NANYANG TECHNOLOGICAL UNIVERSITY

Course: EE3013 Semiconductor Devices and Processing

School: School of Electrical and Electronic Engineering

Lithography – Resist Technology

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Lithography Technology – Lesson Overview

Resist technology:

- Chemistry of resist
- Metrics of resist
- Advantages and disadvantages of positive and negative resist

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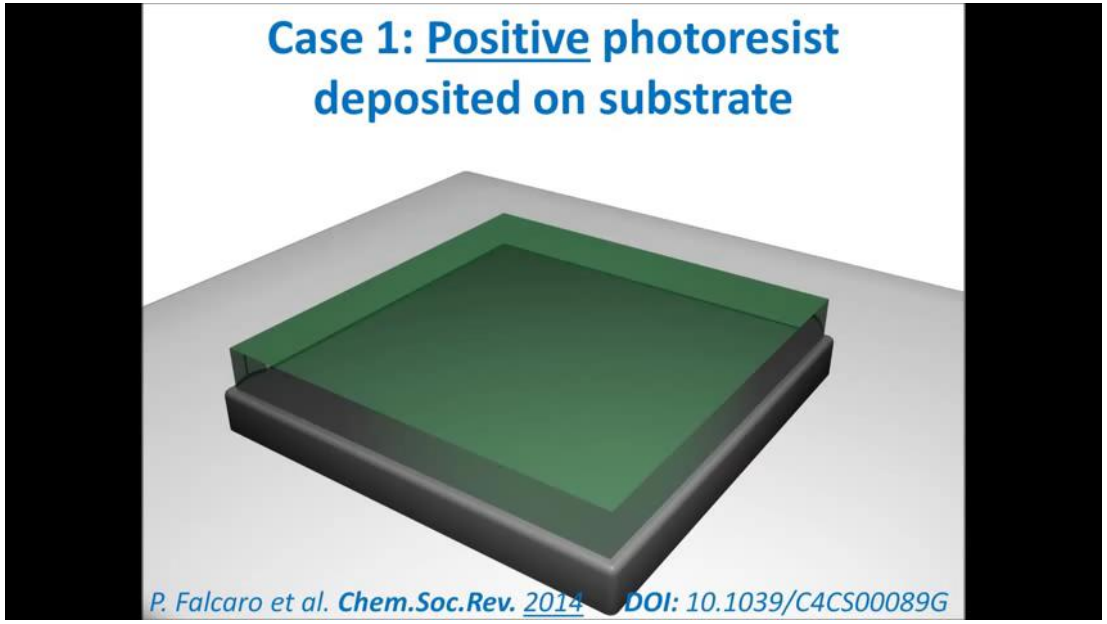
Chemistry of Resist

Positive and Negative Photoresist/ Resist

Positive Resist



Exposed region becomes **more soluble**

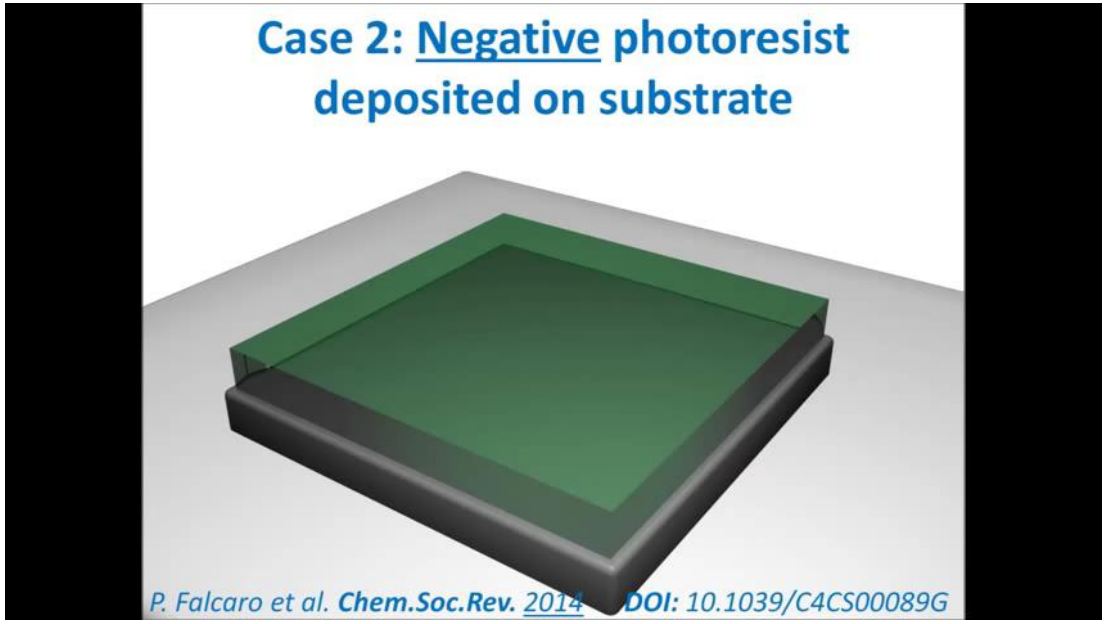
⬇

Wash away **exposed** region

⬇

Pattern formed on substrate is the **same as the mask**

Negative Resist



Exposed region becomes **less soluble**

⬇

Wash away **unexposed** region

⬇

Pattern formed on substrate is the **opposite from the mask**

Positive and Negative Photoresist/ Resist (Cont'd)

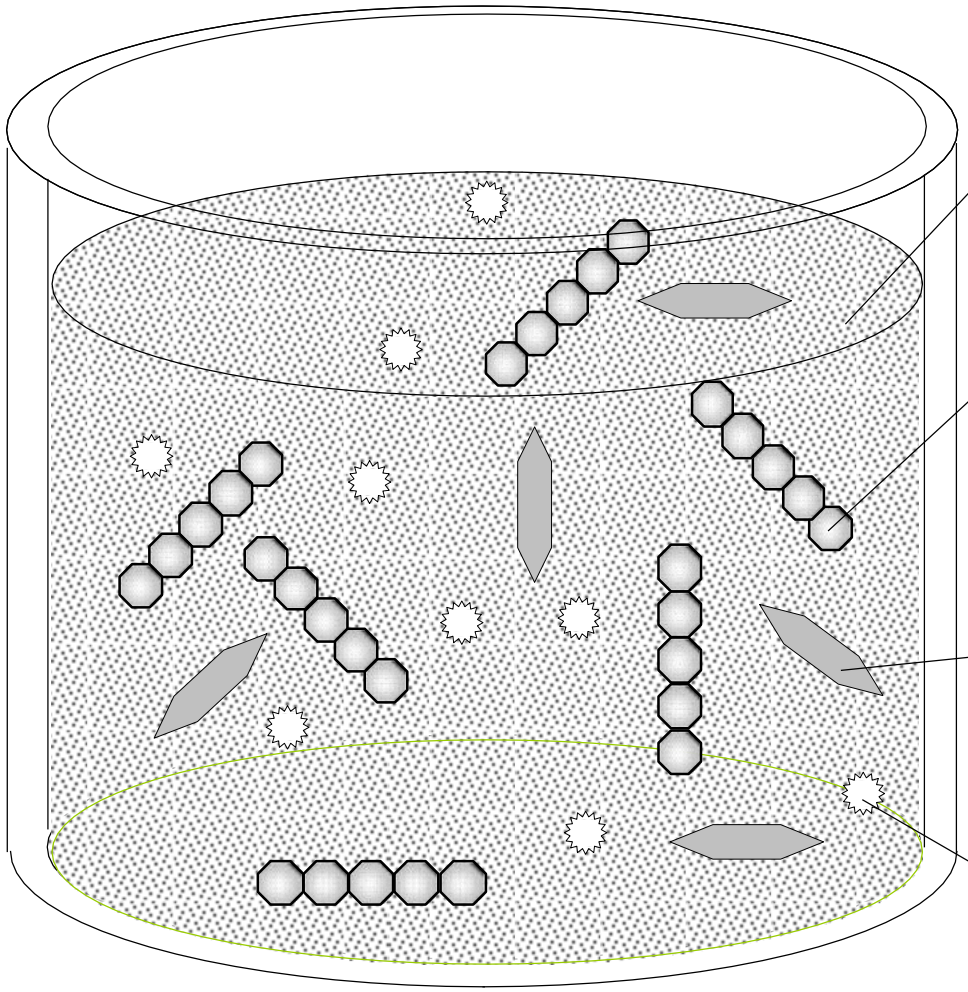
Pause and read carefully

Types of photoresist:

Positive Resist	Negative Resist
Exposed region becomes **more soluble**	Exposed region becomes **less soluble**
Exposed areas are removed and unexposed areas remain after *resist development	**Exposed areas remains** and unexposed areas are removed after *resist development
Patterns formed on the wafer are **the same as those of the mask**	**Patterns** formed on the wafer **are opposite as those of the mask**

**Resist development: A process to remove soluble region, will be discussed.*

Components of Resist



Solvent:
Gives resist its flow characteristics

Resin:
Mix of polymers used as binder; gives resist its mechanical and chemical properties

Sensitisers:
Photosensitive component of the resist material

Additives:
Chemicals that control specific aspects of resist material

Components of Resist (Cont'd)

Main components for lithographic capability:

- Resin: Not opaque at λ
  - Give resist mechanical and chemical properties (reaction to developer, etc.)
- Sensitiser
  - Photo active compound/ group (PAC/ PAG) at λ
- Solvent
  - Keeps resist in liquid state
  - Allows spin coating of the resist
  - Solvent content determines viscosity and hence, the **thickness**
- Additives
  - Capability for further process: Etch resistivity/ implant blocking capability

Chemistry of Positive and Negative Resist

- Positive optical resist
  - **Resin** (Novolac resin)
  - **Sensitiser/ dissolution inhibitor** (PAC = Diazoquinones)
  - **Solvent** (Propylene Glycol Methyl Ether Acetate (PGMEA), N-Methyl Pyrrolidine (NMP), N-butyl acetate, xylene, etc.)
  - **Developer:** Hydroxides (TMAH, KOH, NaOH, etc.)
- Negative optical resist
  - **Resin** (Cyclised synthetic rubber resin)
  - **Sensitiser** (PAC = Bisarylzide)
  - **Solvent** (Aromatic solvent)
  - **Developer** (Organic solvents)

Positive and negative resist have different types of developer due to different photochemical reactions.

Positive Resist

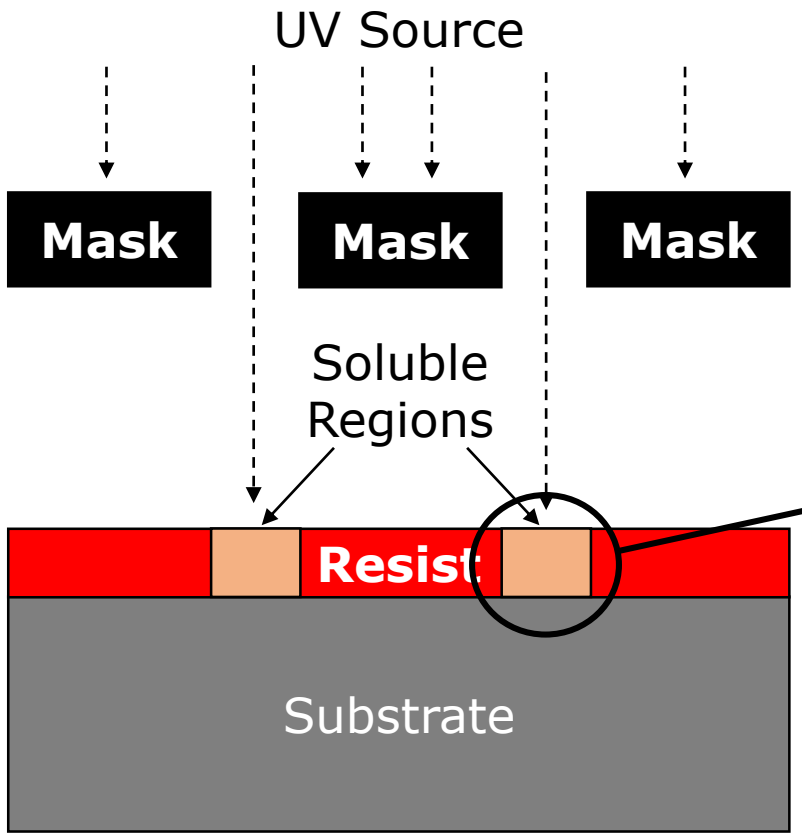
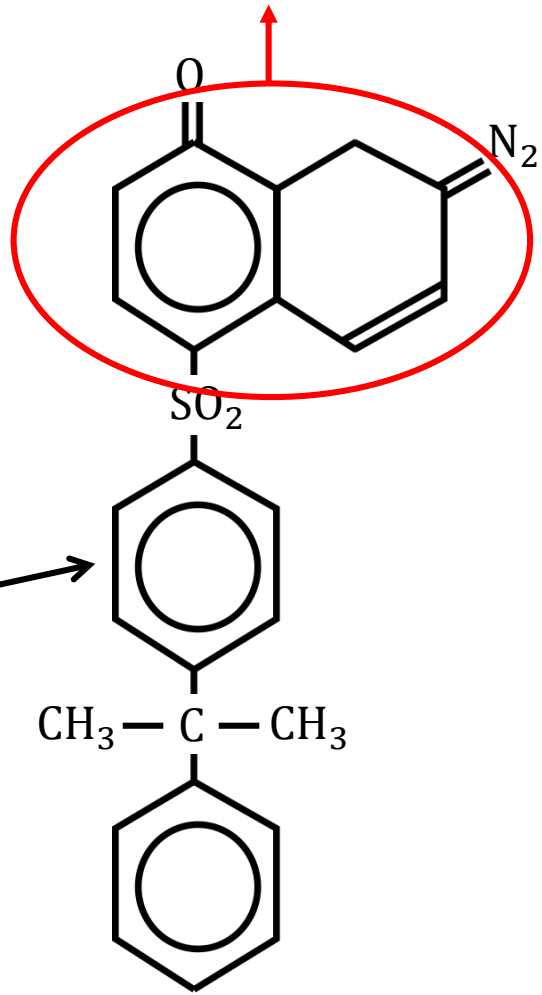
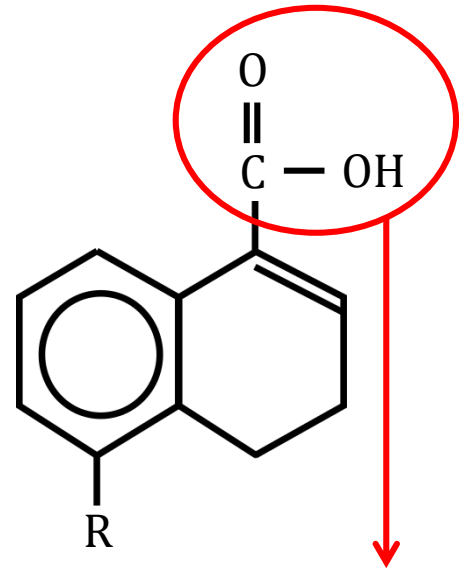


Photo-Active Compound



UV Light



Carboxylic Acid Group

Soluble in base solution

Positive Resist

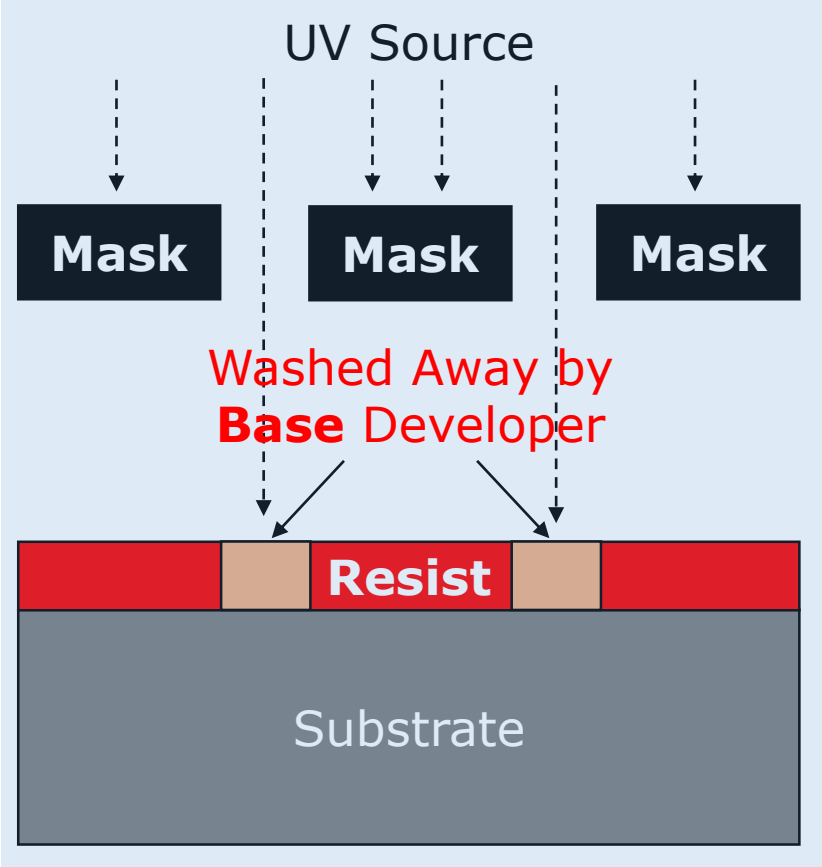
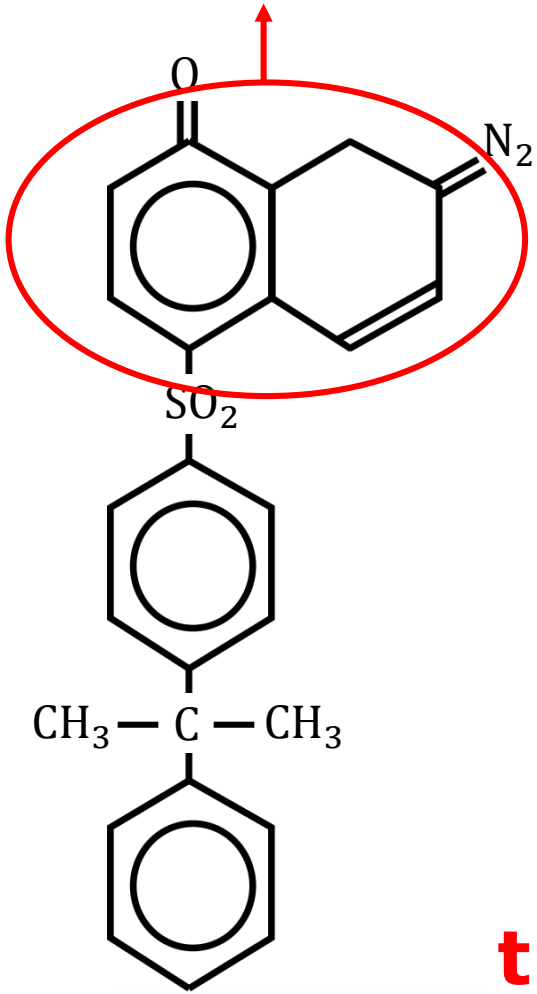
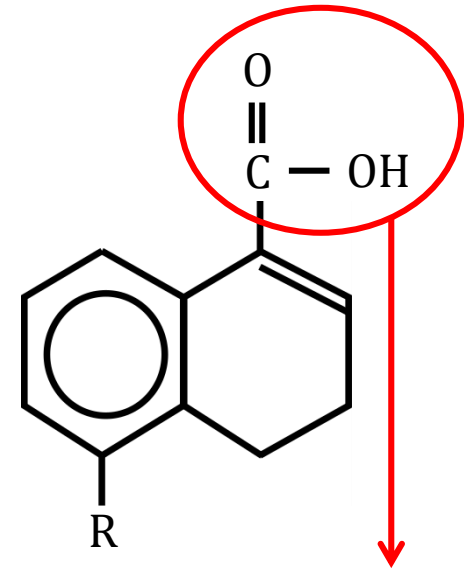


Photo-Active Compound



UV Light

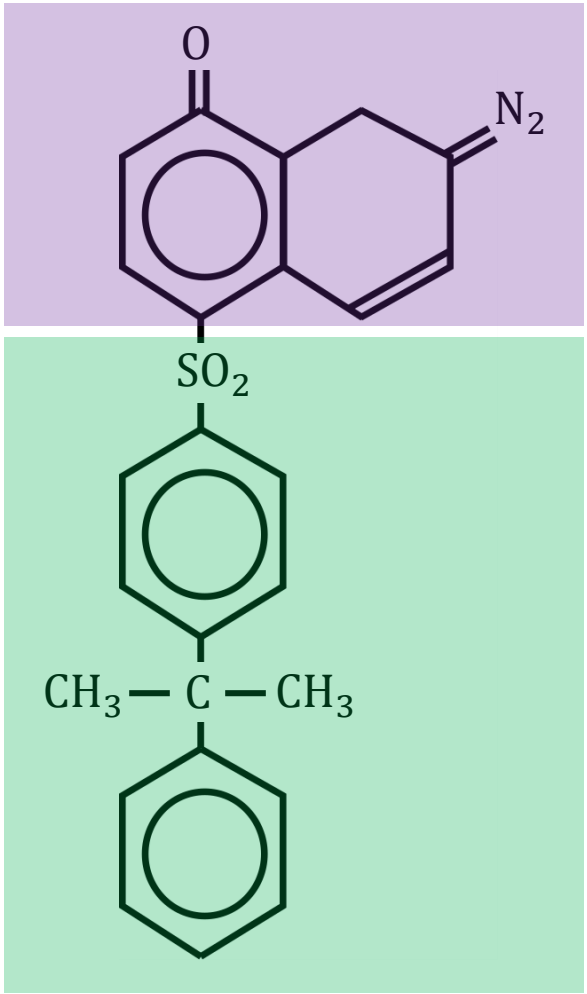


Carboxylic Acid Group

Soluble in Base Solution

How does this transformation happen?

Chemistry in Positive Resist - DQN



DQN

Diazoquinone (DQ) – Photoactive compound.

Novolac (N) – Two CH_3 and one OH groups, dissolves easily in aqueous solution.

Photochemical Reaction in Positive Resist

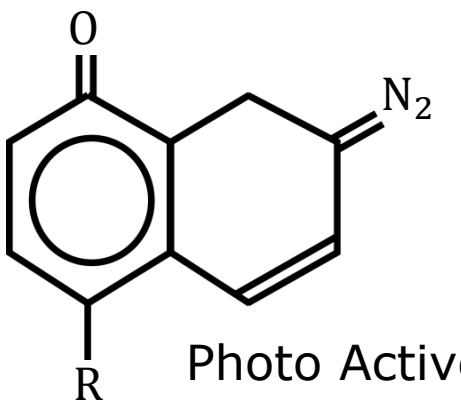
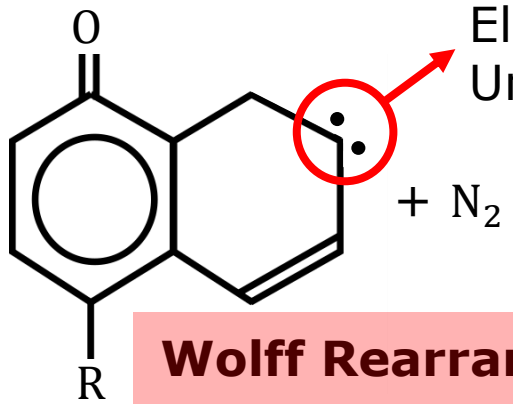


Photo Active Compound

+ Light

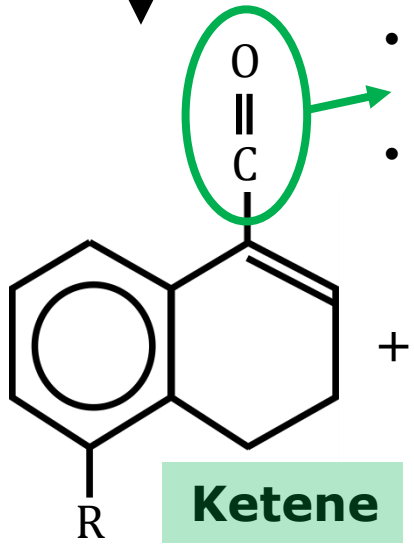


Electron pair –
Unstable compound

Wolff Rearrangement

Unstable compound undergoes Wolff rearrangement to stabilise it.

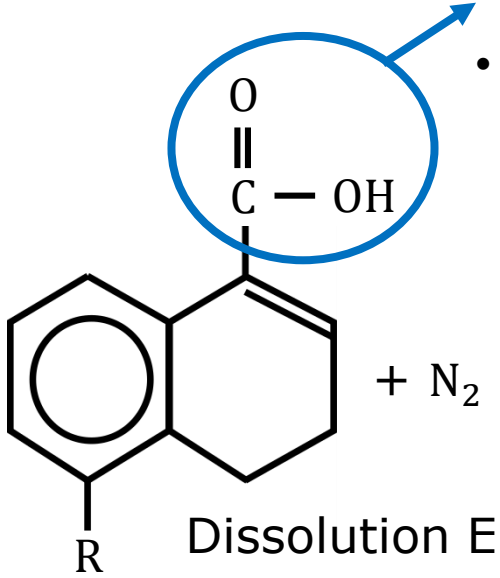
Pause and read carefully



- Carbon moved outside the ring to stabilise the compound.
- Oxygen atom covalently bonded to the carbon atom.

Ketene

+ Water

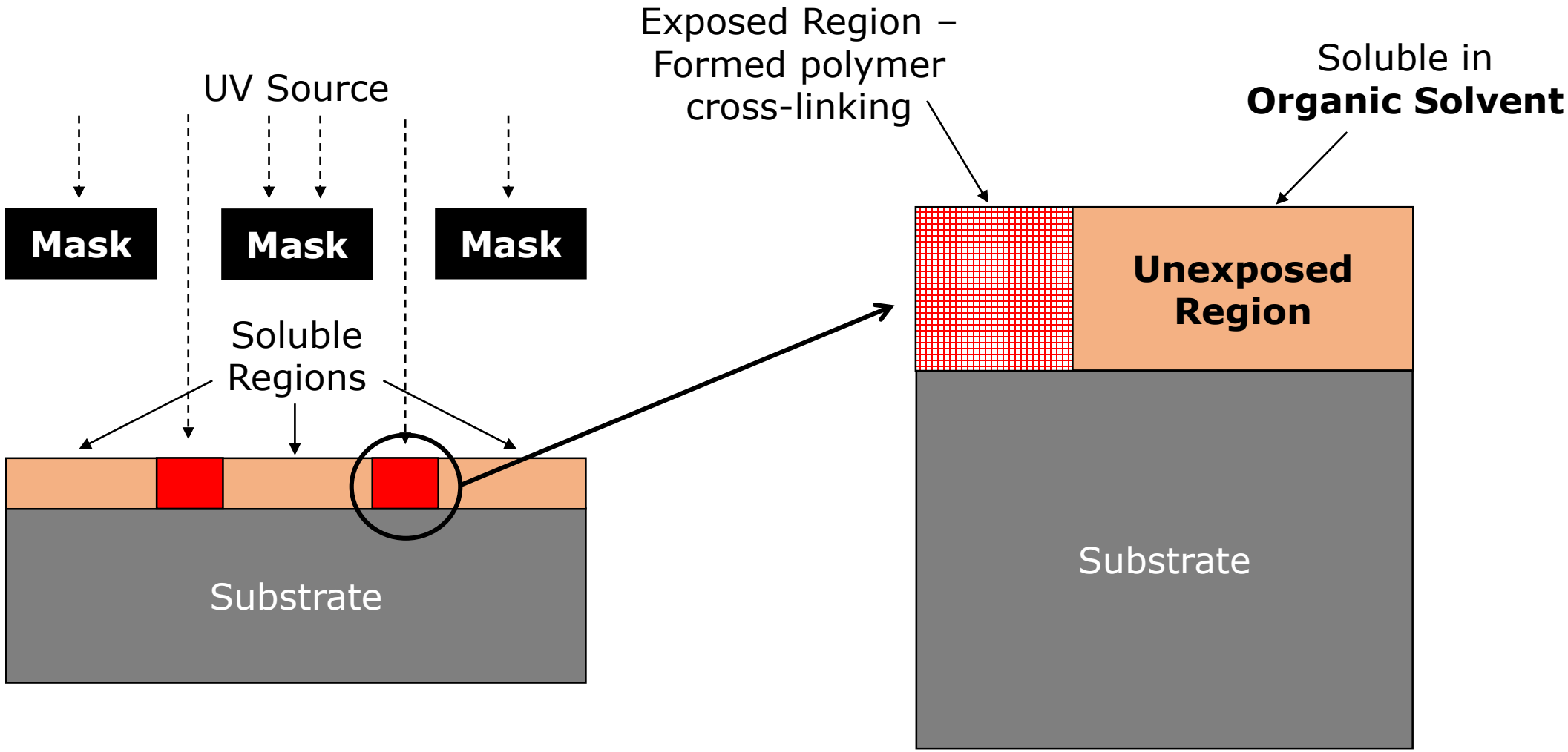


- OH group bonded to the compound.
- Forming carboxylic acid group - Soluble in base developer.

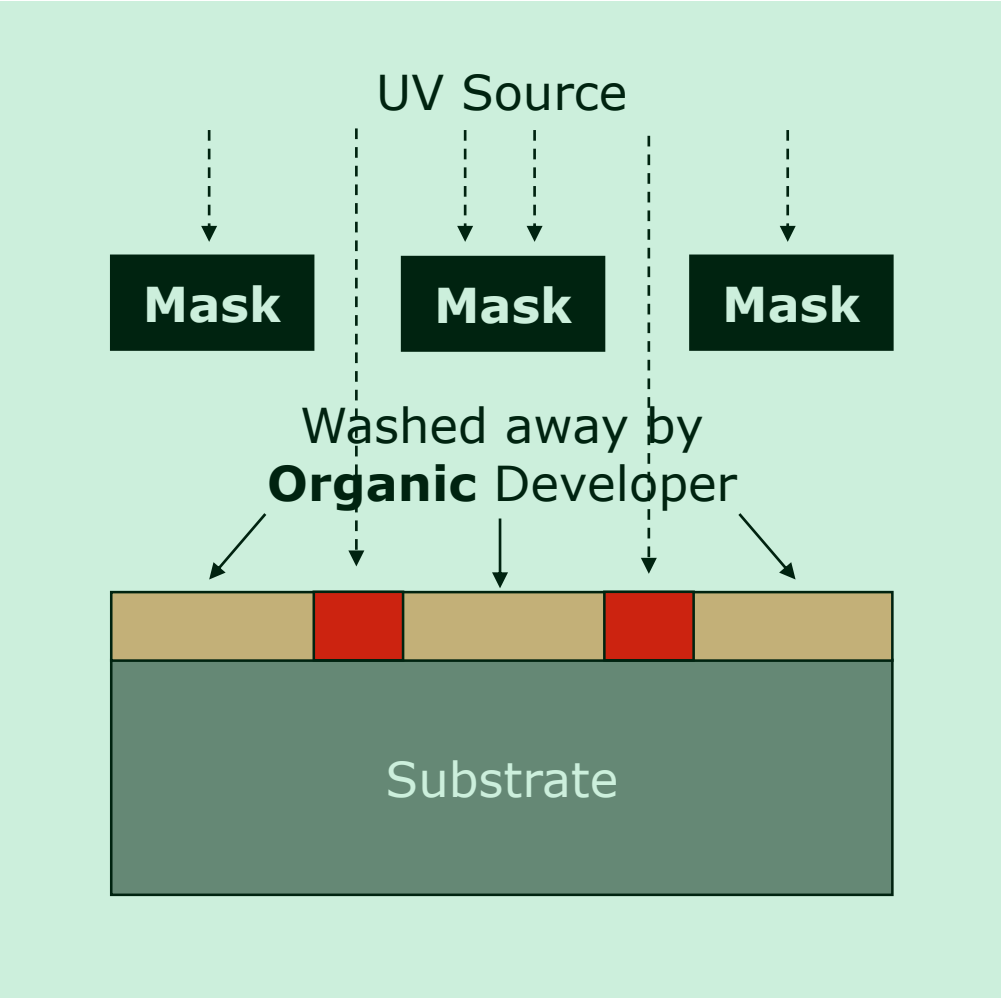
Dissolution Enhancer

Rapid Process

Negative Resist

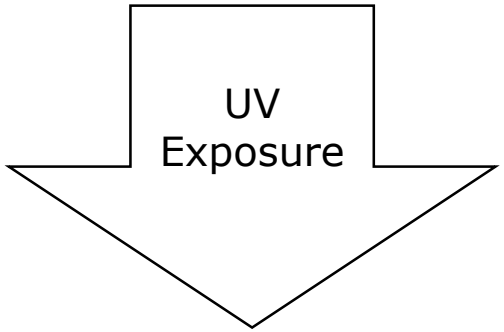
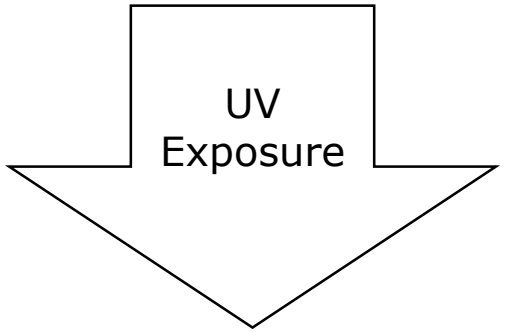


Negative Resist



Reactions of Positive and Negative Resist

Pause and read carefully

Positive Resist	**Negative Resist**
Diazoquinones (DQ) **Insoluble in developer**	Natural Rubber-Based Polymer (Polyisoprene) **Soluble in Developer**
	
Carboxylic Acid **Soluble in Developer**	Cross-Linked Polymer **Insoluble in Developer**
Alkaline Developer (KOH)	***Organic Developer***

Practice Question

Fill in the blanks.

Pause and try out this question

When **positive** resist is exposed to UV source, the light-sensitive chemical in the resist converted into **(carboxylic acid)** groups, which is soluble in **(base)** developer.

When **negative** resist is exposed to UV source, the light-sensitive chemical in the resist forms **(polymer cross-links)**, where the unexposed region can be washed away by **(organic)** developer.

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Metrics of Resist

Metrics of Resist

- Adhesion
- Photo activity
- Resolution
- Contrast
- Viscosity
- Sensitivity
- Etch resistance
- Thermal stability

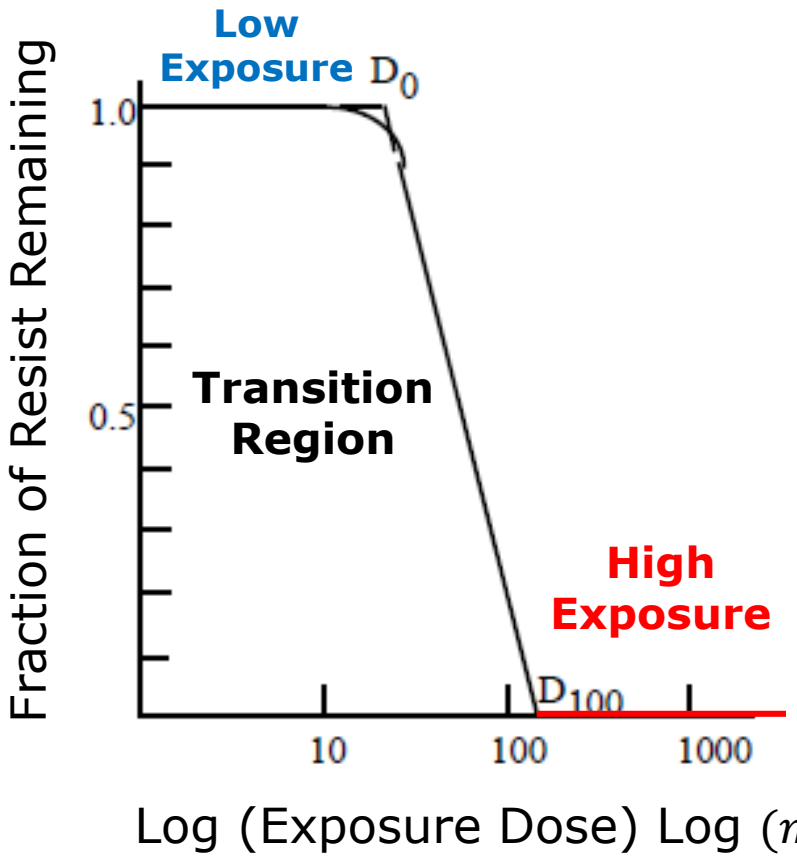
Resolution and Contrast of Resist

- Resolution: How fine a line the resist can reproduce from an aerial image
- Resolution of resist is determined by:
  - Contrast, thickness, and proximity effects
  - Swelling and contraction after development
- Contrast: Ability of resist to distinguish between transparent and opaque regions of the mask
  - Measured by exposing the resist of given thickness to varying radiation dose and measuring dissolution rate

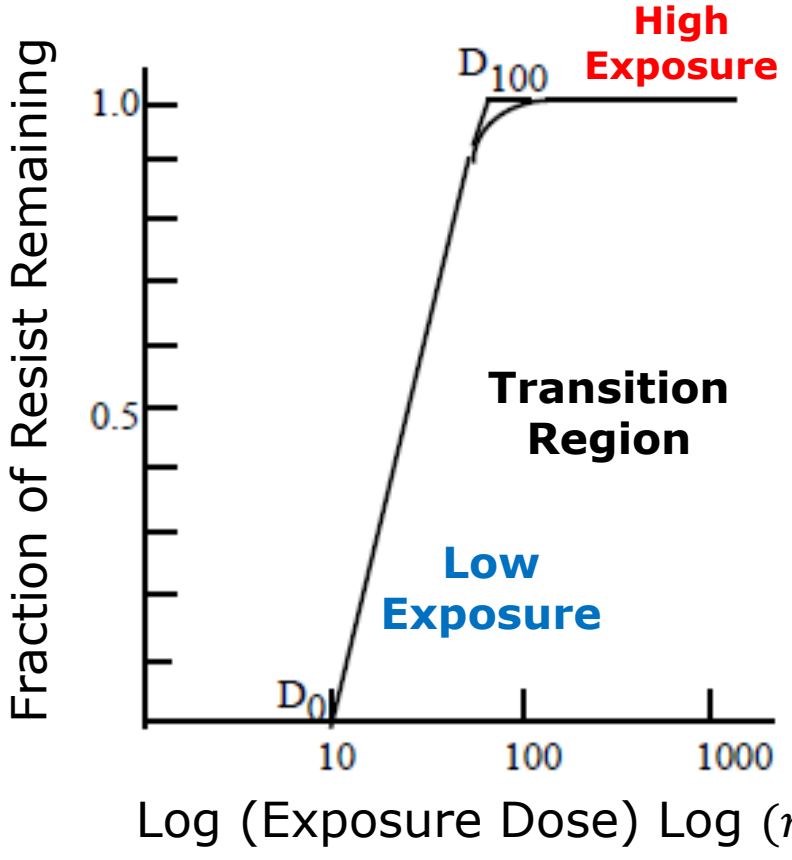
Contrast Curve

- The contrast curve of the resist presents the fraction of remaining resist as a function of exposure dose (mJ/cm^2).

Positive Resist



Negative Resist



$mJ/cm^2 = mW/cm^2 \times sec$

Contrast of a Resist

Contrast, γ, can be defined as:

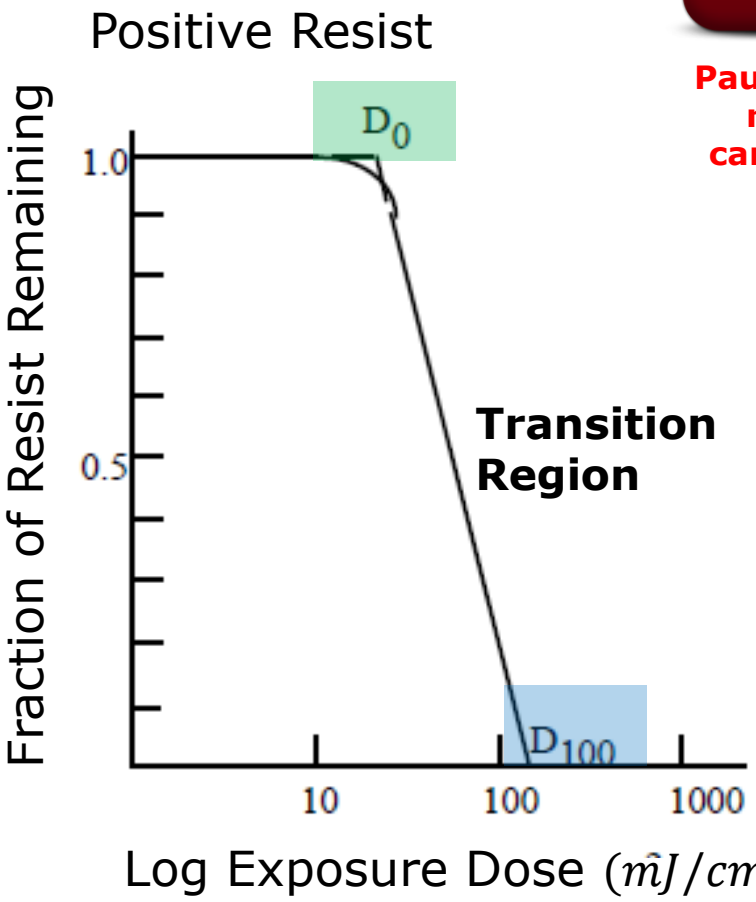
$$\gamma = \left[log_{10} \frac{D_{100}}{D_0} \right]^{-1}$$

D_{100}: Lowest energy dose where **all of the resist is removed**

D_0: Lowest energy dose to **begin to drive the photochemistry**

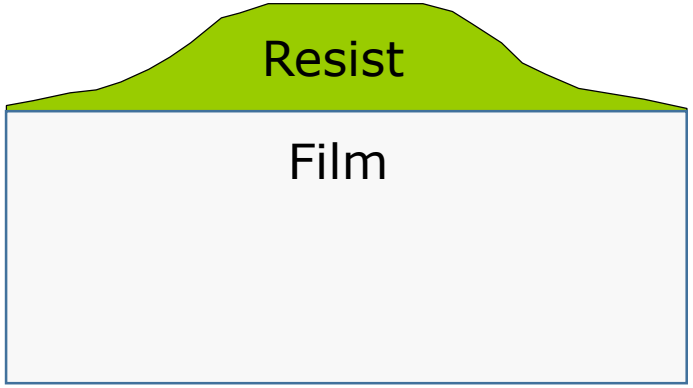
Contrast

- Measures the **ability** of the resist **to distinguish** between **transparent** and **opaque regions** of the mask
- Higher ability to distinguish → **Higher contrast** → **Sharper edge**



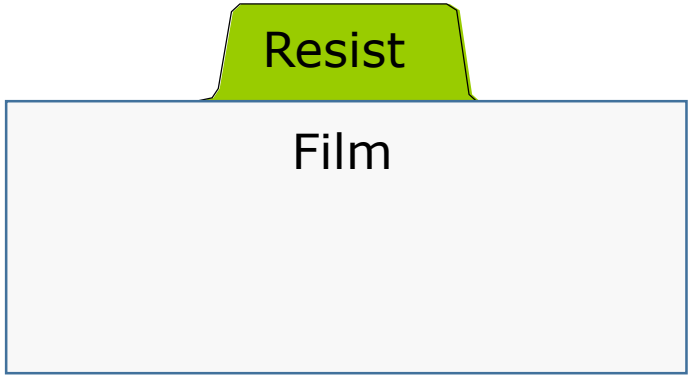
Pause and read carefully

Resist Contrast



Low Resist Contrast

- Sloped walls
- Swelling
- Poor contrast



High Resist Contrast

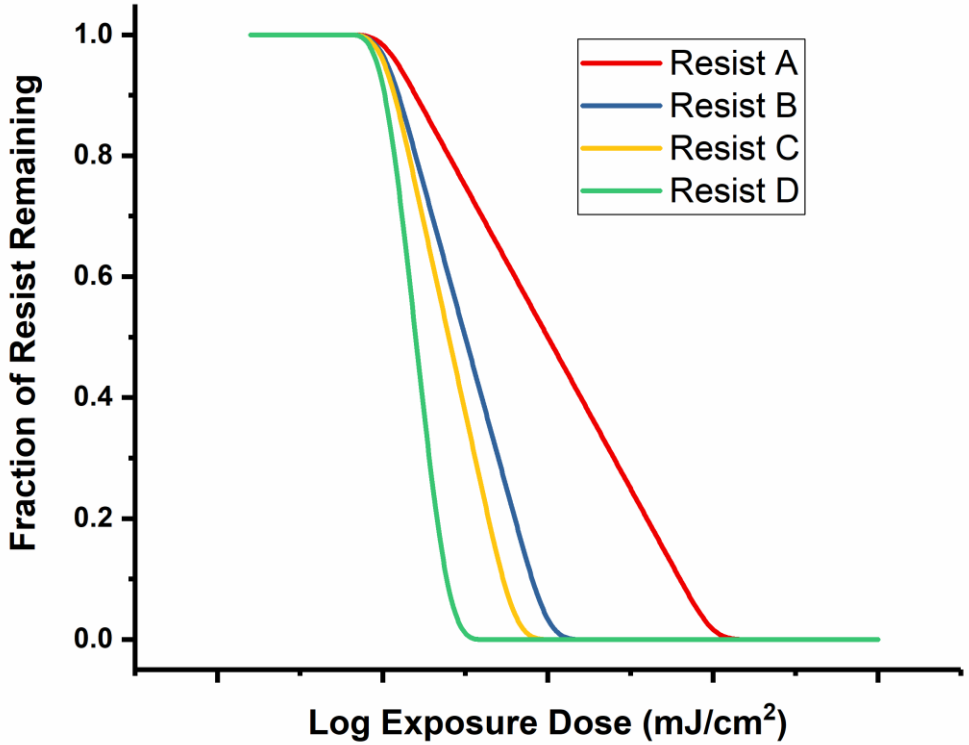
- Sharp edges
- No swelling
- Good contrast

Practice Question 1

The fabrication process of a device requires resist that is capable of **achieving sharp edges**.

Pause and try out this question

Which of the following resists is the most suitable for this purpose?

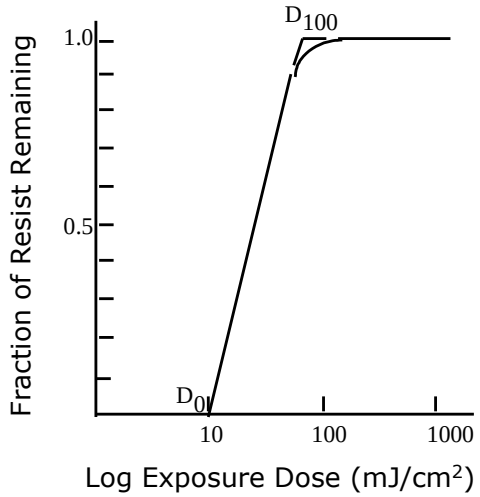


Resist D:

- It has the steepest contrast curve, indicating high contrast value.
- The high contrast value indicates ability to form sharp edges.

Practice Question 2

Figure shows a contrast curve of a photoresist.



Pause and try out this question

1. What type of photoresist is this?
2. Using the estimated values of D_0 and D_{100} from the figure, determine the contrast value γ.
3. What happens of the exposure dose is at a point between D_0 and D_{100}?
4. Discuss whether the resist contrast should be high or low.

Practice Question 2

Pause and read carefully

1. Negative Resist

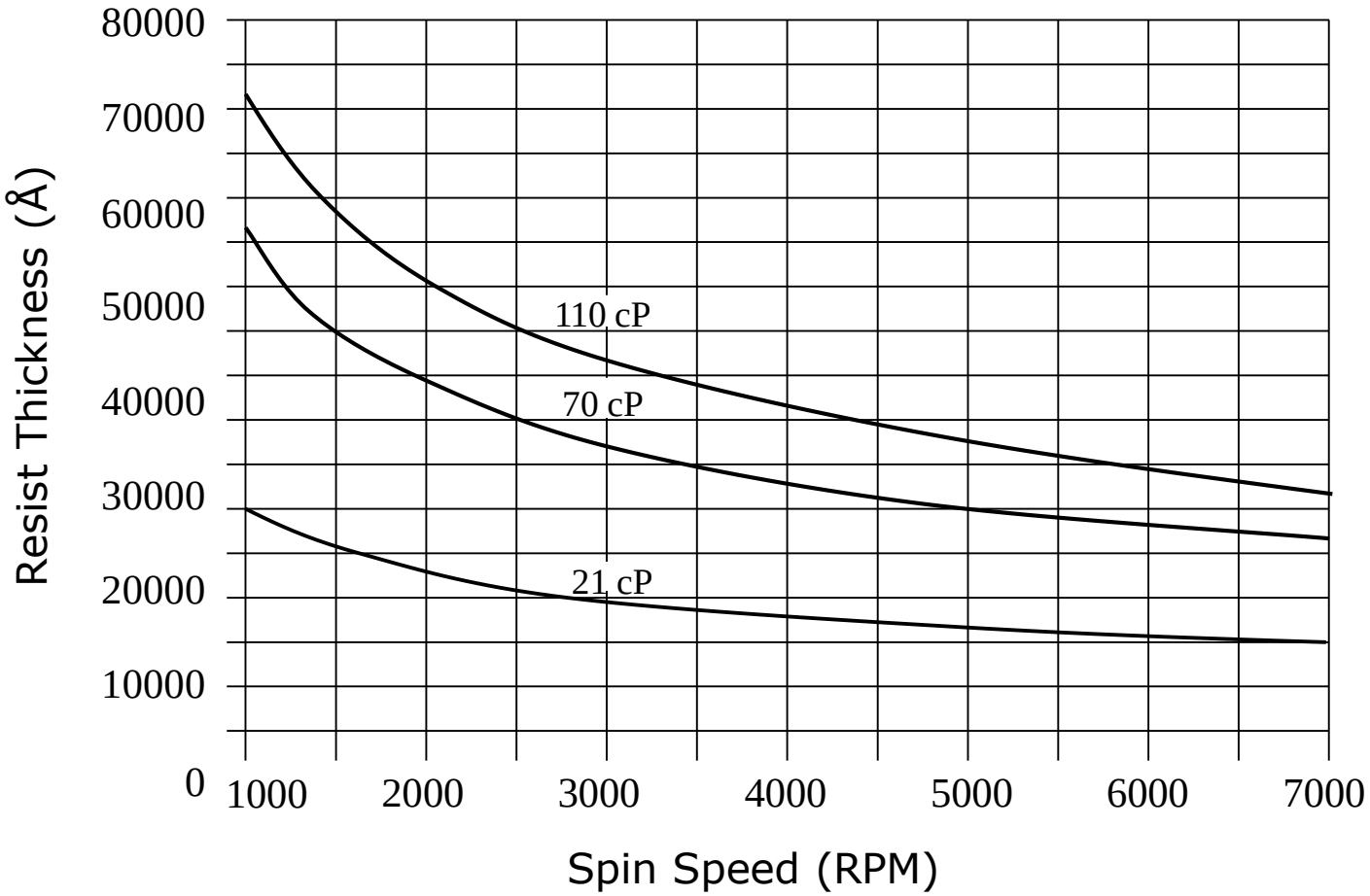
2. $\gamma = \left[log_{10}\frac{D_{100}}{D_0}\right]^{-1} = 1/\ [\log_{10}\frac{90}{10}] = 1.05$

3. Blurred (not sharp) pattern transfer

4. The higher the contrast of the resist, the sharper the line edge. Resist contrast represents the sharpness of the transition from exposure to non-exposure in photoresists. The higher the contrast, the sharper the edge.

Resist Viscosity

Spin speed curve of IX300 (thick DNQ resist) for different viscosity.



Solvent:

- Keeps photoresist in liquid state
- Allows spin coating of the photoresist
- Solvent content determines resist viscosity and hence, the **thickness**

Thinner Resist

$$I_R \cong \left[\frac{viscosity \times solid\ content\ (\%)}{\sqrt{spin\ speed}}\right]$$

Higher Spin Speed

Practice Question 3

Pause and try out this question

An experiment in a spin coating process shows that a final resist thickness of 320nm is obtained when spun at 3000 rev/min.

a) Estimate the spin speed, if a 270nm thick coating of the same resist is required.

b) If the maximum practical spin speed is 4000 rev/min, how would you re-formulate the resist to meet the above required resist thickness of 270nm?

a) Resist Layer Thickness, $I_R \cong \left[\frac{viscosity \times solid\ content\ (\%)}{\sqrt{spin\ speed}}\right]$

$$270 = \frac{\sqrt{3000}}{\sqrt{spin\ speed_1}} x\ 320$$

Therefore new spin speed = 4214 rev/min

b) If the max speed is restricted to 4000 rev/min, the viscosity and/or the solid content of the resist need to be increased in value.

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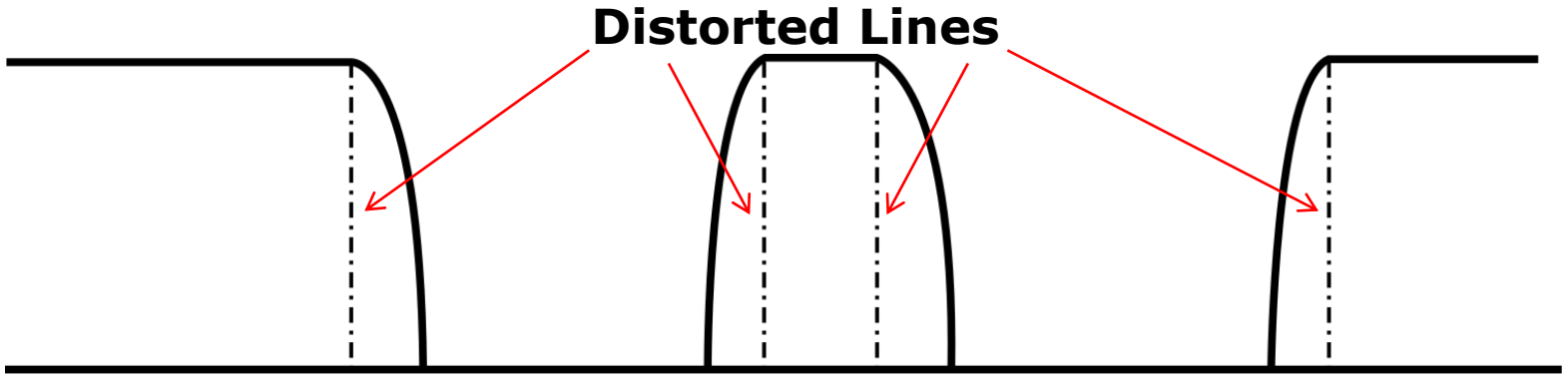
Advantages and Disadvantages of Positive and Negative Resist

Advantages and Disadvantages of Using Negative Resist

Advantages
Well established
Shorter exposure time as compared to positive resist, higher throughput

Disadvantage
Solvent-induced swelling • Broadening of linewidth during development phase • Not suited to features $< 2\mu m$



Developed Negative Resist:

Dashed Lines Indicate Mask Pattern – Solvent-Induced Swelling

Advantages and Disadvantages of Using Positive Resist

Pause and read carefully

Advantages
Does not suffer from swelling
Better resolution
Thick resist available (for etching)

Disadvantage
Lower throughput: Requires much larger energy and longer exposure time

Etching will be discussed in the coming lecture

Advantages and Disadvantages of Resists

Pause and read carefully

Advantages	Disadvantage
Well established	**Solvent-induced swelling** • Broadening of linewidth during development phase • Not suited to features $< 2\mu m$
Shorter exposure time as compared to positive resist, higher throughput	

Negative Resist

Advantages	Disadvantage
Does not suffer from swelling	Lower throughput – requires much larger energy and longer exposure time
Better resolution	
Thick resist available (for etching)	

Positive Resist

Resist Technology - Summary

Resist technology:

- Positive resist forms carboxylic groups after photochemical reaction with UV light, enabling it to be dissolved in the base developer.
- Negative resist forms polymer cross-linking after photochemical reaction with UV light, preventing it from dissolving in the organic developer.
- The important metrics of resist include resolution, contrast, and viscosity.

Practice Question 1

For the next nine statements, choose the type of photoresist, positive (+) or negative (-), that matches the accompanying statement.

Pause and try out this question

a)	+	-	Undergoes a chemical change when exposed to UV light.
b)	+	-	The exposed regions become crosslinked and hardened.
c)	+	-	The exposed regions become soluble and soft.
d)	+	-	The resulting pattern is exactly the same as the mask.
e)	+	-	The resulting pattern is opposite of the mask pattern.
f)	+	-	Swells up during the develop process, which limits Critical Dimensions.
g)	+	-	Has the best resolution of the two types of resists.
h)	+	-	The dominant resist type for use in VLSI processing.
i)	+	-	The preferred resist for use in submicron lithography.

Practice Question 2

Pause and try out this question

An optical lithography system has an exposure power of 0.3 mW/cm^2. The required exposure energy for Resist A is 10mJ/cm^2, and for Resist B is 130 mJ/cm^2.

a) Compare the wafer throughput for Resist A and Resist B. Assume negligible time for setting up the wafers.
b) Identify the type of photoresists for Resist A and Resist B. State the reason for your answers.

Answers:

a) Time taken for Resist A = 10/0.3 = 33 sec – faster throughput
   Time taken for Resist B = 130/0.3 = 433 sec – lower throughput
b) Resist B is likely to be a positive resist. Require much larger energy, and longer exposure time, thus lower throughput. Resist A is likely to be a negative photoresist.