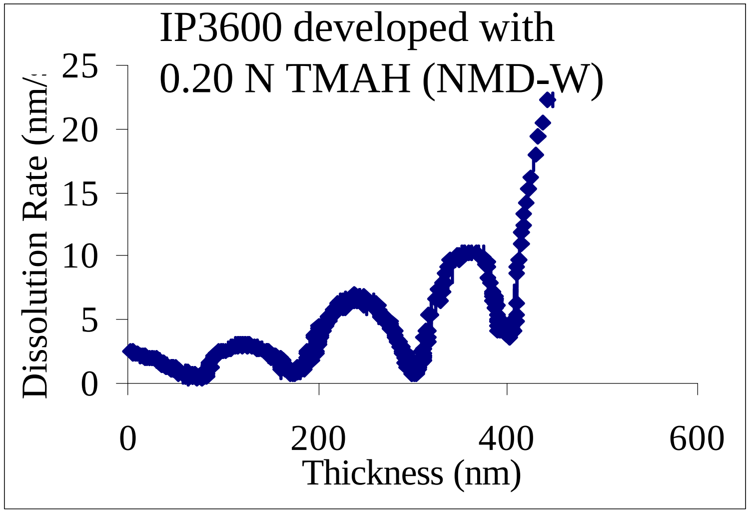


PFI88A5 Notch Location
m ≅ 0.45
(developed w/ 0.23 N TMAH)

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

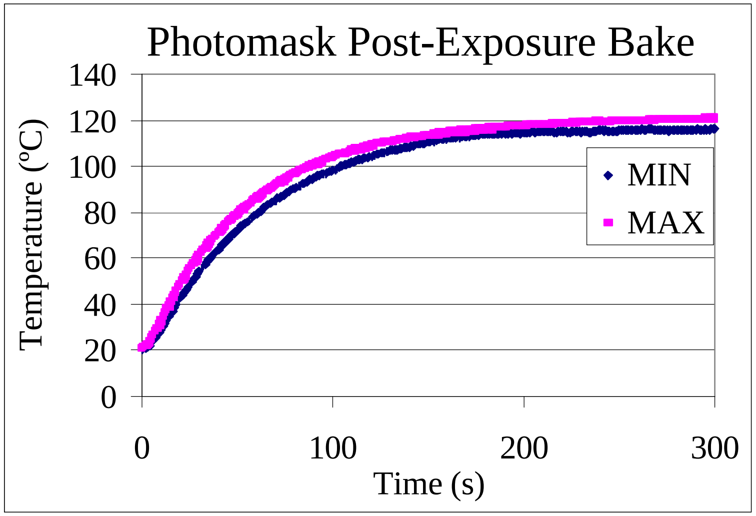
Standing Waves in Photomask Resists

- Lower developer concentration amplifies influence of standing waves



- Hotplate built that mimics the bake profile of photomask surface

- Developed post-exposure bake to minimize standing waves on photomasks



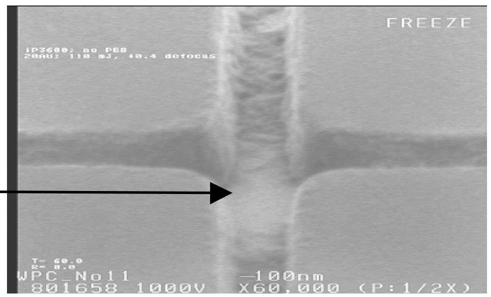
Photomask post-exposure bake improves process latitude

No PEB

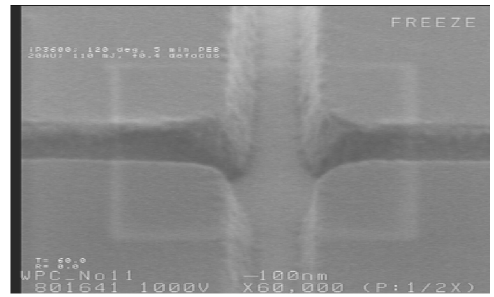
Focus

PEB

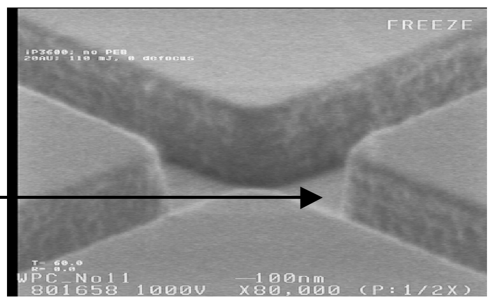
Scum



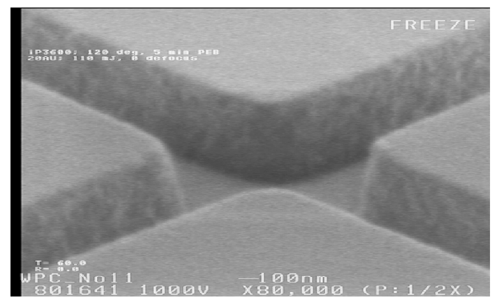
+0.4 μm



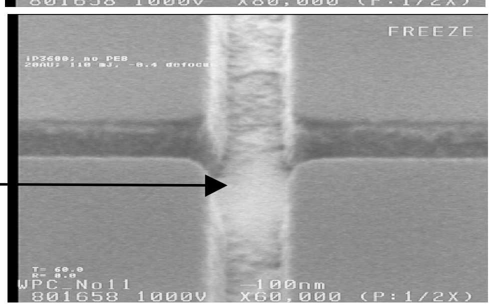
Standing Waves



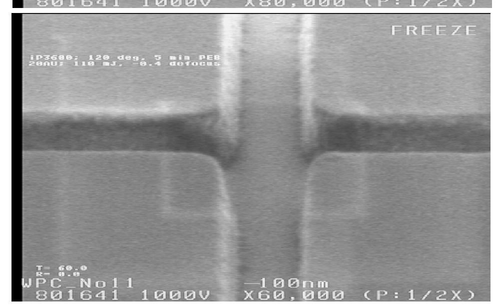
Best Focus



Scum



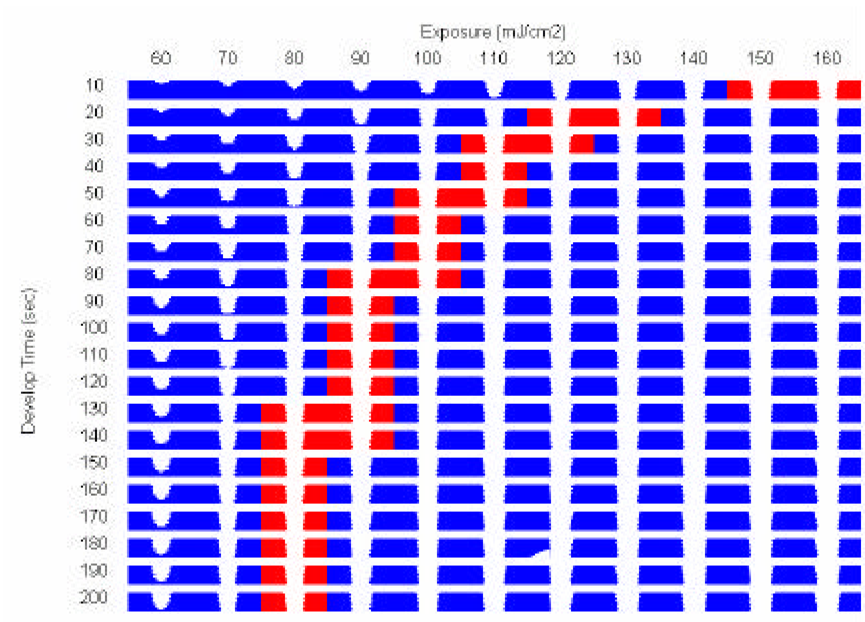
-0.4 μm



IP3600/ 0.23N TMAH (NMD-W)/90 s dev. time/ 110 mJ/cm^2/ 0.5 μm space

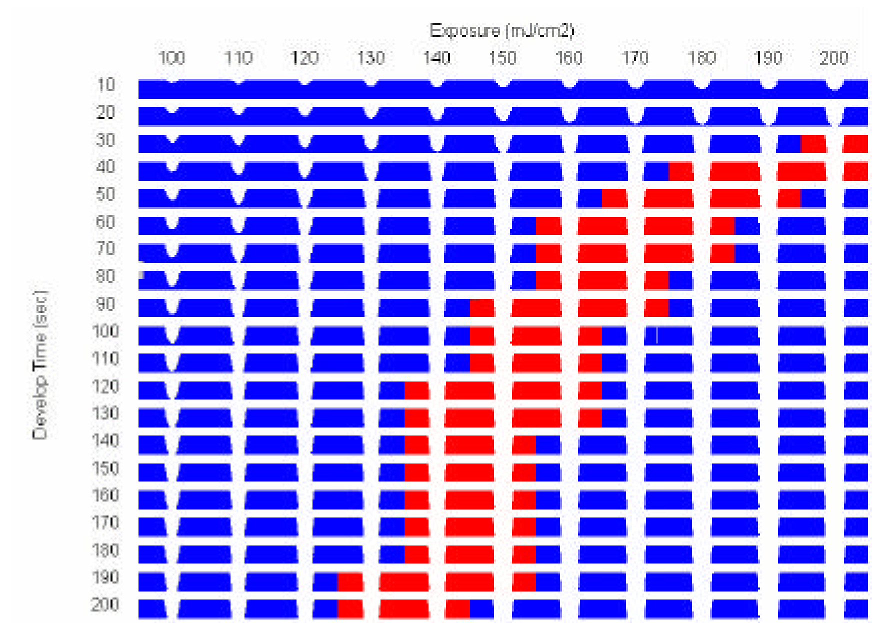
Simulated Process Latitude Improvements for IP3600

Current Photomask Process



IP3600 (TOK)/ 0.26N TMAH
NMD-W/ No PEB

Improved Photomask Process

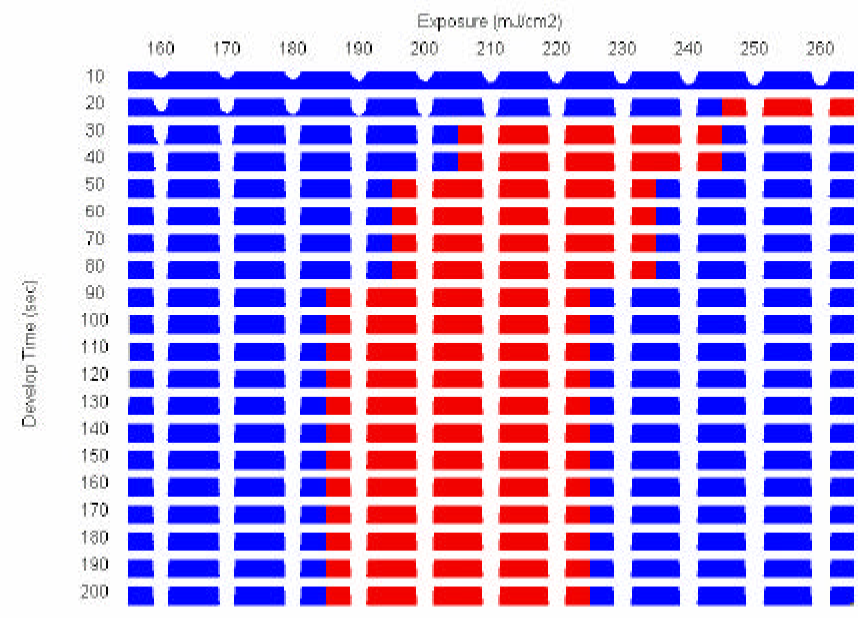


IP3600 (TOK)/ 0.20N TMAH
NMD-W/ PEB

PROLITH 2/ 6.04/ 0.5 µm isolated space/ 82°+ sidewall angle/ ± 5% linewidth latitude

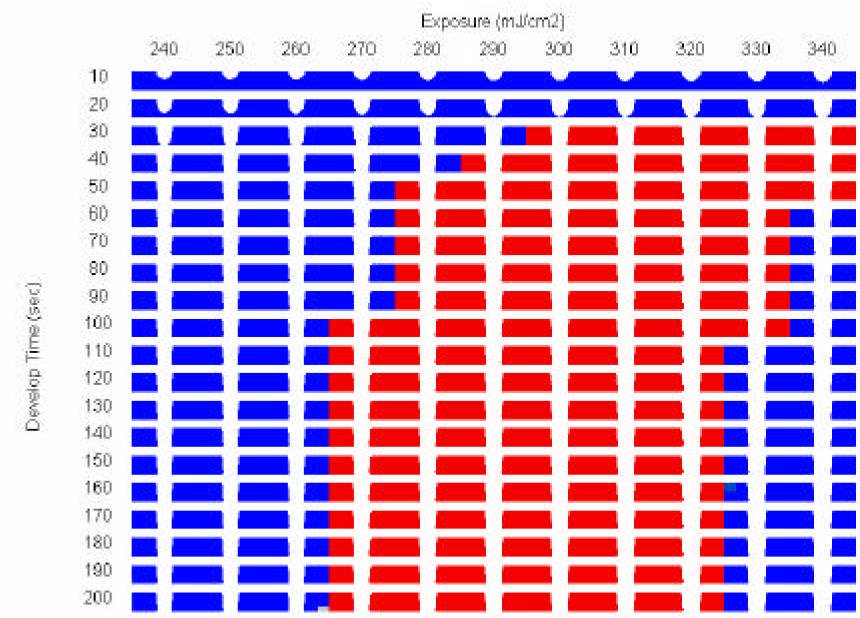
Simulated Process Latitude Improvements for High Resolution Resists

High-Resolution Photomask Process



PFI88A5 (Sumitomo)/ 0.26N TMAH NMD-W/ PEB

Improved High-Resolution Photomask Process

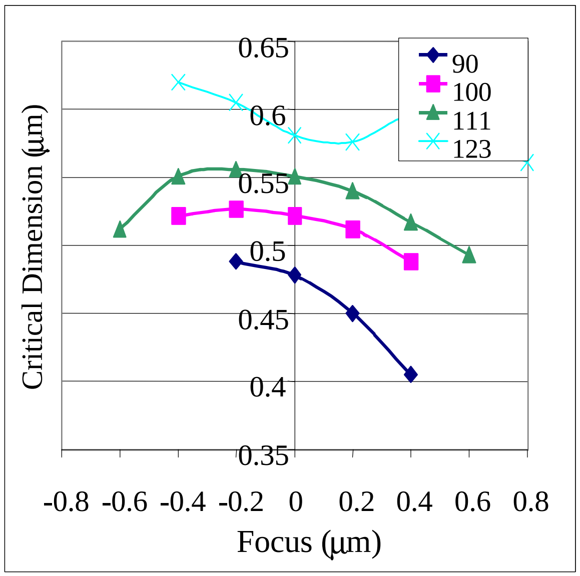


PFI88A5 (Sumitomo)/ 0.23N TMAH NMD-W/ PEB

PROLITH 2/ 6.04/ 0.5 µm isolated space/ 82°+ sidewall angle/ ± 5% linewidth latitude

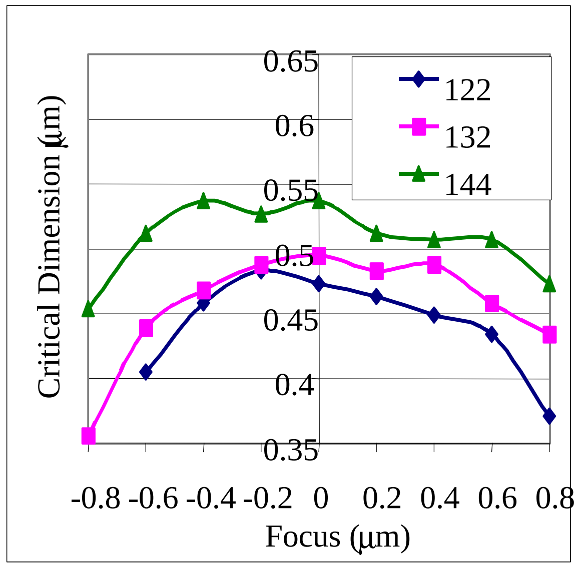
Focus-Exposure Process Latitude Improvements (0.5 μm space)

Current Photomask Process



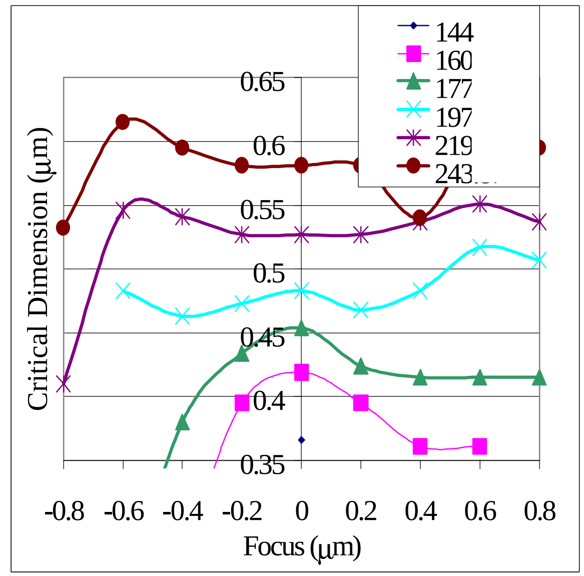
IP3600/ 0.26N TMAH (NMD-W)/ 60 s dev./ No PEB

Improved Photomask Process



IP3600/ 0.20N TMAH (NMD-W)/ 180 s dev./ PEB

High Resolution Photomask Process

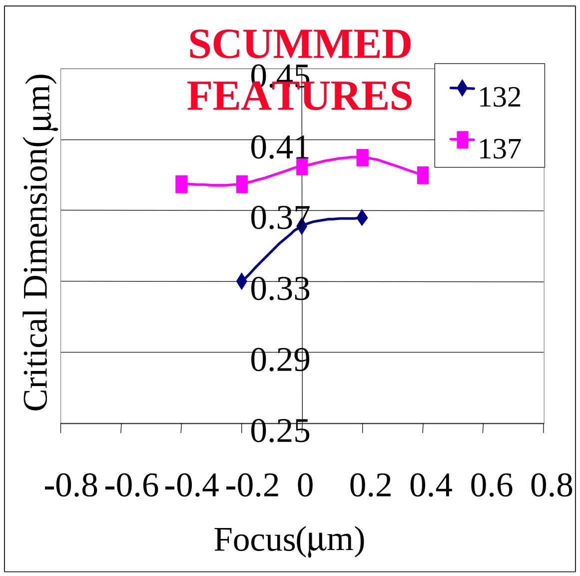


PFI88A5/ 0.26N TMAH (NMD-W)/ 180 s dev./ PEB

Manufacturing trials at the DPI Reticle Technology Center

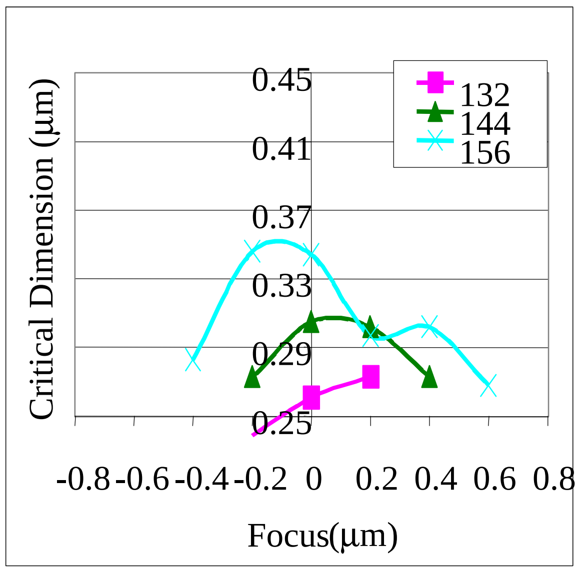
Focus-Exposure Process Latitude Improvements (0.3 µm spaces)

Current Photomask Process



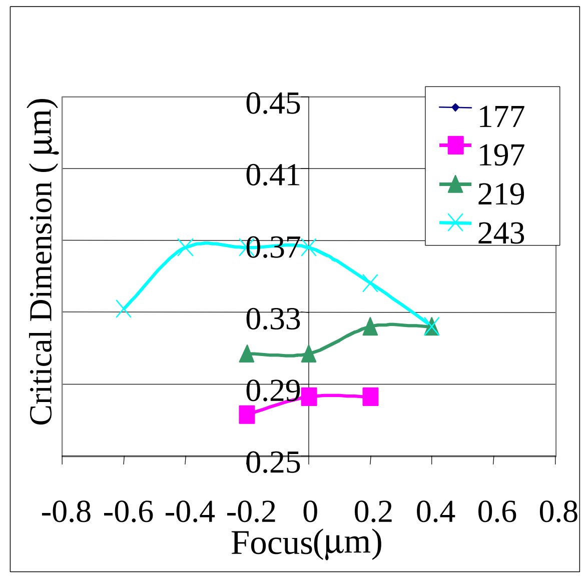
IP3600/ 0.26N TMAH (NMD-W)/ 60 s dev./ No PEB

Improved Photomask Process



IP3600/ 0.20N TMAH (NMD-W)/ 180 s dev./ PEB

High Resolution Photomask Process

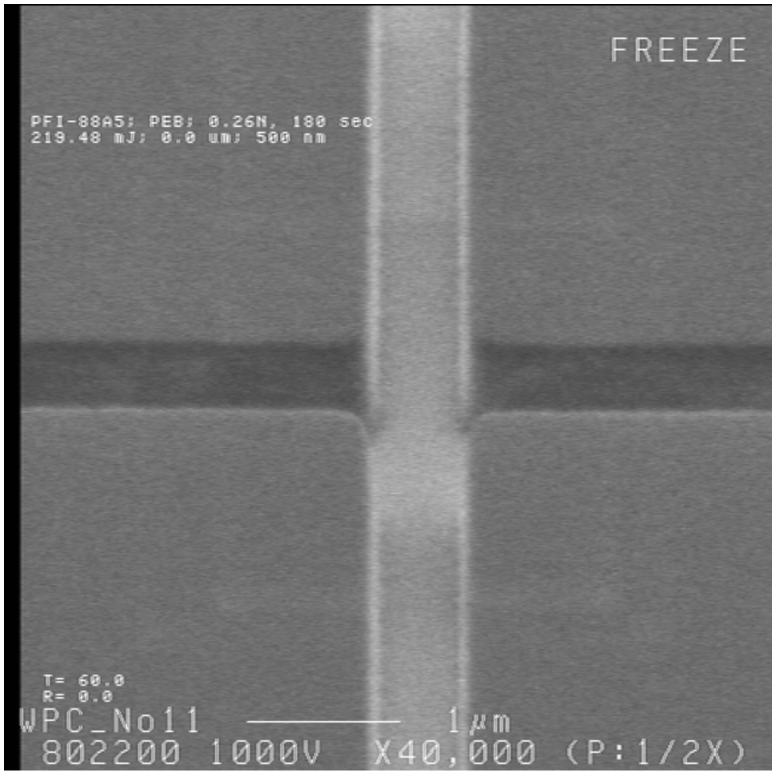


PFI88A5/ 0.26N TMAH (NMD-W)/ 180 s dev./ PEB

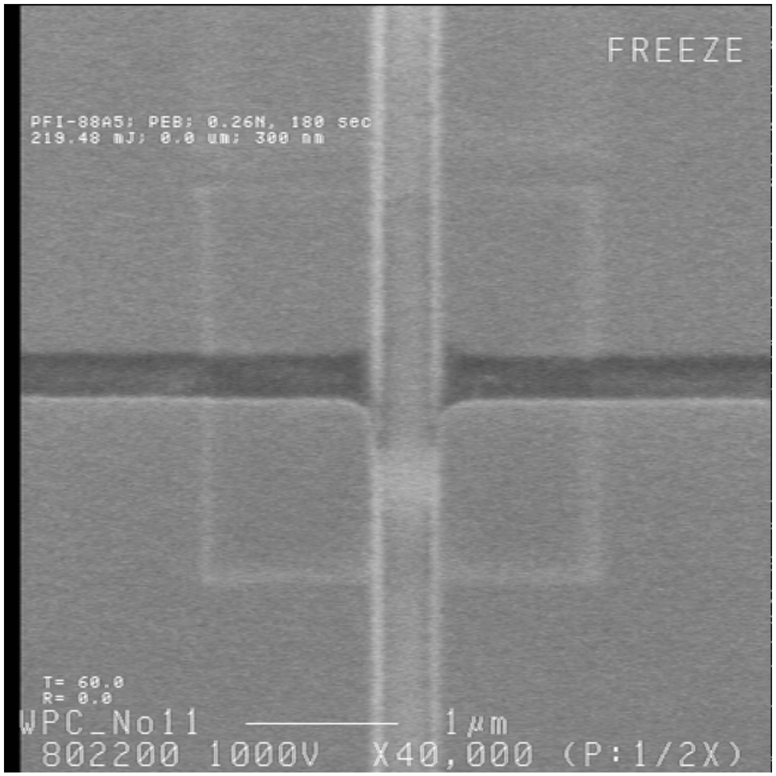
Manufacturing trials at the DPI Reticle Technology Center

High Resolution Optical Photomask Lithography

0.5 µm isolated resist space



0.3 µm isolated resist space



PFI88A5/ 0.26N TMAH NMD-W/
180 s dev. time/ PEB/ 220mJ/cm^2

Optimal Photomask Process for Sub 0.30 µm Resist Features

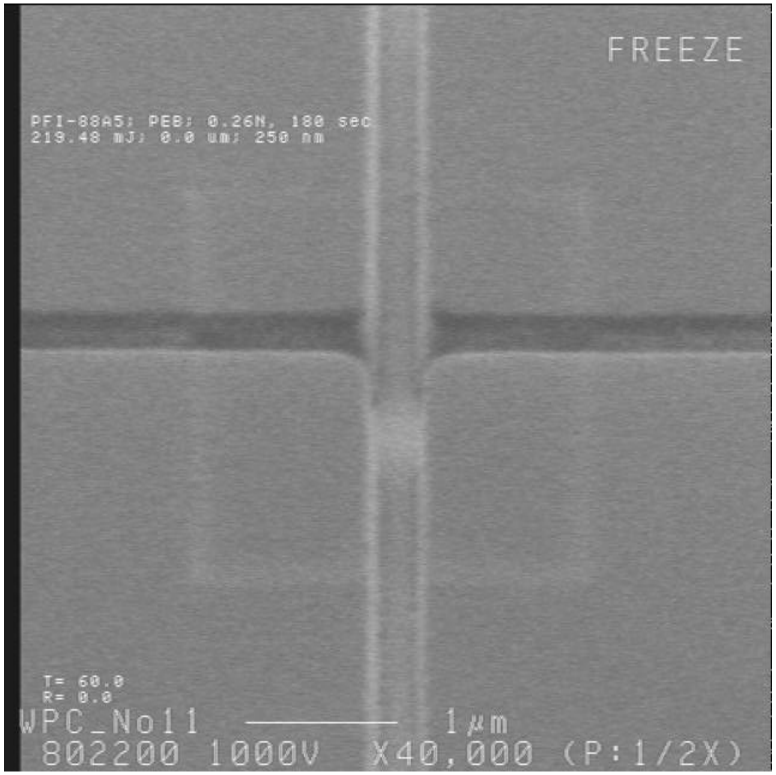
Process Conditions

- High Resolution I-line resists
- Higher exposure energy
- Lower developer concentration
- Longer development time
- Post-exposure bake

Process Parameter Optimization

- Sub-0.30 µm resist features
- Improved focus-exposure process latitude
- Reduce Scumming/ defects
- Reduced CD sensitivity to dose
- Reduce pattern density effects

0.25 µm isolated resist space



PFI88A5/ 0.26N TMAH NMD-W/ 180 s dev. time/ PEB/ 220mJ/cm^2

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- SRC/ National Semiconductor Fellowship
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