Lithography Tool Package

Spin Coating

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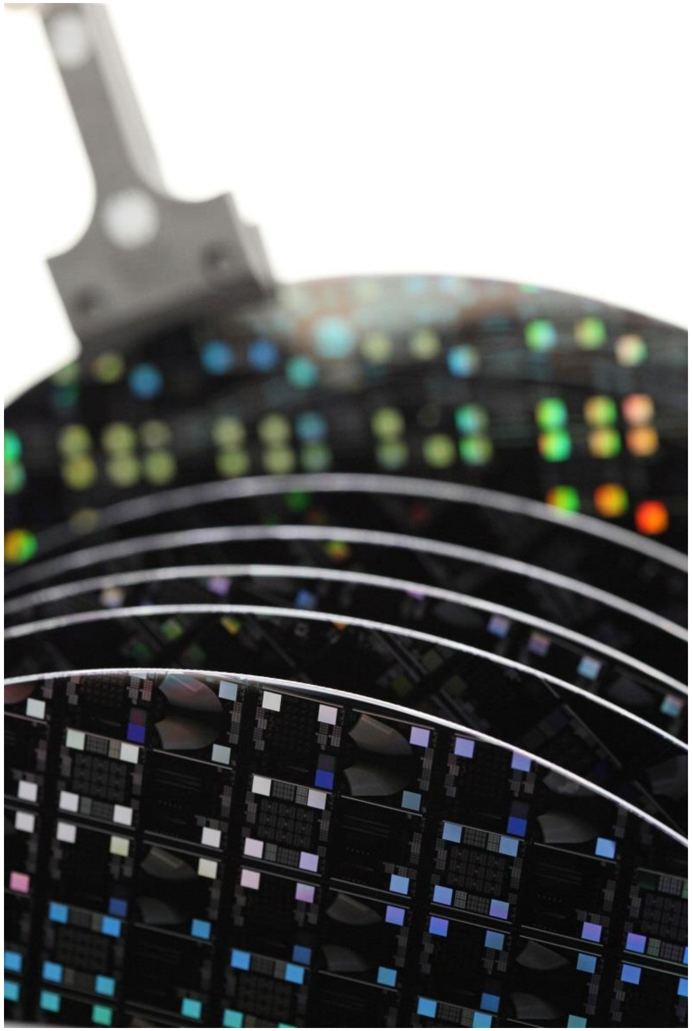


DTU Danchip

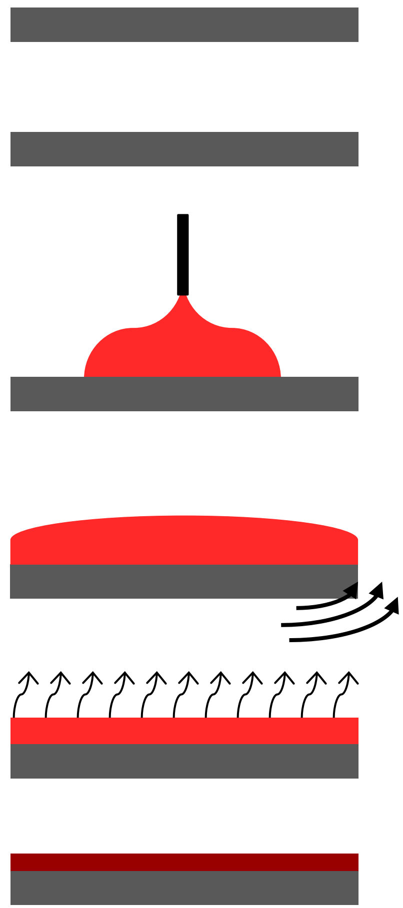
National Center for Micro- and Nanofabrication

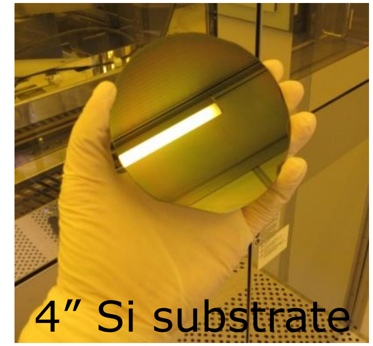
Outline

1. **Introduction**
   - Process steps in UV lithography
2. **Spin coating**
   - Resist composition
   - Pre-treatment
   - Principle
   - Softbake
   - Spin curve
3. **Exposure**
   - Hardware
   - Process parameters
   - Resolution
   - Alignment
4. **Development**
   - Principle
   - Effects
   - Resist tone, photo-chemistry, and contrast
5. **Post-processing and characterization**
   - Post processing
   - Characterization methods
6. **Process effects and examples**
   - Process effects
   - Real life process examples

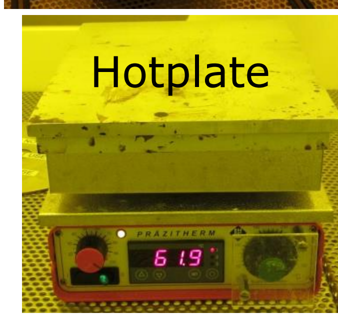
Spin coating: step by step

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





To ensure proper wetting and adhesion of the resist to the substrate surface



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

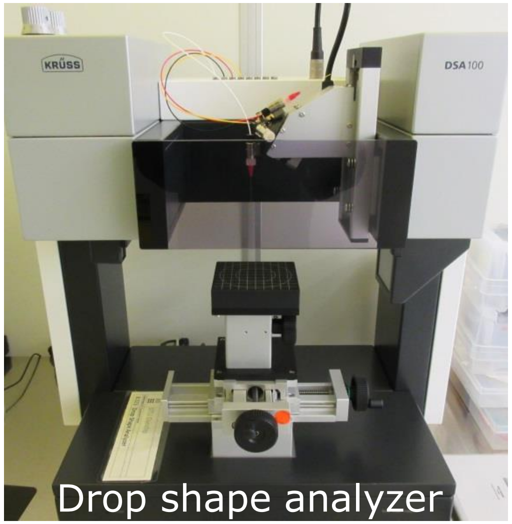
	Substrate types	Shelf life	Comments
HMDS	Si, SiO_2, SiN, glass	Several days	Thick dielectrica or glass substrates require (additional) dehydration before HMDS priming
BHF	Si	~20 min	Only Si
Dehydration	Si, SiO_2, SiN, glass	minutes	Recommended for SU-8
AP-3000	Si, SiO_2, SiN, glass, III-V	?	Not a standard process

Before coating: contact angle

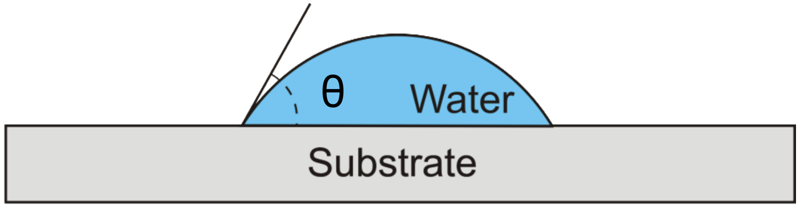
- Measuring the contact angle of water to the substrate can be used to characterize the substrate surface prior to coating

- Drop shape analyzer is used
  - Water droplet on a substrate
  - The contact angle is obtained through image analysis

- Optimal contact angle depends on resist and process, but is typically
  - $\theta = 60\text{–}75^{o}$ ($\theta_{substrate} \approx \theta_{resist}$)

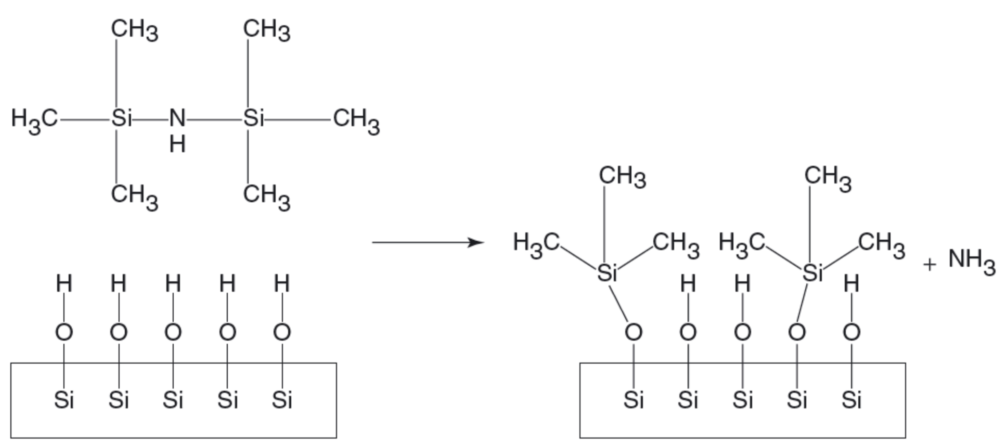


Drop shape analyzer



Pre-treatment: HMDS vapour priming

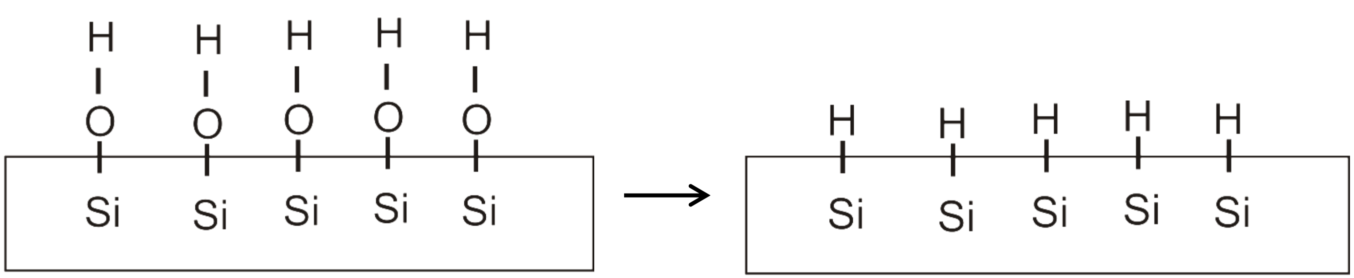
- 1,1,1,3,3,3 **H**exa**m**ethyl**d**i**s**ilazane (HMDS)
- Process:
  - Substrate is heated in vacuum to dehydrate
  - Substrate is exposed to HMDS vapour
    → OH groups are replaced by $Si(CH_3)_3$
  - Vapour is pumped out
- Some spin coaters have in-line HMDS priming



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
  - Desorption of H leads to reformation of native oxide



Hydrophilic, $\theta < 10^{\circ}$

More hydrophobic, $\theta \approx 70^{\circ}$

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)

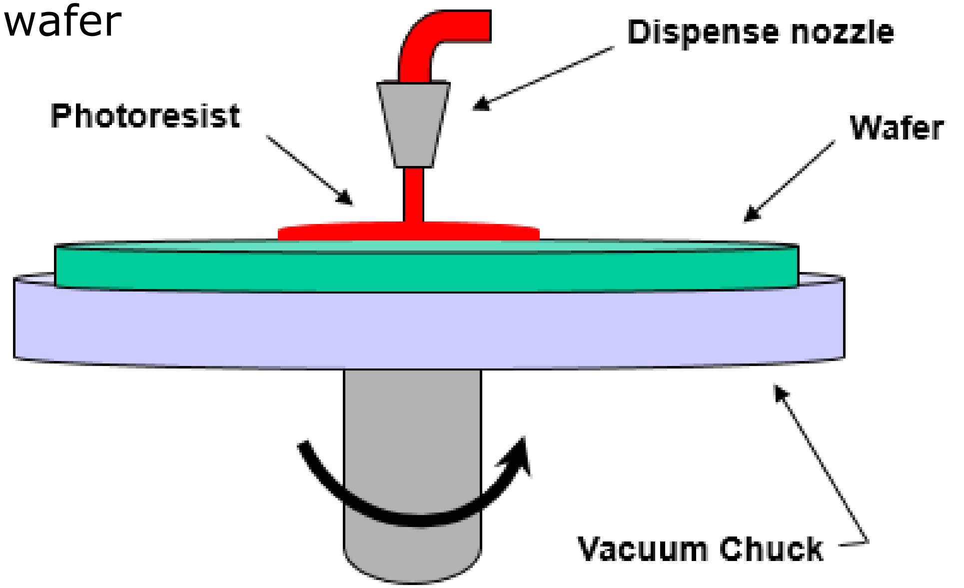
UV Resist	MiR 701	nLOF 2020	5214E	4562	SU-8
Thickness	1.5–4 μm	1.5–4 μm	1.5–4 μm	5–10 μm	4–200 μm

Spin coating: 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

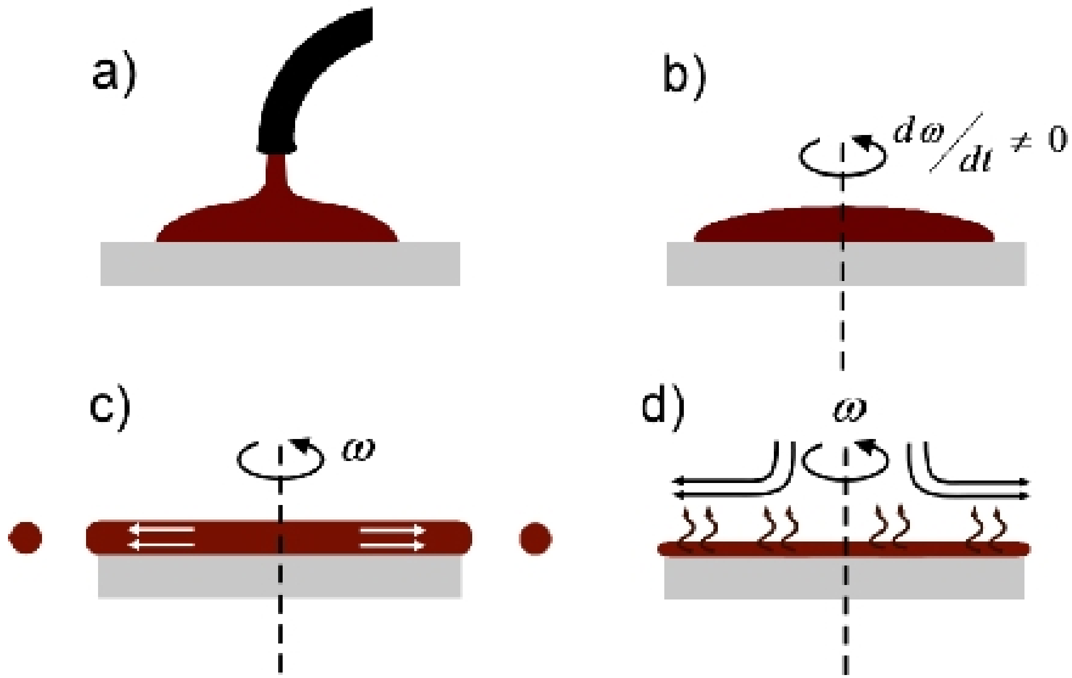
Spin coating: phases during coating

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

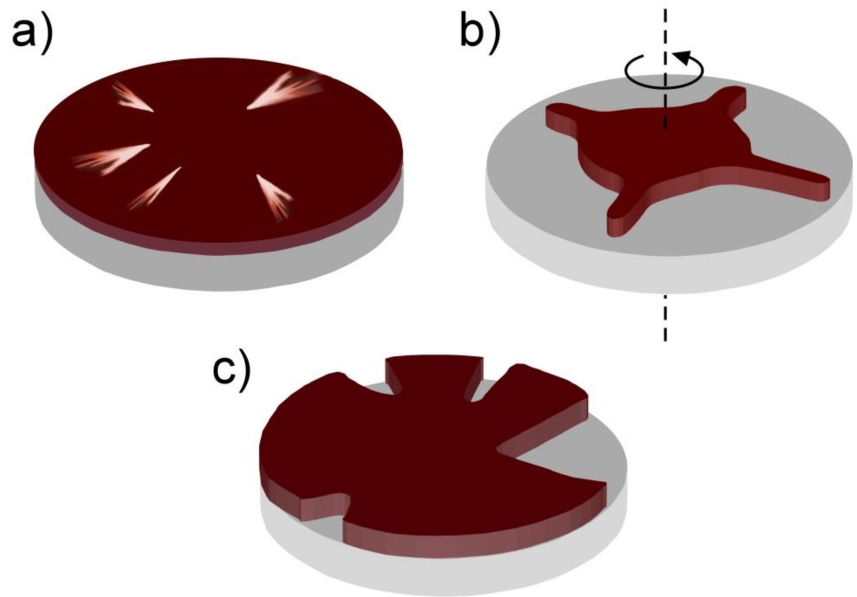
Coating imperfections

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

d) **Structured substrates**
causes comet-like defects, and in some cases uncoated areas



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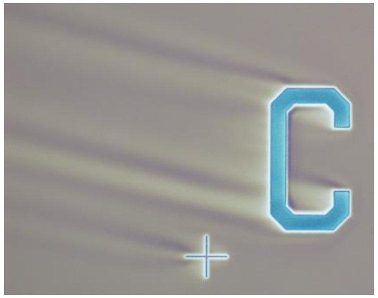
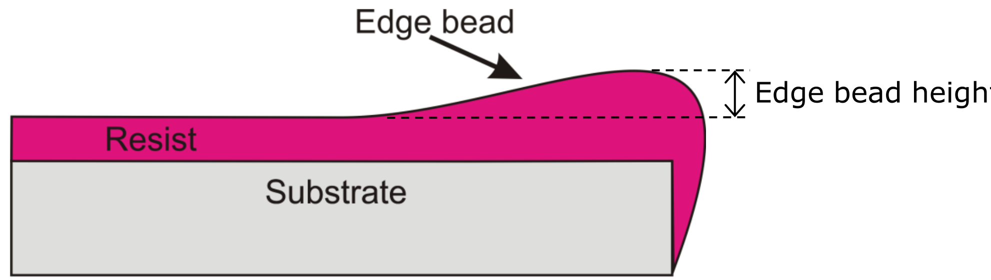
d)



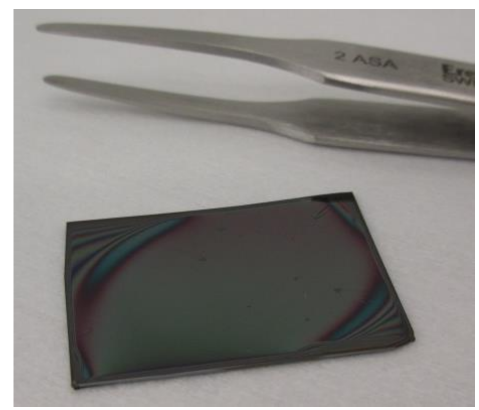
AR-P 6200 (CSAR) spin coated on substrate with pattern etched ~1 µm into Si

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, leading the formation of a ”bulge” at the wafer edge
  – known as an *edge bead*

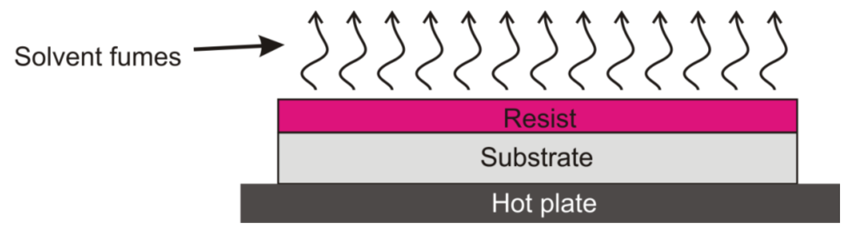


- Typically the edge bead height is comparable to the resist thickness and it may be several mm wide
- Not a problem for standard UV resists spin coated on wafers
- Non-circular substrates exhibit more edge bead
- Edge beads are usually removed with solvent
  – **E**dge **B**ead **R**emoval (EBR)
- Edge beads can in some cases be reduced by careful design of the spin coating recipe, or exposure
- Edge beads may also be reduced by spin coating under a co-rotating cover (Gyrset®) –a saturated solvent environment and less turbulence reduces the effect



After coating: softbake

- Post-coating bake = ‘softbake’
- Soft bake is performed in order to drive out solvent from resist film
  - Increase mechanical stability of the resist
  - Prevent resist sticking to mask
  - Typically 90ºC for 60–120 seconds



- Softbake is usually performed on a hot plate
  - Contact baking: Wafer in contact with hot plate (vacuum)
  - Proximity baking: Wafer kept above hot plate (e.g. 1 mm)
- Increasing softbake temperature yields:
  - Thinner film (more solvent evaporates)
  - Decreased photosensitivity (thermal decomposition of photo-active component)
  - >120 ºC: risk of crosslinking, making the resist insensitive to exposure

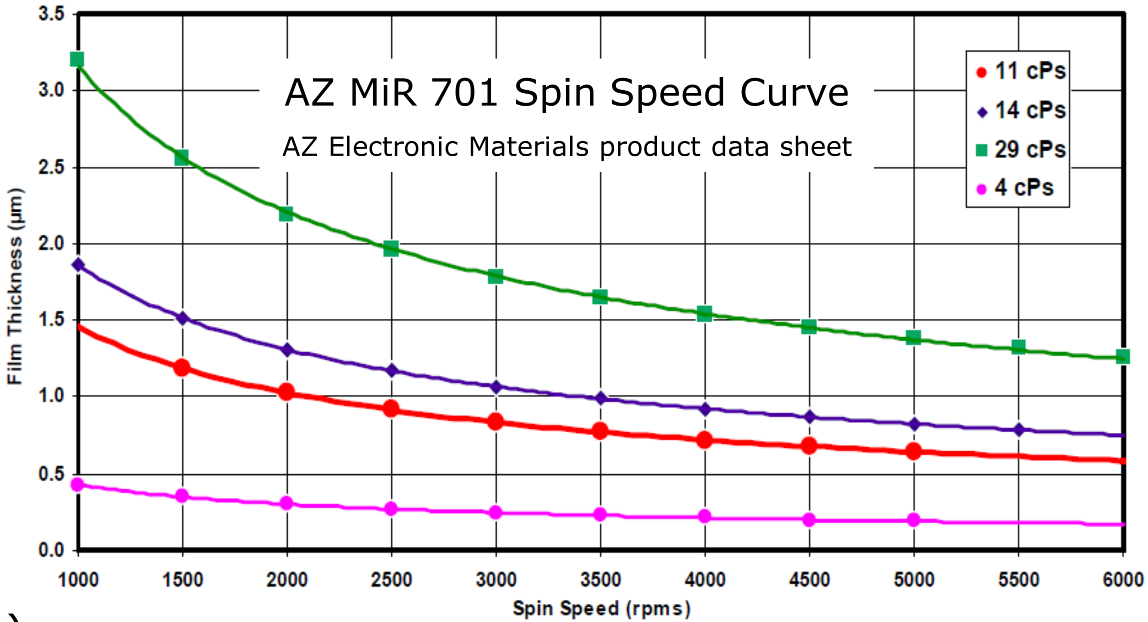
Spin coating: the spin curve

- In spin coating, the **final film thickness** depends

strongly on:
- viscosity
- spin speed
- spin time
- exhaust

less on:
- spreading
- acceleration

but not on:
- dispensed resist volume
(as long as there is enough)



- A spin curve is only valid for constant viscosity, spin time, softbake, etc.
  - only accurate for one particular equipment in one particular cleanroom

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), $\alpha < 0.5$

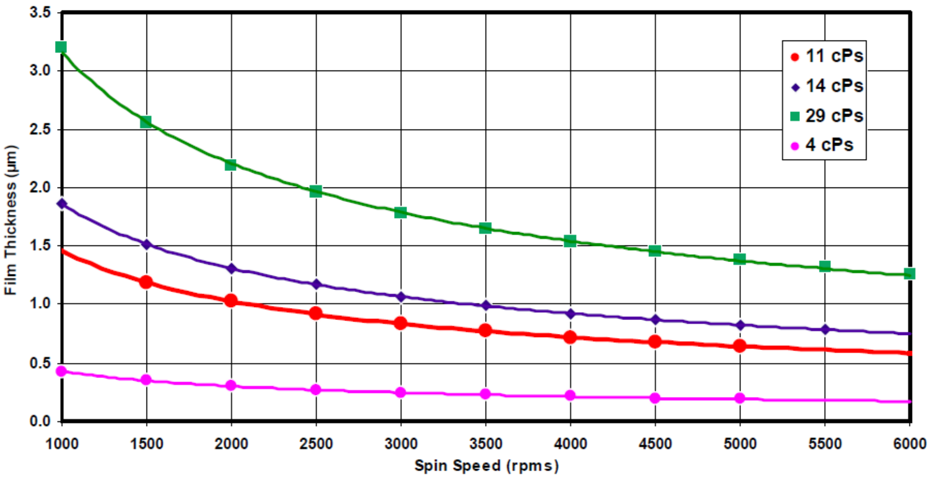
Spin coating: exercise

- 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.

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

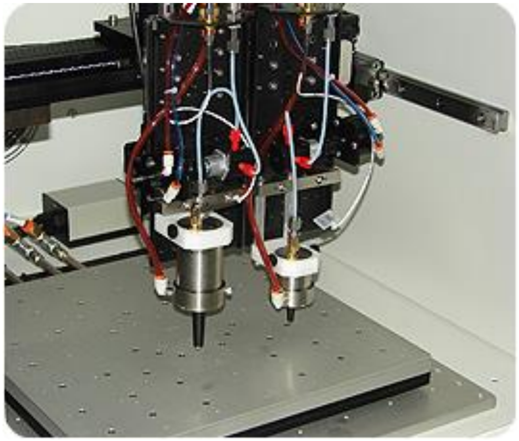
$$z = K'\frac{1}{\sqrt{\omega}}$$

AZ MiR 701 Photoresist Spin Speed Curve



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