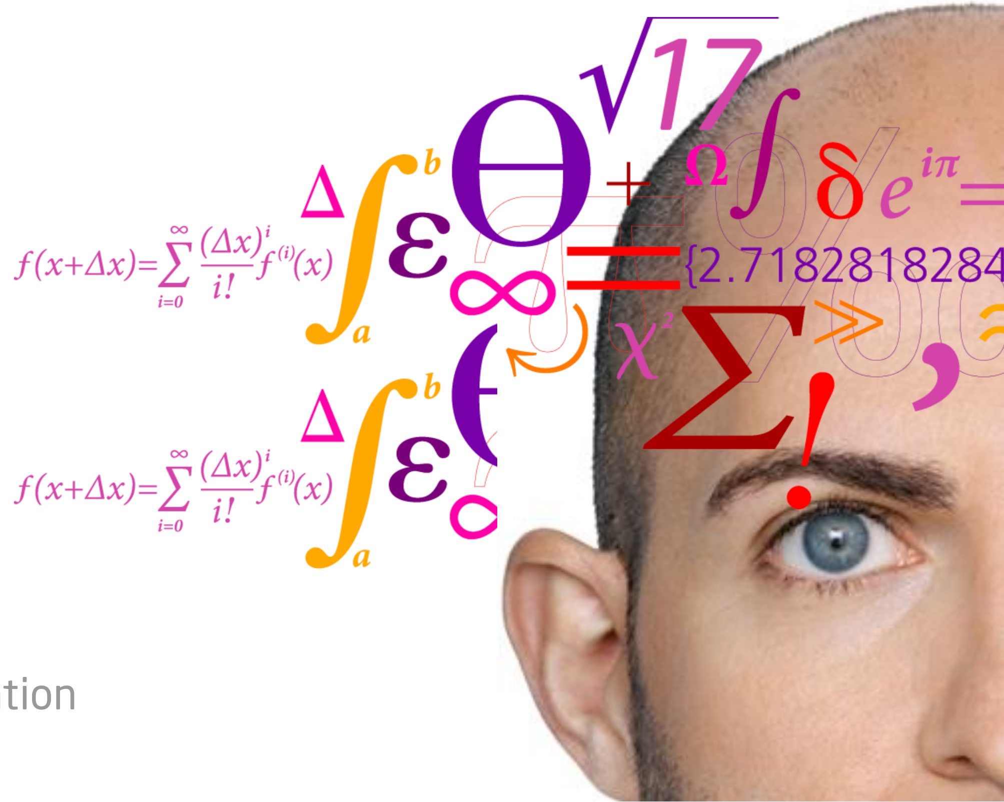
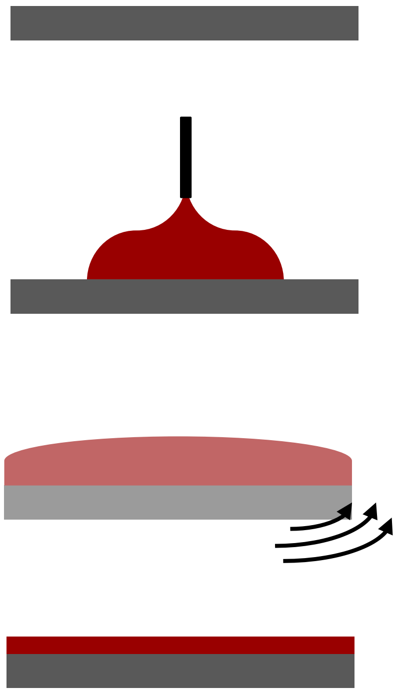
Lithography Tool Package

Spin Coating



DTU Danchip
National Center for Micro- and Nanofabrication

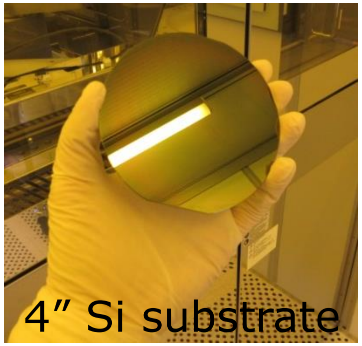
Spin coating



substrate

resist

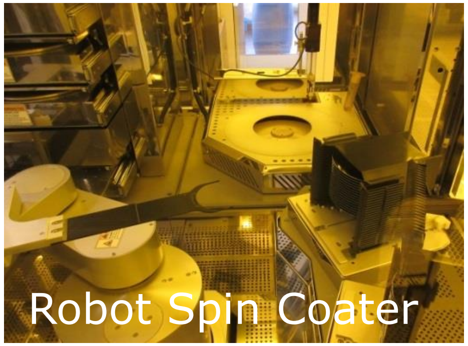
spinning



4″ Si substrate

Wafer boxes

Resist bottles



Robot Spin Coater

Manual Spin Coater

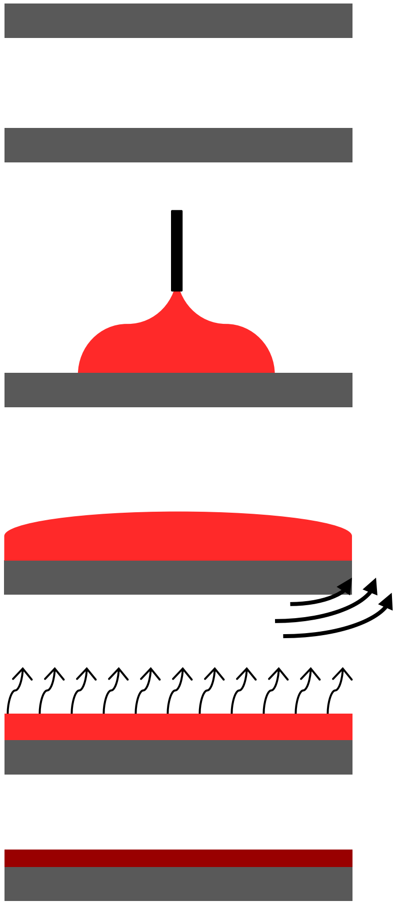
Photoresist: composition

- **Resin**: Monomers or polymer chains of varying length (solid at RT)
- **Photo-active component** (PAC): Reacts with UV-light during exposure and changes the resin
- **Solvent** (~70%): Dissolves the resin in order to enable coating

- Thermal stability
  - Good up to ~100ºC
  - At higher temperatures: reflow (rounding), embrittlement, burning
- Chemical resistance
  - Acid: good
  - Base: poor (develops)
  - Solvent: bad (dissolves)

	MiR 701	nLOF 2020	5214E	4562	SU-8
Thickness	1.5–4 µm	1.5–4 µm	1.5–4 µm	5–10 µm	4–200 µm

Spin coating: step by step

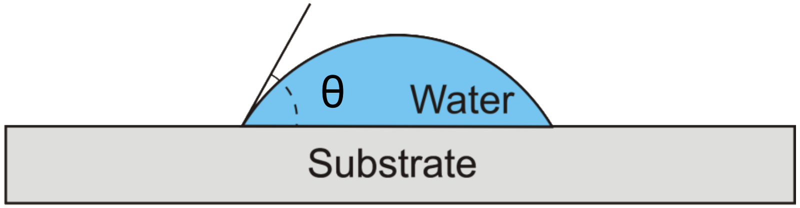


- Substrate
- Pre-treatment
- Resist deposition
- Spinning
- Softbake
- Resist film on substrate

Before coating: substrate pre-treatment

- Also called *priming* or *adhesion promotion*
- Purpose:
  - To obtain proper wetting properties of the resist on the substrate
  - To ensure good adhesion of the resist to the substrate surface

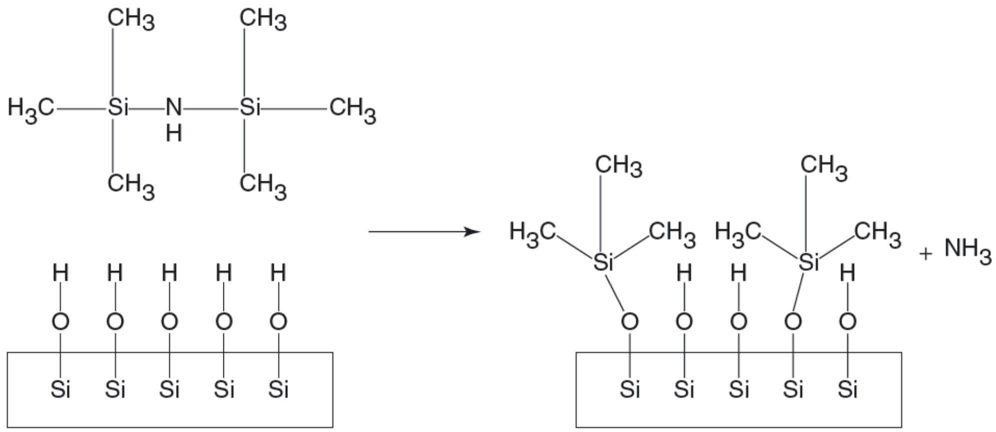
- Substrate surface pre-treatment
  - Silicon: HMDS priming or HF dip
  - Oxide or nitride layer: HMDS priming
  - Glass substrates: HMDS priming
  - Dehydration prior to priming may be necessary for thick oxide/nitride layers and glass substrates
  - Not all resists benefit from HMDS priming: SU-8 → only dehydration



- Contact angle:
  - Water droplet on a substrate
  - Optimal contact angle depends on resist and process, but is typically θ = 60–75° ($\theta_{substrate} \approx \theta_{resist}$)

Pre-treatment: HMDS vapour priming

- 1,1,1,3,3,3 **H**exa**m**ethyl**d**i**s**ilazane (HMDS)
- Process:
  - Substrate is heated in vacuum to dehydrate
  - Substrate is exposed to HMDS vapour
    → OH groups are replaced by $Si(CH_3)_3$
  - Vapour is pumped out
- Some spin coaters have in-line HMDS priming
- Shelf life after priming: days, maybe weeks

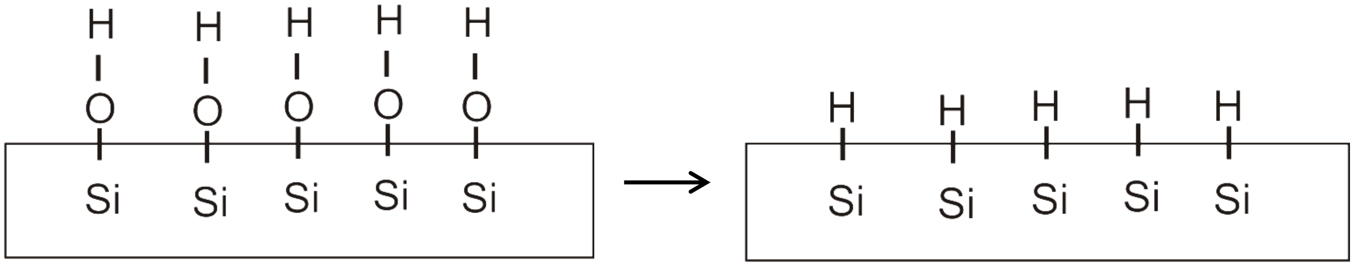


Hydrophilic, θ < 10º

More hydrophobic, θ < 60º

Pre-treatment: silicon priming by HF dip

- Remove native oxide and passivate Si surface
- Process:
    - – Substrate is immersed in HydroFluoric acid for 20–30s
        - ➢ Native oxide is etched
        - ➢ Dangling silicon bonds are terminated by hydrogen atoms
    - – Rinsed in water and dried
- Shelf life after HF dip: Spin coat within ~20 minutes
    - – Desorption of H leads to reformation of native oxide



Hydrophilic, θ < 10º

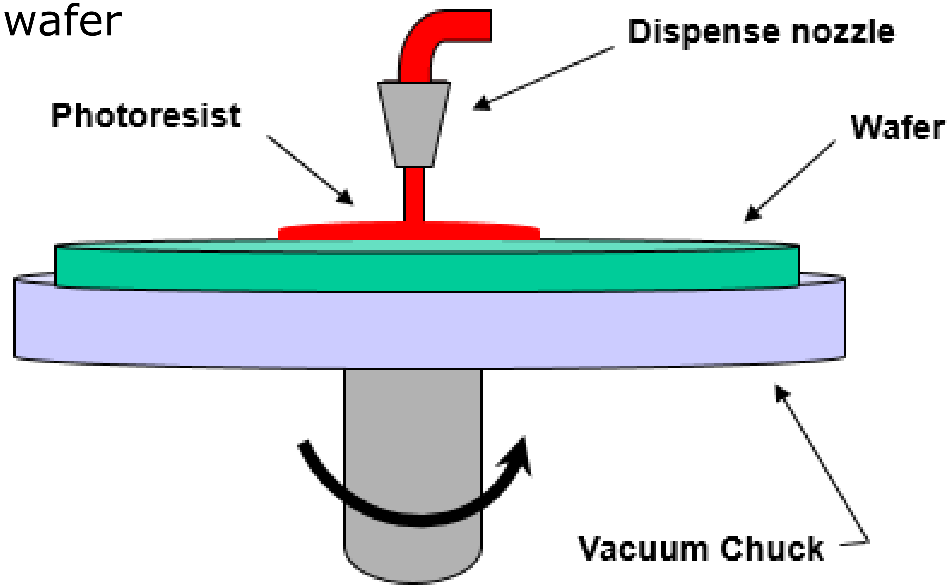
More hydrophobic, θ ≈ 70º

Spin coating: basic principle

- The wafer is held by vacuum on a motorized chuck
- Photoresist is dispensed on the wafer
- The wafer is rotated, spreading the resist across the wafer
  - Spin speed is typically 2000–5000 rpm
  - Most of the resist (ca. 95%) is spun off the wafer
- A uniform layer remains on the wafer

Typical process:

- Dispense
  - static or dynamic
- Spreading (optional)
  - low rpm, short time
- Spin-off
  - high rpm, 30–60s
  - defines the thickness



Integrated Micro Materials, Lithography Process Overview
http://www.imicromaterials.com/technical/lithography-process-overview

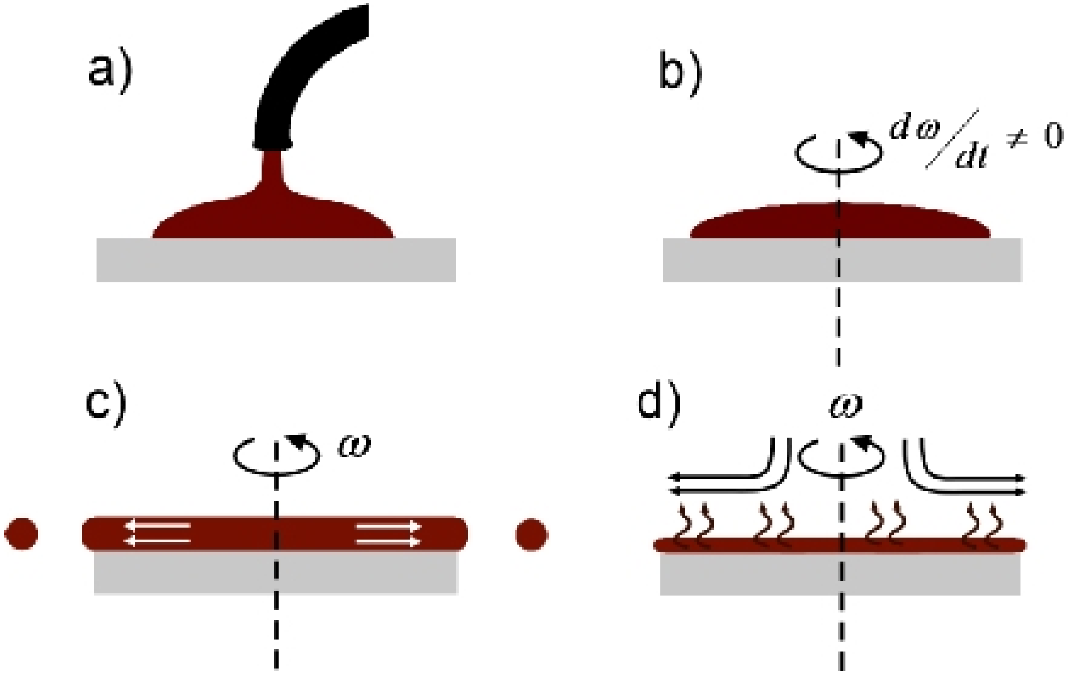
Spin coating: phases during coating

a) Resist dispense

b) Acceleration (spread)

c) Flow dominated

d) Evaporation dominated



Basic Models of Spin Coating, S. L. Hellstrom
http://large.stanford.edu/courses/2007/ph210/hellstrom1/

- Modelling is a complex fluid dynamic problem
- Local phenomena (exhaust, temperature, etc.) can affect film thickness
- In practice, engineers rely on empirical formulae and spin curves

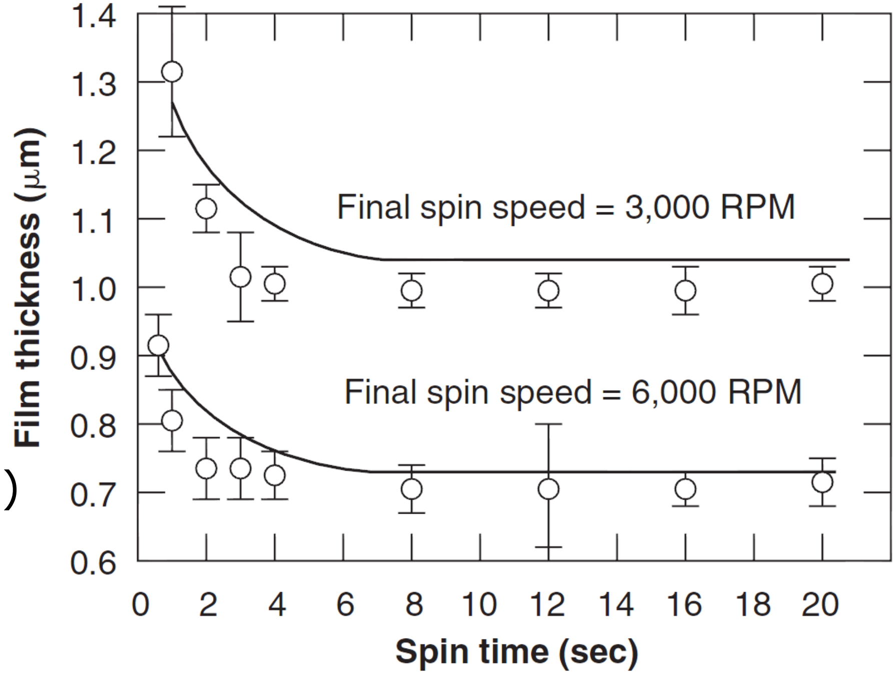
Spin coating: film thickness vs. time

- The thickness reaches a final value, when no more resist is centrifuged off the wafer
- The final thickness, as well as the time to reach it, depends strongly on:
  - viscosity
  - spin speed
  - exhaust

  less on:
  - spreading
  - acceleration

  but not on:
  - dispensed resist volume

  (as long as there is enough)



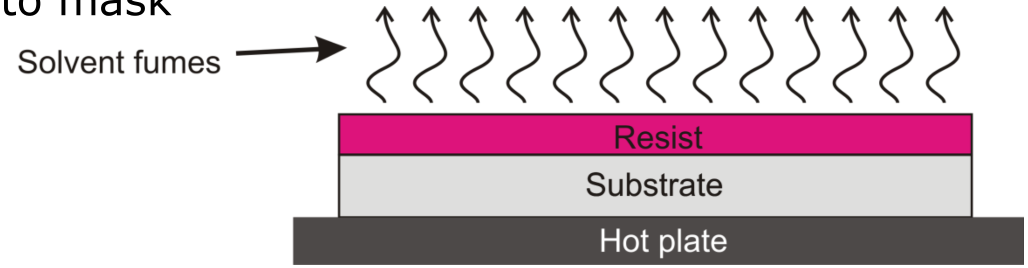
Photolithography, Scotten W. Jones, IC Knowledge LLC

- Film thickness vs. time follows an inverse power law

$$thickness \propto \frac{1}{\sqrt{time}}$$

After coating: softbake

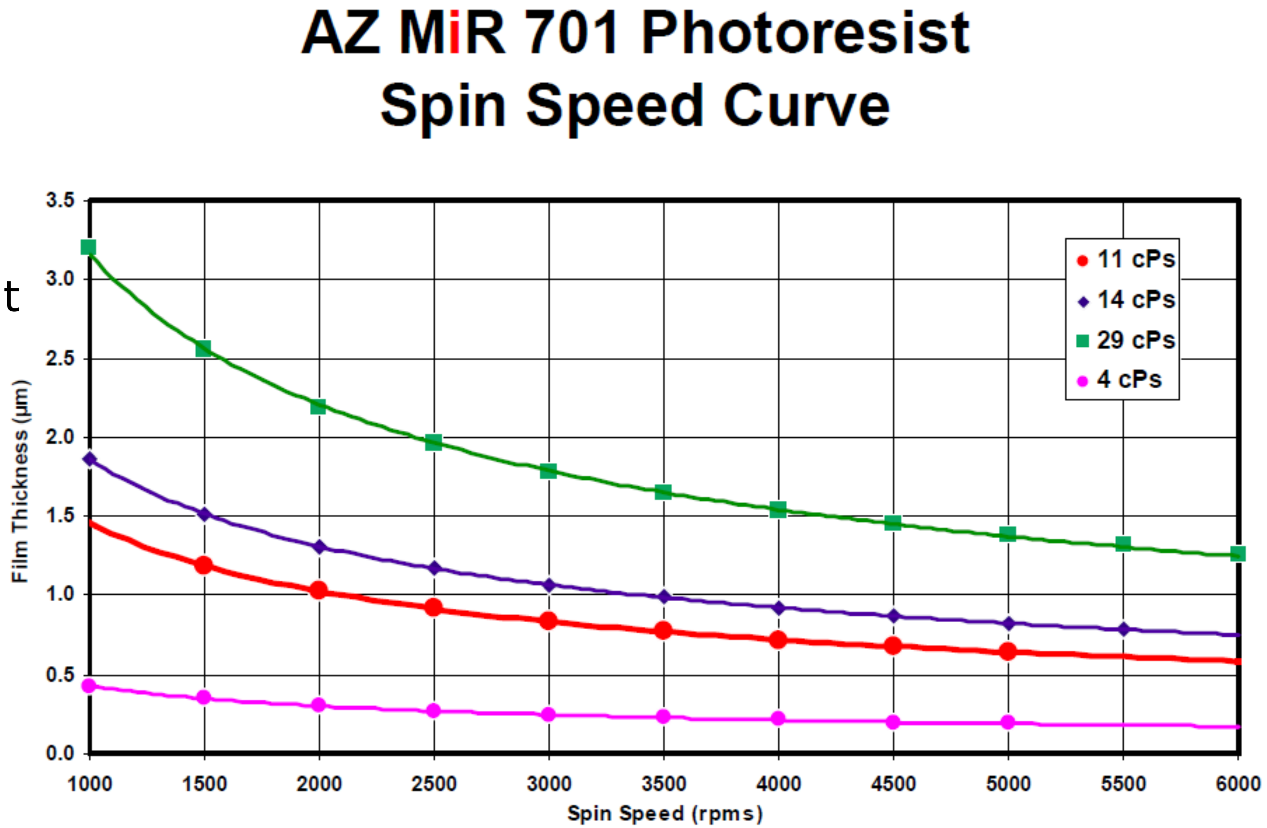
- Post-coating bake = “softbake”
- Soft bake is performed to partially drive out solvent from resist film
  - Increase mechanical stability of the resist
  - Prevent resist sticking to mask
  - Diminish dark erosion



- Softbake is usually performed on a hot plate
  - Contact baking: Wafer in contact with hot plate (vacuum)
  - Proximity baking: Wafer kept above hot plate (100 µm – 1 mm)
  - Typically 90°C for 60–120 seconds
- Increasing softbake temperature:
  - Thinner film (more solvent evaporates)
  - Decreased photosensitivity (thermal decomposition of photoinitiator)
  - >120 °C: risk of crosslinking, making the resist insoluble in developer

Spin coating: the spin curve

- Film thickness (after softbake) vs. spin speed



AZ Electronic Materials product data sheet

- A spin curve is valid for constant
  - viscosity
  - spin time
  - softbake
  - equipment

Spin coating: Modelling spin curves

Fitting spin curves has yielded the following empirical formula for the final film thickness:

$$z = K \frac{C^{\beta}\eta^{\gamma}}{\omega^{\alpha}}$$

z: film thickness

η: viscosity

C: solids concentration

ω: spin speed

K, α, β, and γ: constants

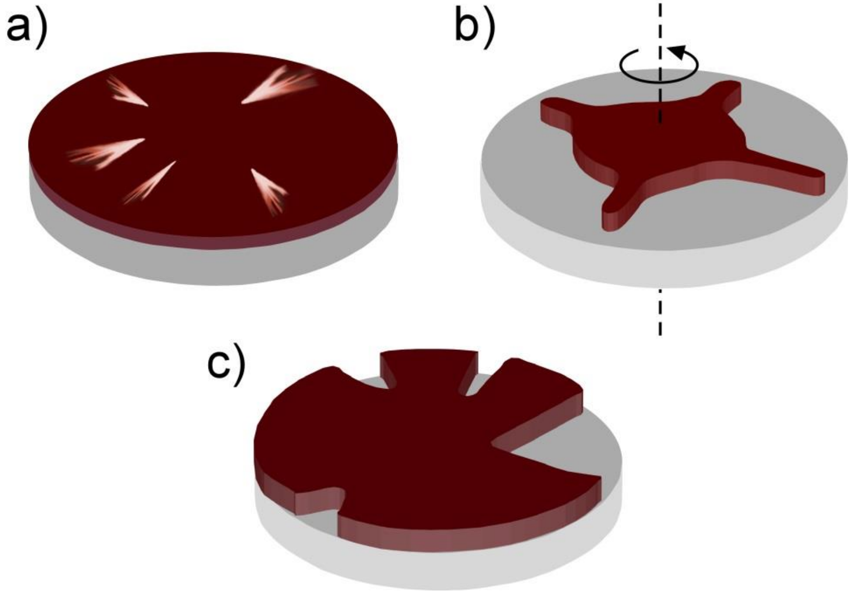
Adapted from Marc J. Madou "*Manufacturing Techniques for Microfabrication and Nanotechnology*" 2011.

- K is a calibration constant, and is commonly combined with η, C, β, and γ into a resist, process, and equipment specific calibration constant, K'
- For UV resists with medium-low viscosity $\alpha \cong 0.5$, i.e.

$$z = K' \frac{1}{\sqrt{\omega}}$$

- For thicker resists (e.g. SU-8 2075), α approaches 1
- For thinner resists (Deep-UV and E-beam), $\alpha < 0.5$

Coating imperfections



Basic Models of Spin Coating, S. L. Hellstrom
http://large.stanford.edu/courses/2007/ph210/hellstrom1/

a) **”Comets”**
Usually caused by particles on wafer or in resist

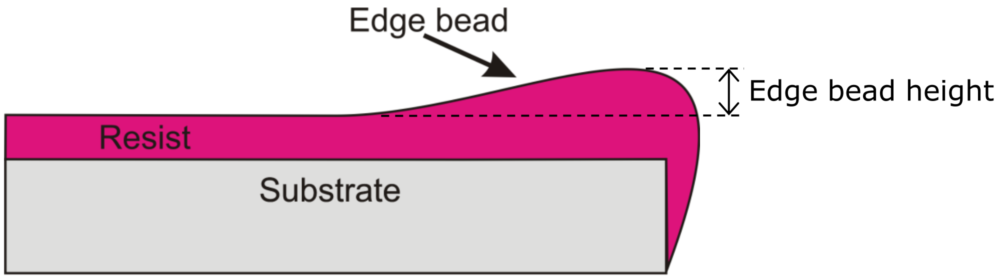
b) **Non-uniform resist spreading**
Poor substrate wetting or very high viscosity

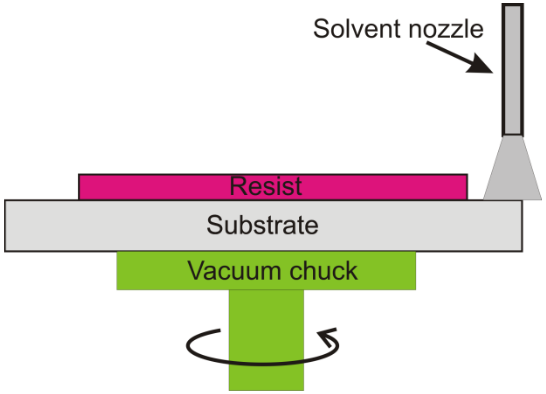
c) **Uncoated areas**
Too small dispense volume, not in the centre, or chuck not level

- Spin coating resist on substrates with structures from previous processing causes comet-like defects, and in some cases uncoated areas. Higher dispense volume may be needed for full coverage.
  The film thickness on/in and around the structures may differ from unstructured areas, and some structures may not be coated at all.

Spin coating: edge bead

- At low spin speeds and/or highly viscous resists, the surface tension of the resist starts to compete with the centrifugal forces pulling the resist off the wafer edge
- This leads to the formation of a ”bulge” at the wafer edge – known as an *edge bead*
- Typically the edge bead height is comparable to the resist thickness and may be several mm wide

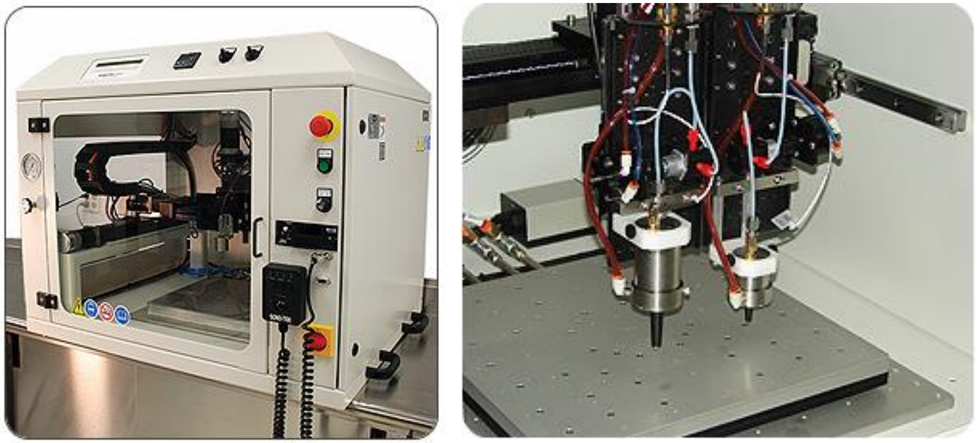




- Non-circular substrates exhibit more edge bead
- Edge beads are usually removed with solvent – **E**dge **B**ead **R**emoval (EBR)
- Edge beads can in some cases be reduced by careful design of the spin coating recipe
- Edge beads may also be reduced by spin coating under a co-rotating cover (Gyrset®) – A saturated solvent environment reduces the evaporation of solvent from the resist film

Alternatives to spin coating

- Spray coating
  - Structured samples may be coated conformally
  - Non-circular samples
  - Bulky samples



http://www.sono-tek.com/

- More exotic coating methods:
  - Dip coating
  - Roller coating
  - Curtain coating
  - Electrodeposited resist (requires conductive substrate)
  - Dry resist film → Roll lamination

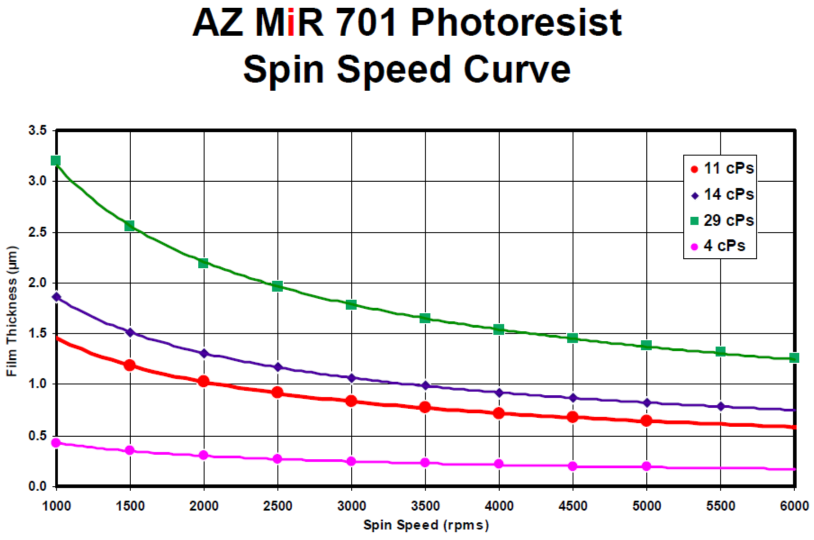
- Possible at DTU Danchip

Spin coating: exercise

- Spin coating of AZ MiR 701 at 2500 rpm yields a film thickness of 2.1 µm. Estimate the spin speed needed to obtain 1.5 µm.

- $K' = z\sqrt{\omega} \Rightarrow z_1\sqrt{\omega_1} = z_2\sqrt{\omega_2}$
- $\omega_2 = \frac{{z_1}^2}{{z_2}^2}\omega_1 = \left(\frac{2.1\ \mu m}{1.5\ \mu m}\right)^2 \times 2500\ rpm = 4900\ rpm$

$$z = K'\frac{1}{\sqrt{\omega}}$$



Outline

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    - Spin curve
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    - Process parameters
    - Resolution
    - Alignment
    - Photo-chemistry
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    - Effects
    - Resist contrast
    - Pattern transfer
    - Post-processing
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    - Process effects
    - Real life process examples