# Lecture 18 –
# Optical Lithography 3 - Resist

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Nanophotonics and Nano-scale Fabrication
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# Photoresist

- The most commonly used photoresist nowadays is a two-component system which consists of the novolac resin and the diazonaphthoquinone photoactive compound (PAC; a dissolution inhibitor).

**novalac**

1. Inert to photochemistry
2. For film-forming
3. For adhesion
4. For chemical resistance
5. For thermal resistance

**PAC**

1. Responsible for photochemistry
2. Quantum efficiency:

$$\phi = \frac{\text{\# of molecules transformed}}{\boxed{\text{\# of photons absorbed}}}$$

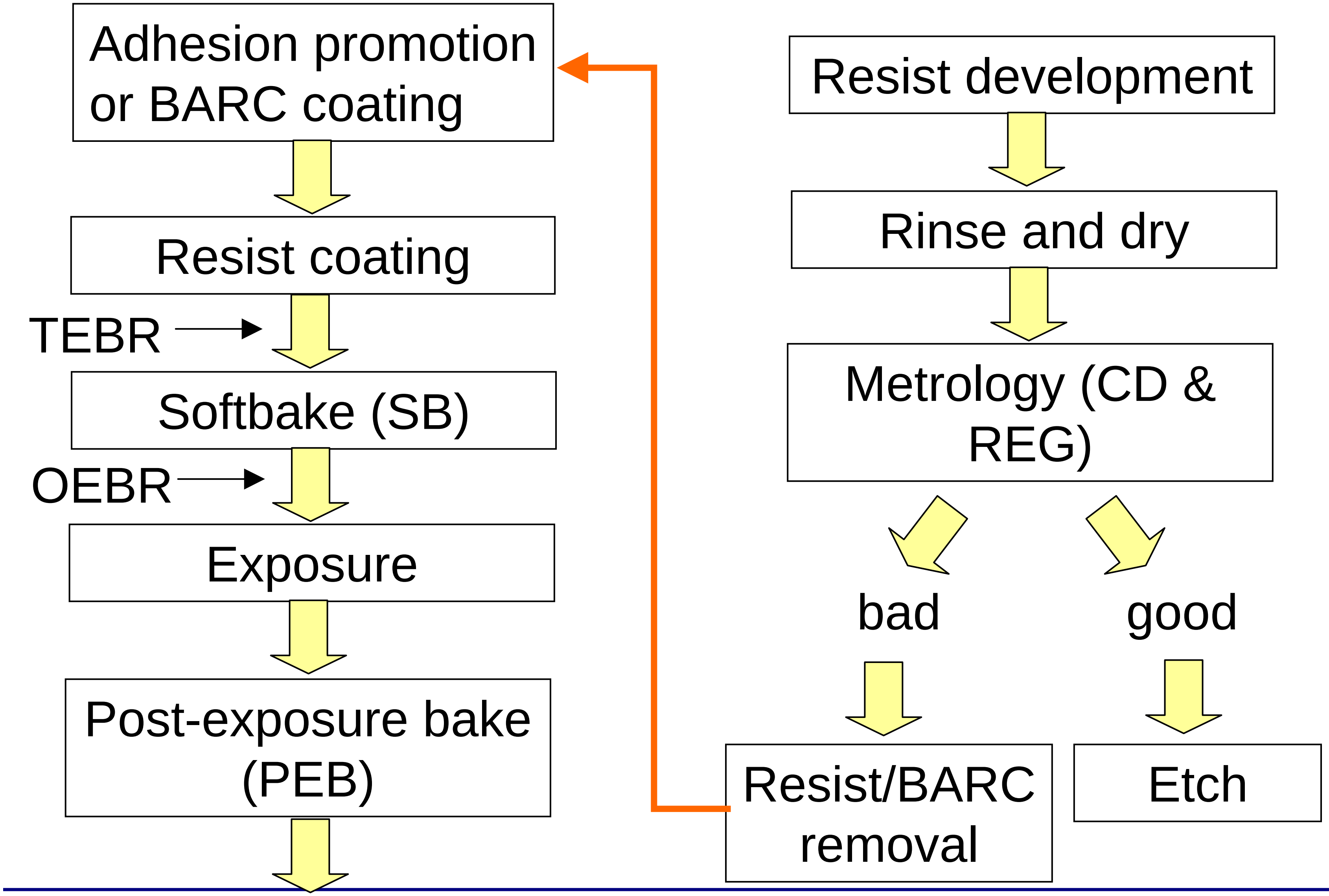
Not the total intensity!

# Chemically amplified DUV resist

- Since the quantum efficiency of a regular resist is ~ 100 fold smaller at the DUV wavelength, chemical amplification is used.
- Instead of optically destroying the dissolution inhibitors, chemically amplified DUV resist creates acid by photochemical reactions. Acid then destroys the inhibitor at an elevated temperature (PEB). Each acid molecule can trigger the catalysis event to destroy several inhibitors → amplification.

Ref: H. Ito, “Chemical amplification resists,” IBM J. R&D, **41** (1997)

# Resist process overview



Adhesion promotion or BARC coating

Resist coating

TEBR

Softbake (SB)

OEBR

Exposure

Post-exposure bake (PEB)

Resist development

Rinse and dry

Metrology (CD & REG)

bad

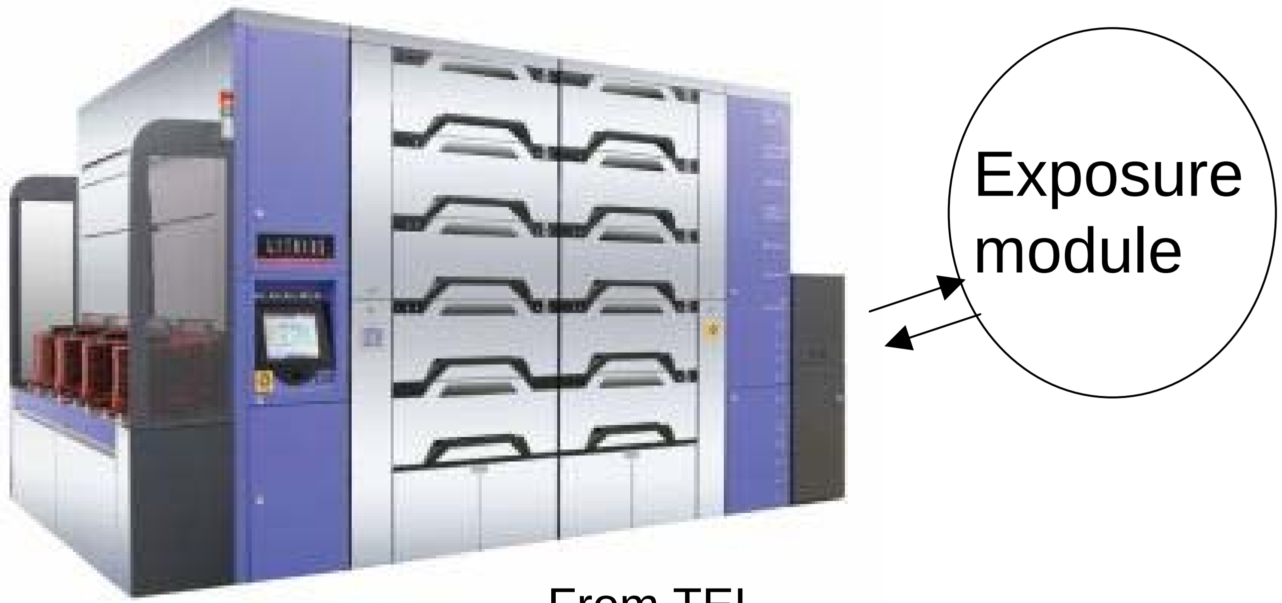
good

Resist/BARC removal

Etch

# Resist process environment control

- Resist process happens in a controlled environment (track).



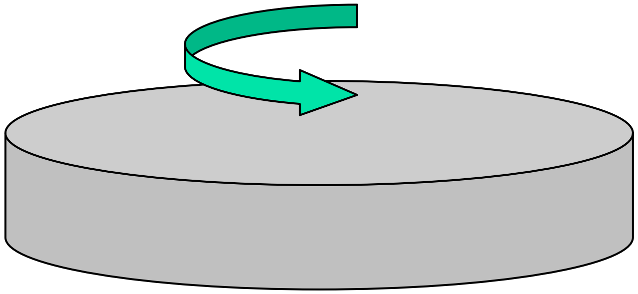
Exposure module

From TEL

# Adhesion promotion

- The most common adhesion promoter is HMDS (hexamethylenedisiloxane). Applied in vapor phase (100-160 ° C.

# Spin coating



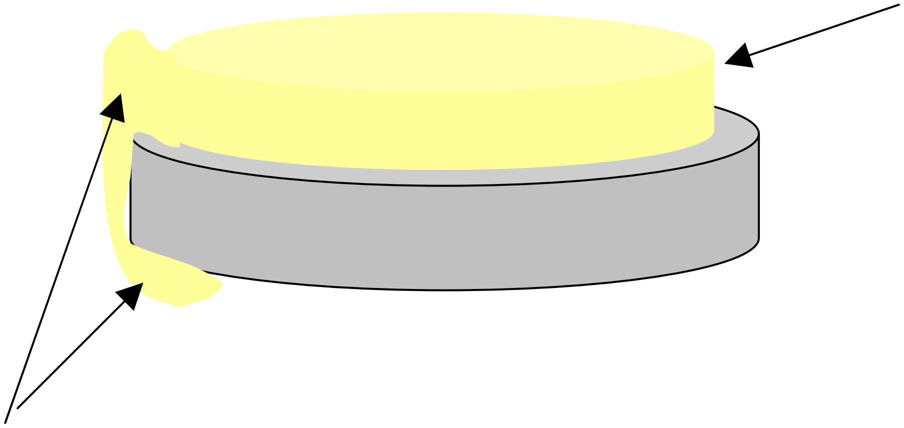
Resist thickness $t = \frac{KC^{\beta}\eta^{\gamma}}{\omega^{\alpha}}$

$\omega$ = spin angular speed
$C$ = resist concentration
$\eta$ = molecular weight

1. Low spin speed results in a thicker resist toward the edge of the wafer
2. High spin speed results in opposite thickness profile as well as random variation in thickness due to thermal effects.
3. Best spinning speed 2000 ~ 4000 rpm.

# Edge bead removal (EBR)

- The resist on the edge of the wafer is often removed (EBR) to reduce potential contamination sources and help the vacuum chuck to hold the wafer.
- TEBR: use chemicals to remove the edge bead
  OEBR: use optical source to expose the edge bead



resist

Thickness variation and spill over to the back

# Softbake (SB)

- Purpose: To remove the residual solvent and anneal the stress. Note some resists do require some solvent to remain in order to improve the photochemical reaction speed.

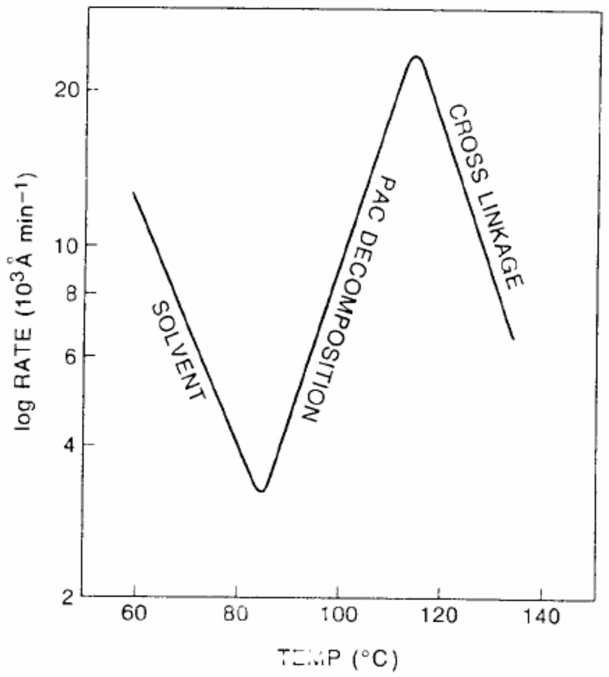


*Figure 28.* Dissolution rate of a typical commercial positive photoresist (DNQ–novolac) as a function of prebake temperature.

From *Introduction to Microlithography*

# Exposure (Dill's model)

- Concentration of dissolution inhibitor = *M(z,t)*

$$\alpha = AM(z,t) + B \longrightarrow$$

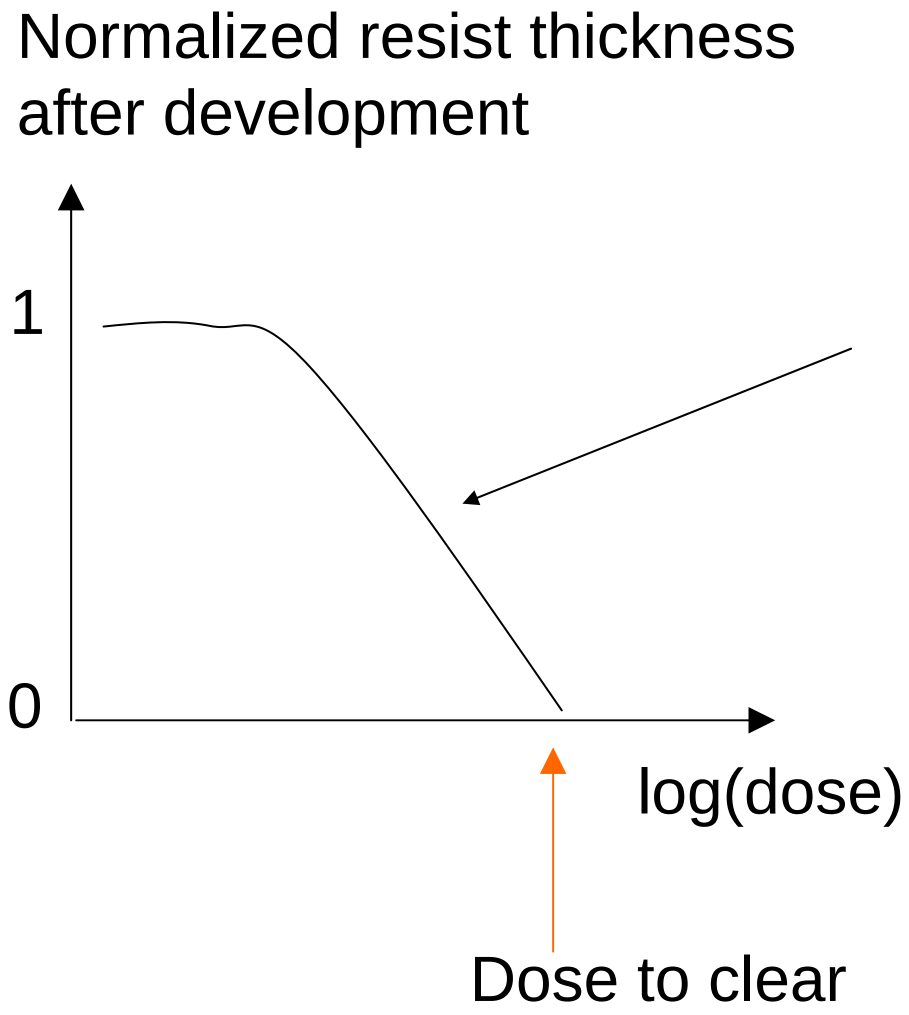
As *M(z,t)* reduces, the absorption will be bleached.

$$I(z,t) = e^{-\alpha z}$$

$$\frac{\partial M(z,t)}{\partial t} = -I(z,t)M(z,t)C$$

It is very important for bleaching to happen. Otherwise, there will be no light that can reach the bottom of the resist to clear. This is the main reason that photoresist used for G- or I-line does not work well at the DUV wavelength.

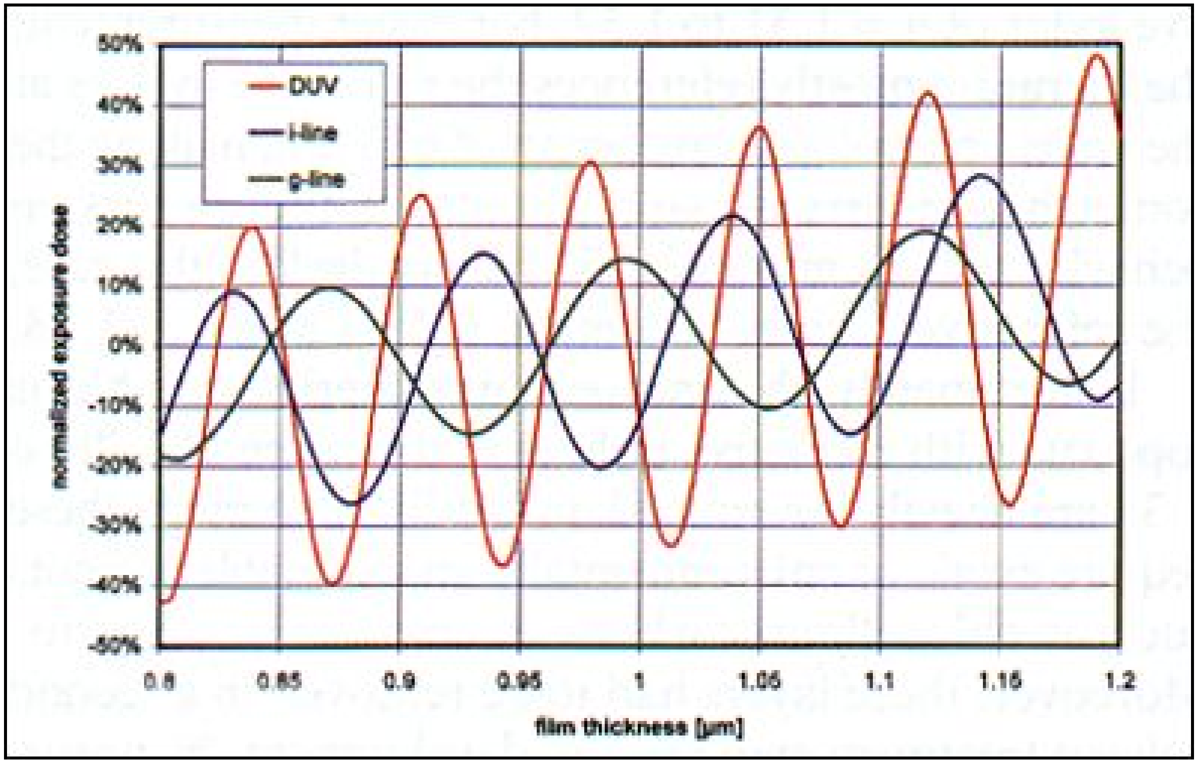
# Resist characteristics



The slops determines the contrast and dose sensitivity.

# Swing curve

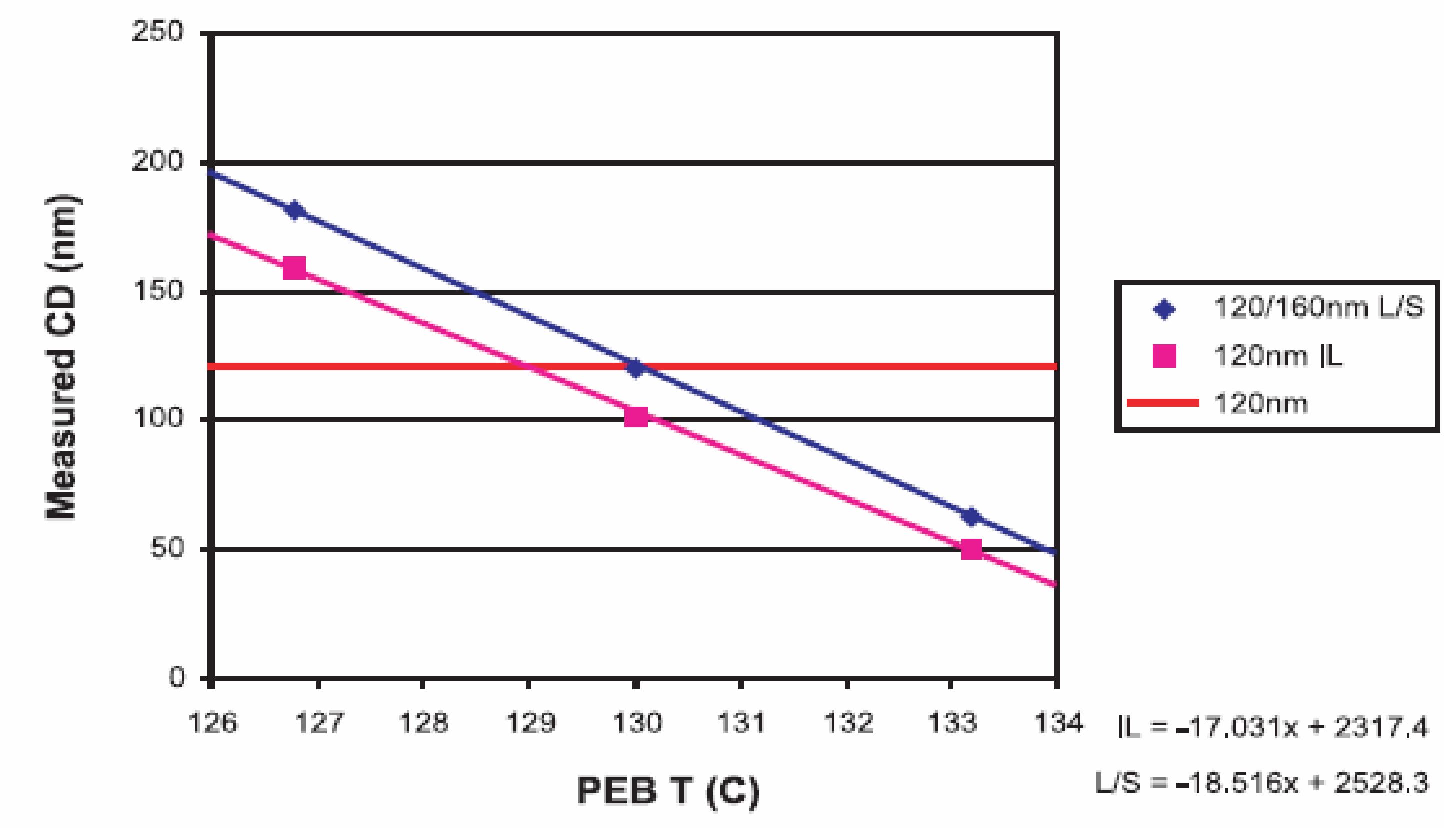
- Swing curve plots the “dose to clear” vs film (e.g. resist) thickness.



# Post exposure bake (PEB)

- PEB is different from the “hardbake” before an etching process.
- PEB is used to induce the diffusion of photogenerated compound in order to smooth out the interference effect on the resist profile.

# PEB temperature vs CD



From Future-Fab International, issue 12.

# PEB delay vs resist profile

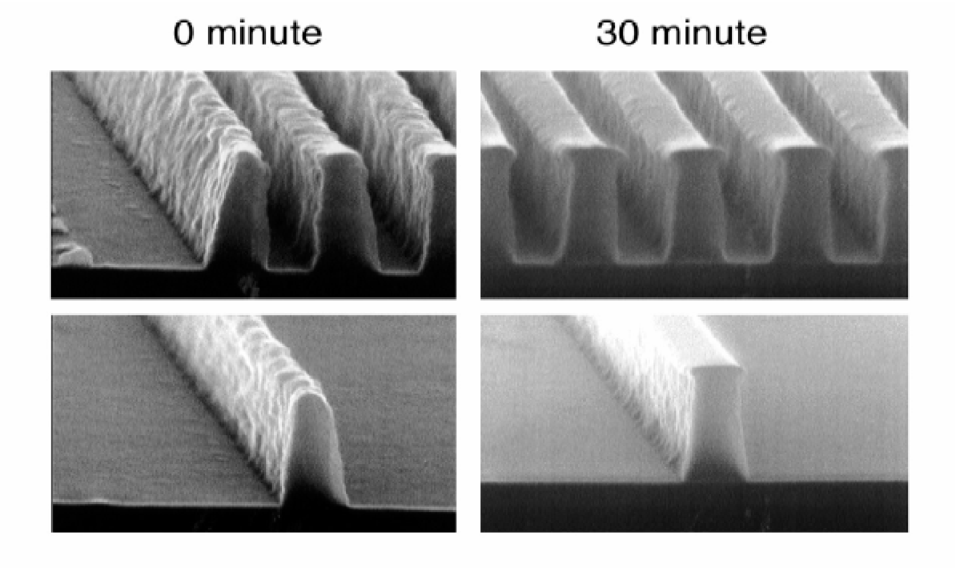


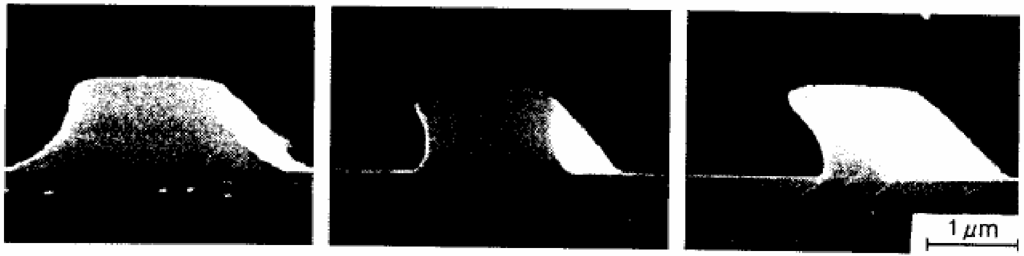
*Figure 13. PEB delay effects on acrylate resist #3 on AR19 BARC (820 A). Ammonia concentration = 0.6ppb, N-methyl pyrlidone (NMP) concentration = 0.08ppb.*

From Future-Fab International, issue 12.

Reactions with airborne molecules, such as ammonia or amines, neutralize acid near the top of the resist film, forming a mushroom cap.

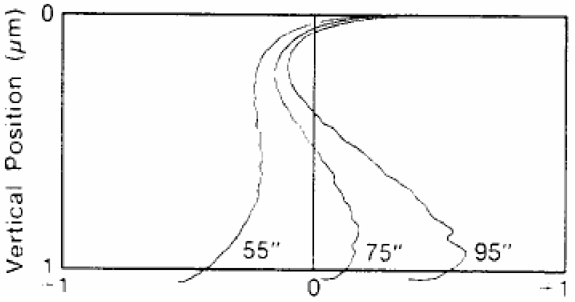
Reactions with certain substrates, such as TiN, neutralize acid near the bottom of the resist, forming a foot.

# Development time vs resist profile



Dev. Time = 55"  Dev. Time = 75"  Dev. Time = 95"

(a) Experiment



Horizontal Position (μm)

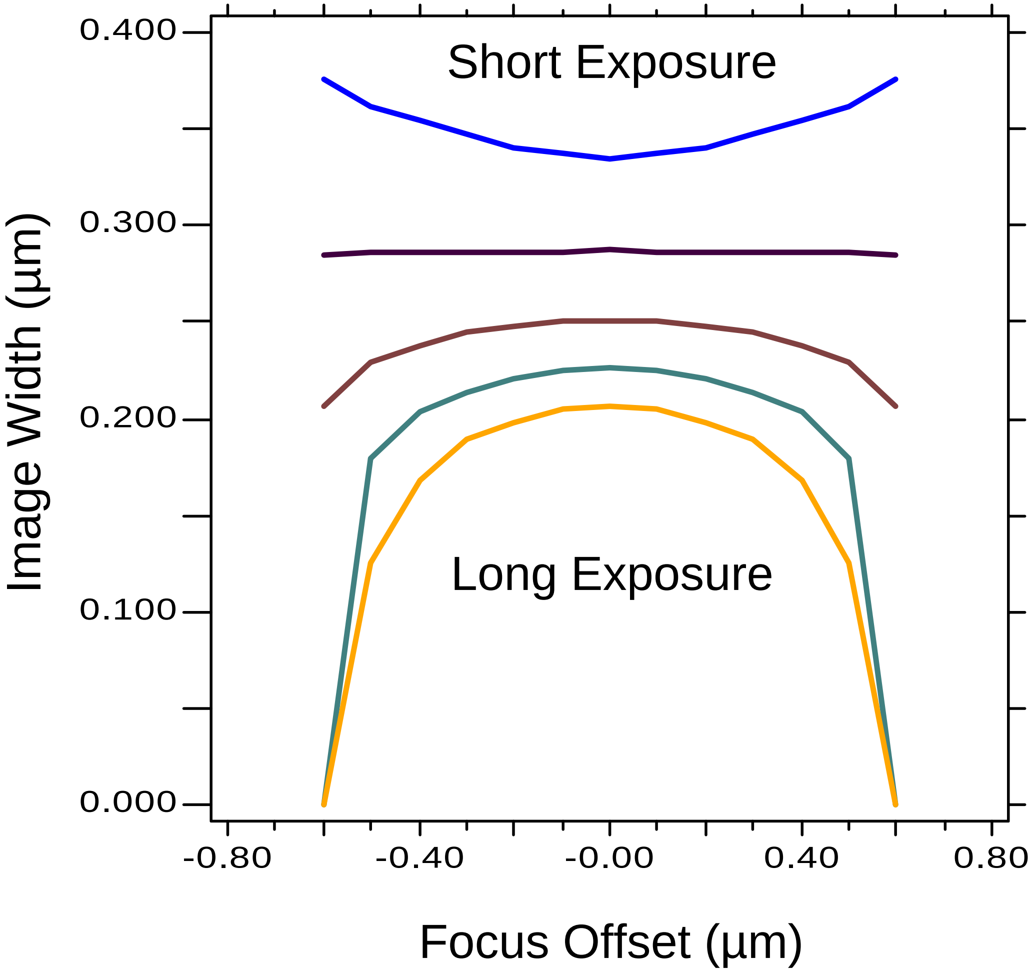
(b) Simulation

***Figure 57.*** Cross-sectional view of MRS resist profiles as a function of development time. (Reproduced with permission. Copyright 1982 Institute of Electrical and Electronics Engineers, Inc.)

From *Introduction to Microlithography*

# Focus-Exposure Matrix (FEM)

Bossung plot:



- Focus window
- Exposure latitude

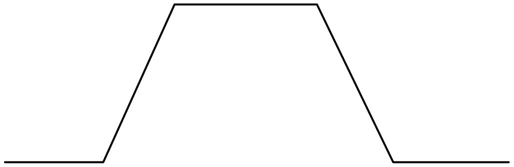
# Metrology

- Registration: overlay measurement
- CD

# Resist profile by top-down measurement

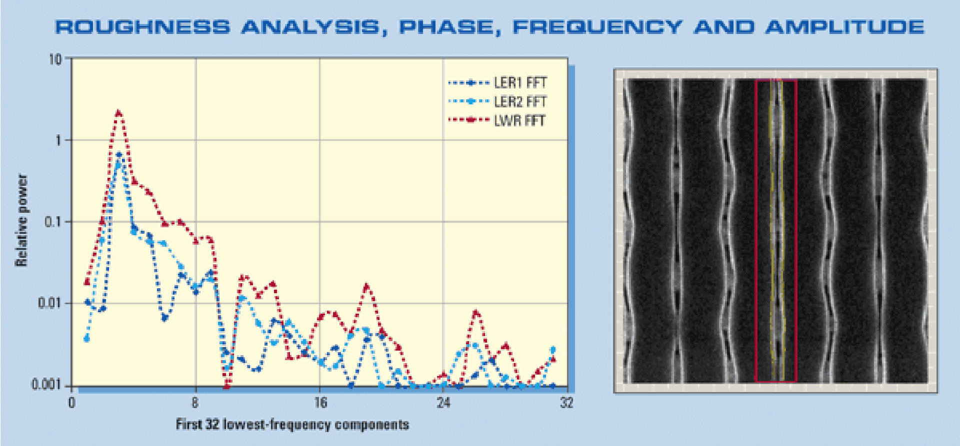
Sloped profile

X-section



Top-down SEM

LER (line edge roughness)



1. Line edge roughness is playing an increasing role in determining pattern- and performance-limited yield entitlements. It is a fact of life for 193 nm lithography, which now must carry the industry for at least three generations with the aid of immersion technology. LER's increasing importance will demand innovation in CD-SEM imaging, measurement and analysis. (Source: KLA-Tencor)