Questions

1. *Please explain the specifics of ALD in comparison to CVD!*
2. *What are the steps of an ALD cycle?*
3. *Please name potential applications of ALD thin films!*

4. *Please name the basic process steps in the process flow of lithography and patterning!*
5. *Please name and discuss the equation for the resolution! (How to lower critical dimension CD = min. printable feature size)*
6. *Please name the applied resolution enhancement techniques (RET)*

7. *Please define the terms "anisotropy" and "selectivity"!*
8. *What are potential dry etching techniques? Please name the respective etching mechanisms and the achievable anisotropy!*
9. *Please draw a reactor for reactive ion etching and name the different parts!*

Q1 Please explain the specifics of ALD in comparison to CVD!

A L D	C V D
• Precursors react seperately	• Precursors react at same time
• Thickness is controlled by the numbers of circles	• Thickness is controlled by time; precise control of parameters (F, T, …)
• Highly reactive precursors	• Less reactive precursors (risk gas phase reaction → particle formation)
• Overdosing of precursor is allowed	• Exact precursor doping is important to ensure a desired deposition rate

Atomic Layer Deposition: Comparison of ALD and CVD

A L D

- *Highly reactive precursors*
- *Precursors react separately on the substrate*
- *Precursors do not decompose at process temperature*
- *Uniformity ensured by the saturation mechanism*
- *Thickness control by counting the number of reaction cycles*
- *Surplus precursor dosing acceptable*

C V D

- *Less reactive precursors*
- *Precursors react at the same time on the substrate*
- *Precursors can decompose at process temperature*
- *Uniformity requires uniform flux of reactants and temperature (in reaction rate limited case)*
- *Thickness control by precise process control and monitoring*
- *Precursor dosing important*

Q2 What are the steps of an ALD cycle?

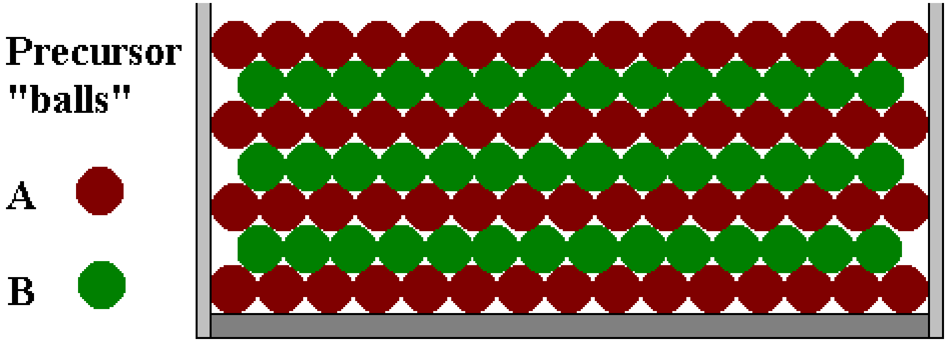
How many steps per cycle (min.)? 4 steps (two precursors for binary material (TiN, AlOx) or elemental Cu)

Step 1: Precursor A dosing – chemisorption, complete saturation of the available adsoption sites
Step 2: Purge step – removal of non-reacted precursor (A) and reaction by-products
Step 3: Precursor B dosing – chemisorption, complete saturation of the available adsoption sites
Step 4: Purge step – removal of non-reacted precursor (B) and reaction by-products

How many cycles are combined for complete film deposition? (GPC: 0.5 A/cycle, target film thickness is 5 nm)

- 100 cycles

Atomic Layer-by-layer Growth

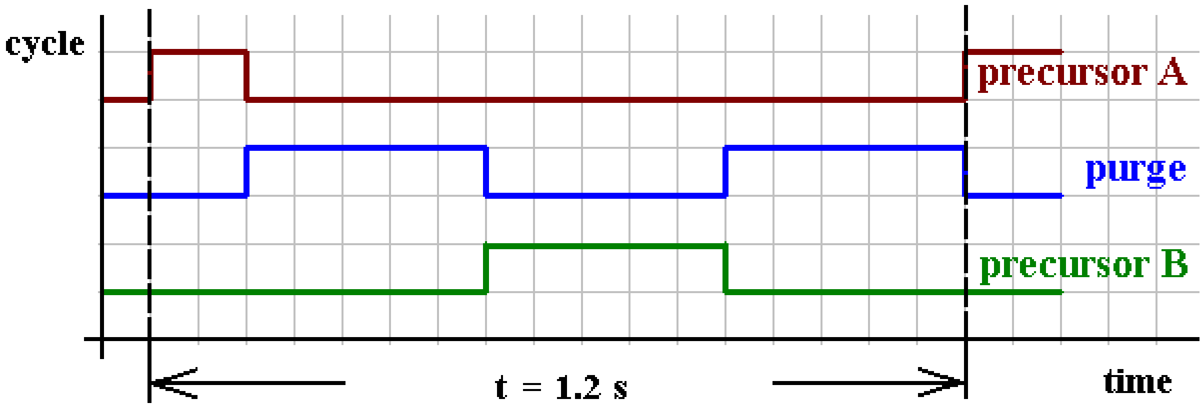


The intrinsic surface control mechanism:

Saturation of all the reaction/adsorpion sites

Purging step

ALD Cycle



Q3 Please name potential applications of ALD thin films! (in production)

Applications	Materials
1) Gate dielectric	HfOx,
2) Diffusion barrier films	TiN, TaN
3) Capacitor electrodes	TiN, TaN,
4) Capacitor dielectrics	Al2O3,

Atomic Layer Deposition: Processes for IC Industry

High-k gate dielectrics

- *Replacement of current SiO_2/Si_3N_4 films*
- *Processes available for ZrO_2, HfO_2, mixed materials*
- *Targeted (equivalent) oxide thickness - EOT: ~ 1.0 nm*

High-k capacitor dielectrics

- *Replacement of current SiO_2/Si_3N_4, Ta_2O_5 films*
- *ALD processes for Al_2O_3, Ta_2O_5*

Diffusion barriers (to avoid Cu diffusion)

- *Replacement current sputtered diffusion barriers*
- *ALD processes for TiN, W(C)N, Ta(C)N, mixed nitrides*

Conducting/Metal films

- *ALD Cu seed layers for Cu electroplating*
- *Electrodes for high k gate and capacitor applications (metals & metal nitrides)*

EOT – equivalent oxide thickness

Q4 Please name the basic process steps in the process flow of lithography and patterning!

1) Wafer priming: dehydration bake (annealing) / adhesion promoter deposition
2) Coating of photo resist (PR): spin-on coating
3) Soft or pre-exposure bake: drive-off solvent
4) Exposure using mask (positive resist → exposed areas get resolvable)
5) Post exposure bake
6) Development of PR: patterning of PR, remove exposed part (pos. Exp.)
7) Hard bake: crosslinking = hardening of resist, prepare for next step (etching, implantation)
8) Dry etching
9) Resist stripping (wet, dry , both)
10) Cleaning

Q4 Please name the basic process steps in the process flow of lithography and patterning!

1) pre-treatment: dehydration bake / adhesion promotor deposition
2) spin-on deposition / coating of the wafer with photoresist (PR)
3) Pre-exposure bake (drive of solvent)
4) Exposure (mask): positive resist: exposed areas will change ist properties and get resolvable
5) Post-exposure bake
6) Development of PR (patterning the PR, etching the exposed areas in a liquid solution)
7) Hard bake: making the PR more crosslinked, resistive to the etching process
8) Dry Etching – pattern the film using the PR mask (additional hard mask may be required)
9) PR stripping / removal by combination of dry/wet process
10) [cleaning]

3.6.2 Lithographic Process

Overview

Wafer Prime (HMDS)

ARC Coating
ARC Bake

↓

Resist Coating

↓

***S**oft **B**ake, **P**ost **A**pply **B**ake*

↓

Exposure

↓

***P**ost **E**xposure **B**ake*

↓

Develop

↓

***H**ard **B**ake*

↓

(UV Harden)

If Specifications are not met

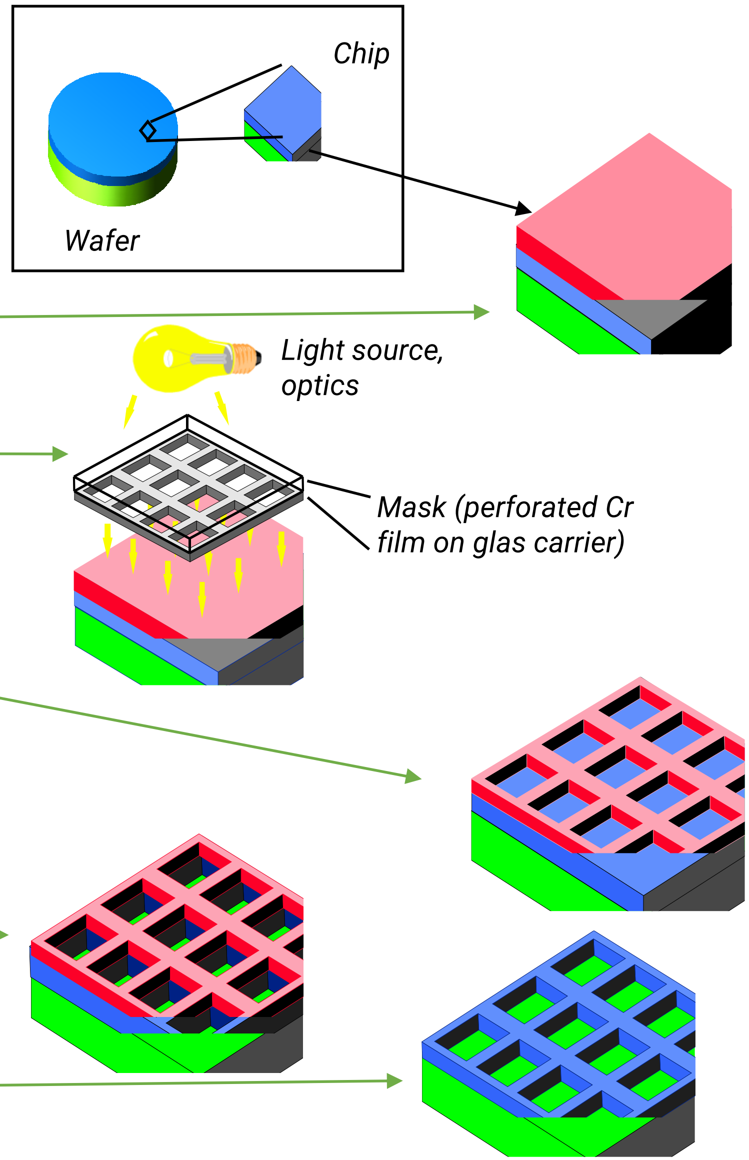
Rework

↓

Pattern transfer (etching, implantation)

↓

Resist removal (stripping, dry, wet)



HMDS – Hexamethyldisilazan (Primer)
ARC - Anti-reflective coating

Q5 Please name and discuss the equation for the resolution!

(How to lower critical dimension CD = min. printable feature size)

$$l_{min} = k_1 \cdot \frac{\lambda}{NA}$$

Wavelength (prop)
Numerical aperture NA (inverse prop)
K1 factor (prop)

Wavelength: visible light (300-700nm) → DUV 193 nm → EUV (soft x-ray) 13.5 nm
NA: increase by improving optics (DUV: refractive; EUV reflective),
NA=n*sin(alpha) → increase n by immersion litho (water instead of air)
K1: lower by using resolution enhancement techniques (RET)

Q5 Please name and discuss the equation for the resolution! (How to lower critical dimension CD = min. printable feature size)

$$l_{min} = k_1 \cdot \frac{\lambda}{NA}$$

Ways to reduce l_{min}:

1) Reduce exposure wavelength (some 100 nm … DUV 248/193 nm … EUV/soft X-ray 13.5 nm)
*2) Increase the numerical aperture NA: improving optics, increase n (move from air → water = immersion litho; NA = n * sin(beta)*
3) RET – resolution enhancement techniques!

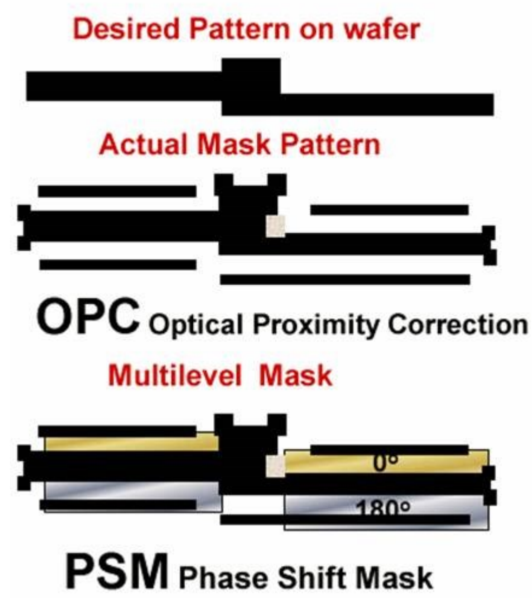
- *reduce λ (→ DUV → EUV → X-ray)*
- *increase NA (immersion litho)*
- *reduce k_1 (RET)*

Q6 Please name the applied resolution enhancement techniques (RET)

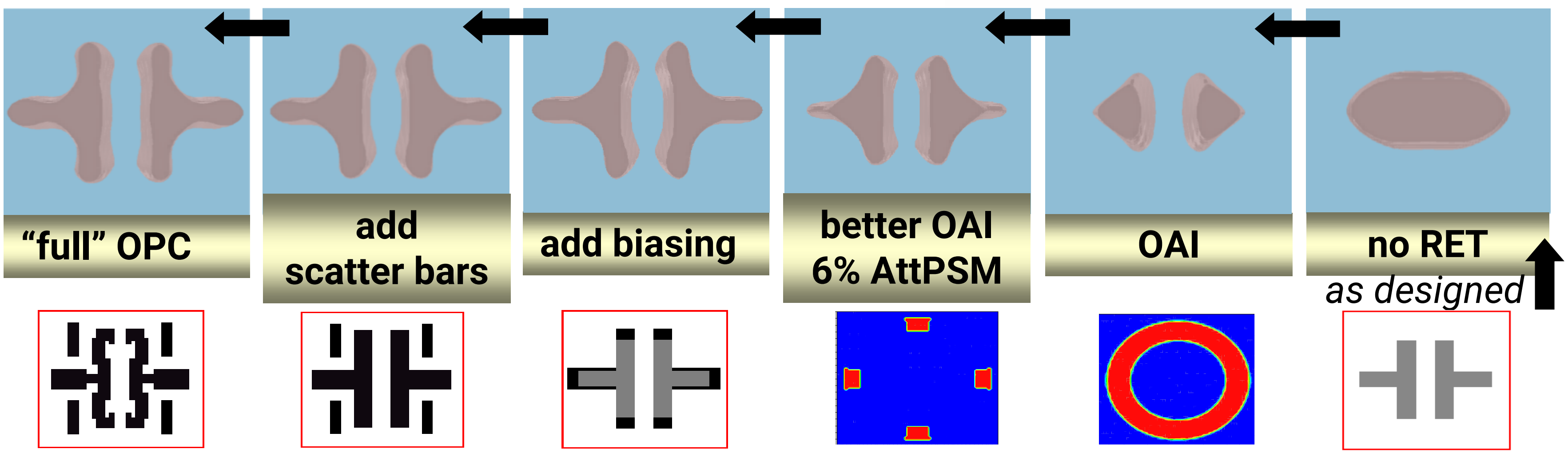
1) Optival Proximity Correction (OPC)
2) Off-Axis illumination (OAI)
3) Double exposure
4) Phase shift maks (PSM)

Combination of RET Solutions

- *This is what the designer drew*
- *Added 'scattering bars' and serifs to make the polygon print more exactly*
- *Added additional phase features to allow printing smaller features at the same wavelength*



Accurate and flexible modeling is key!



(Courtesy ASML)

Q7 Please define the terms “anisotropy” and “selectivity”!

Anisotropy:

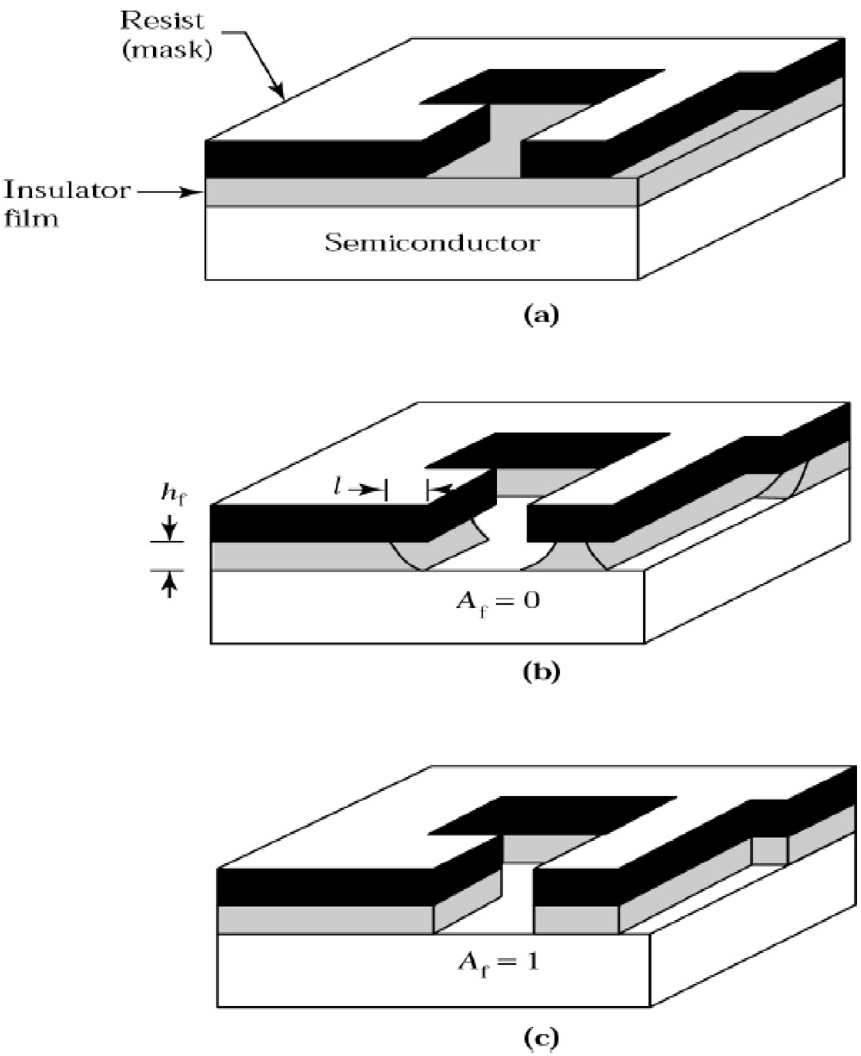
- Anisotropy is the rate of vertical etching compared to the rate of horizontal etching

Selectivity:

- Selectivity is the ratio of etch rates of different materials

Degree of Anisotropy:

$$A_f \equiv 1 - \frac{l}{h_f} = 1 - \frac{R_l t}{R_v t} = 1 - \frac{R_l}{R_v}$$



For isotropic etching: $\boldsymbol{R_l = R_v}$ ***and*** $\boldsymbol{A_f = 0}$

For completely anisotropic etching: $\boldsymbol{R_l = 0}$ ***and*** $\boldsymbol{A_f = 1}$

Selectivity: Ratio of etch rates of different materials

$S_{(to)\ resist} = R_{etched\ film} / R_{resist}$

$S_{(to)\ underlayer} = R_{etched\ film} / R_{underlayer}$