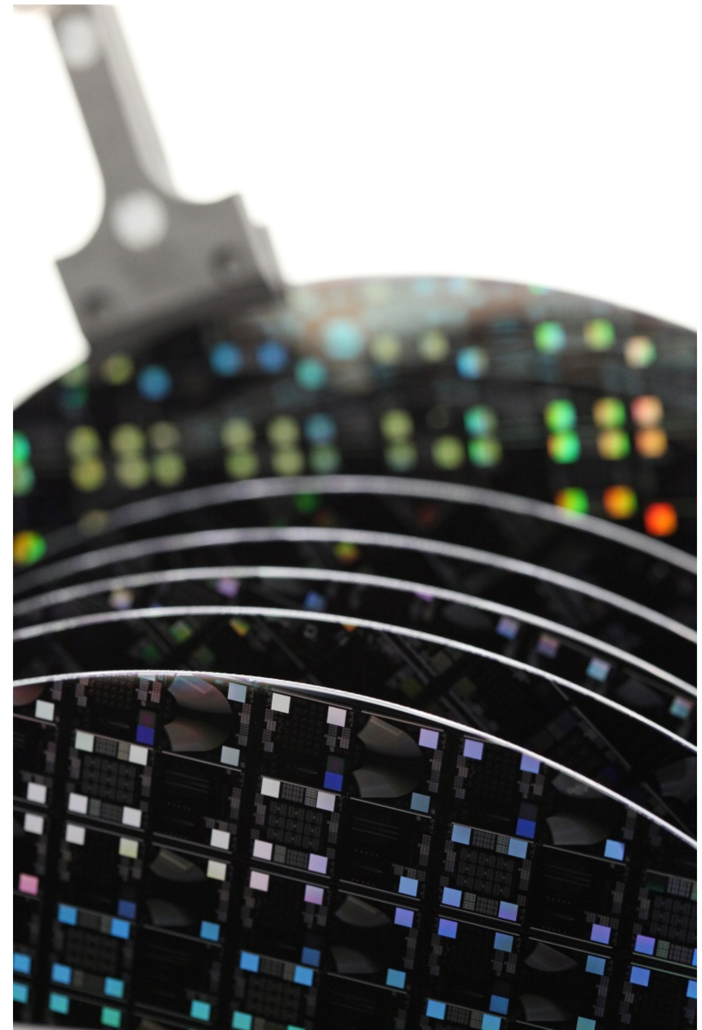
# Lithography Tool Package

## 4. Development



*Thomas Anhøj and Tine Greibe*

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   - Characterization methods
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   - Process effects
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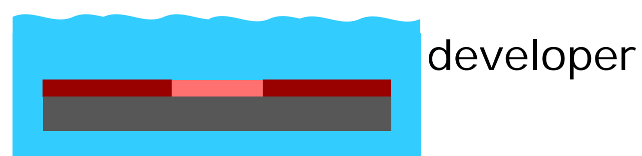
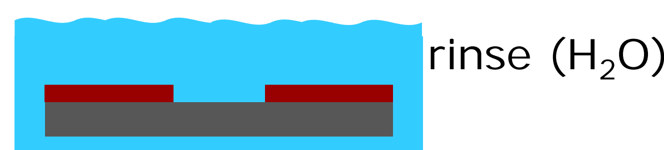
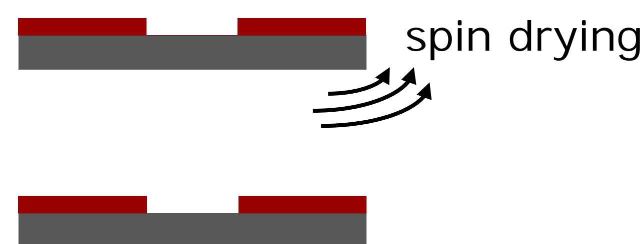
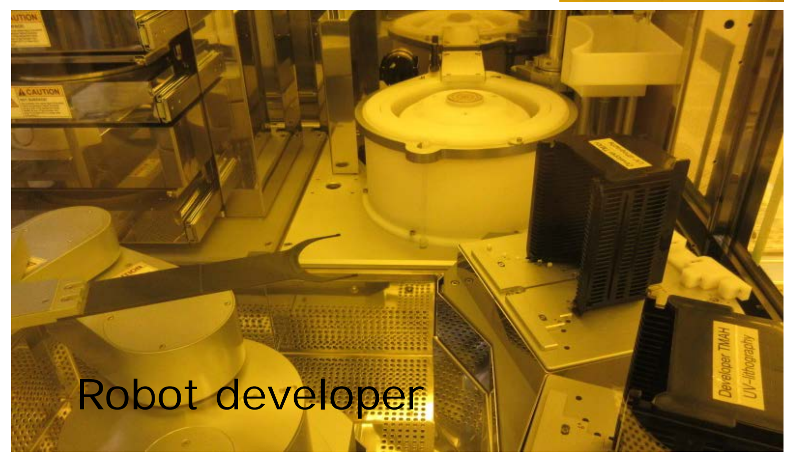
# Development





# Development: principle

- **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

- In the exposure, light activates the photo-active compound which changes the solubility of the resist in the developer in the exposed areas
- In some resists, the photo-chemistry is a catalytic process, which is activated/assisted thermally in a so-called **P**ost-**E**xposure **B**ake (PEB)

**Methods**

- Submersion: the substrate is submerged in a bath of developer
- Puddle: developer is dispensed onto the surface of the substrate, and held there by surface tension
- Spray: developer is sprayed onto the substrate

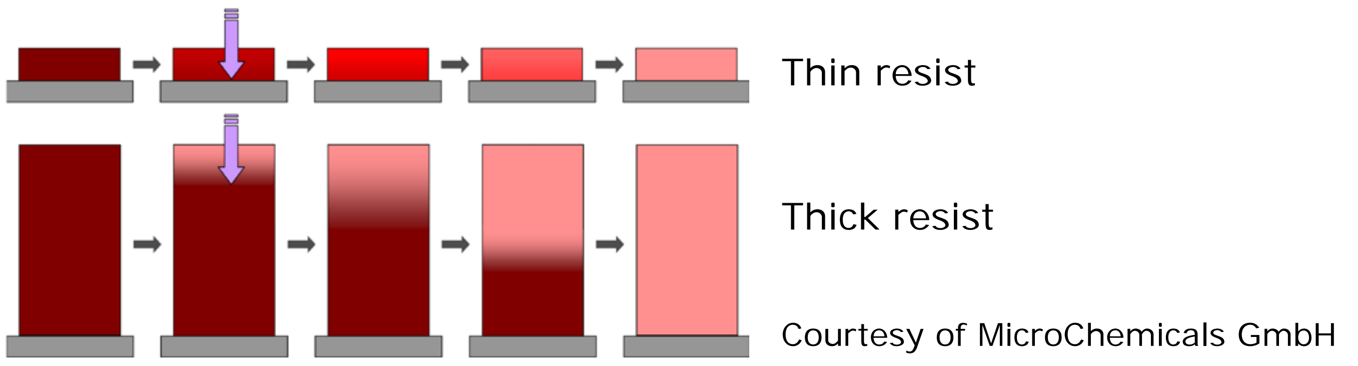
# Development: resist tone

| | Positive tone | Negative tone |
|---|---|---|
| Coating | | |
| Exposure | | |
| Post-exposure bake | | |
| Development | | |
| Pattern | | |

# Photoresist: tone

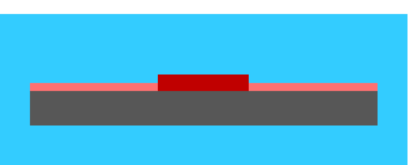
## Positive tone

- Exposed resist becomes soluble in developer
- Polarity change or chain scission
- Bleaching during exposure enables straight sidewalls even for thick resist




Courtesy of MicroChemicals GmbH

## Negative tone

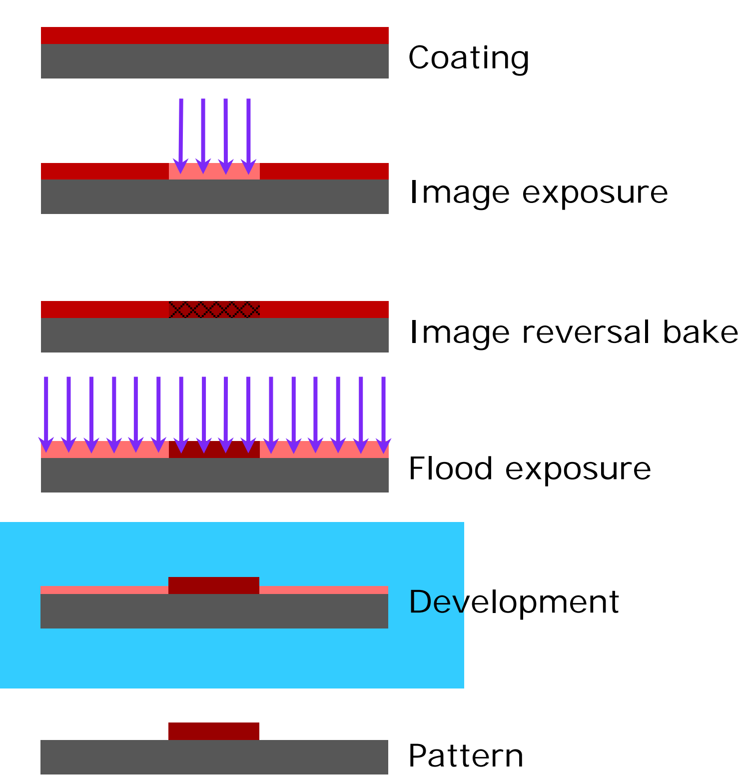


- Exposed resist becomes insoluble in developer
- Polarity change or cross-linking (usually requires PEB)
- Special case: no bleaching (AZ nLOF 2020) → always negative sidewalls

# Photoresist: special categories

- Image reversal resist (AZ 5214E)
  - Positive resist changed to negative by additional process steps
  - Cross-linker ($NH_3$) is added, activated by the *image reversal bake*
  - The temperature of the image reversal bake is a critical parameter
  - Requires flood exposure before development

- Chemically amplified resists
  - Photo-initiation is catalytic
  - Requires PEB
  - Dose = light + heat
    → higher throughput



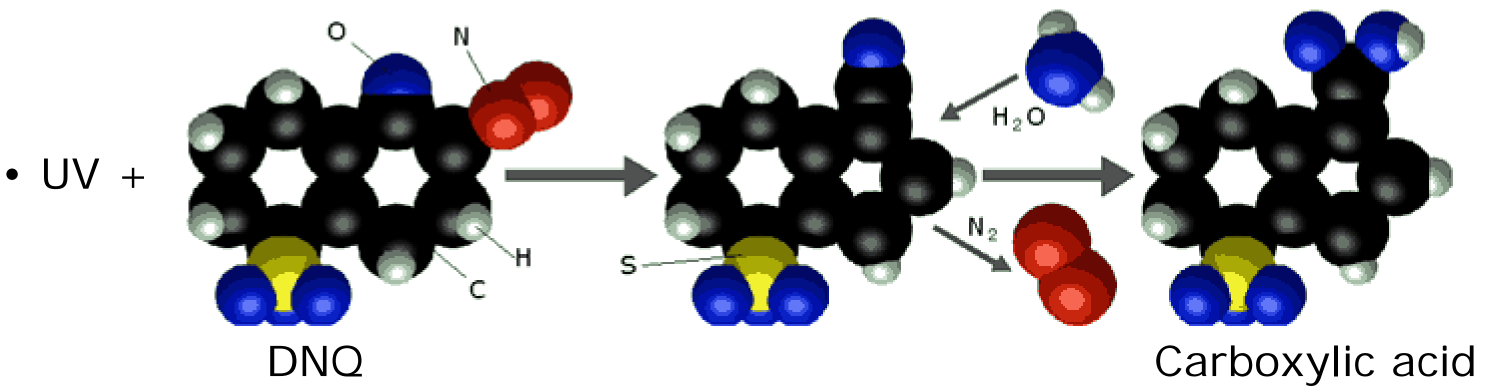
# Developers at DTU Danchip

- AZ 351B
  - NaOH in water (base)
  - buffer additive (for submersion)
- AZ 726 MIF
  - TetraMethylAmmonium Hydroxide (TMAH) in water (base)
  - wetting agent (for puddle)
- mr-Dev 600
  - PGMEA for SU-8 development (solvent)

| 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 |
| AZ 351B | (x) | (?) | x | x | |
| AZ 726 MIF | x | x | x | x | |
| mr-Dev 600 | | | | | x |
| Positive | x | | x | x | |
| Negative | | x | x | | x |

# Photoresist: photo-chemistry

- AZ 5214E, AZ 4562, and AZ MiR 701 have **d**iazo**n**aphtho-**q**uinone-sulphonate (DNQ) as the photo-active component, or photo-initiator
- UV +

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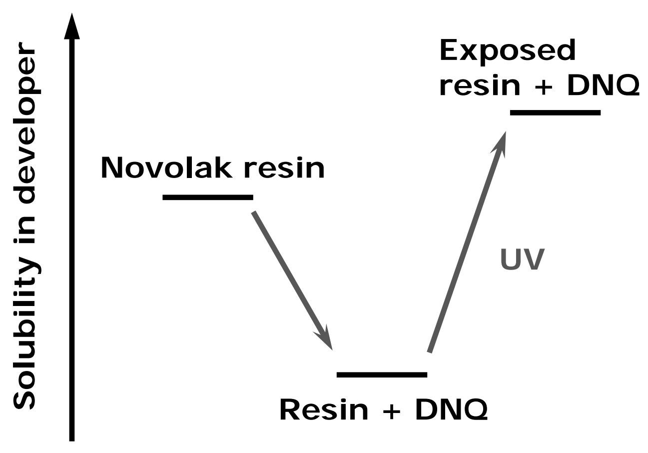
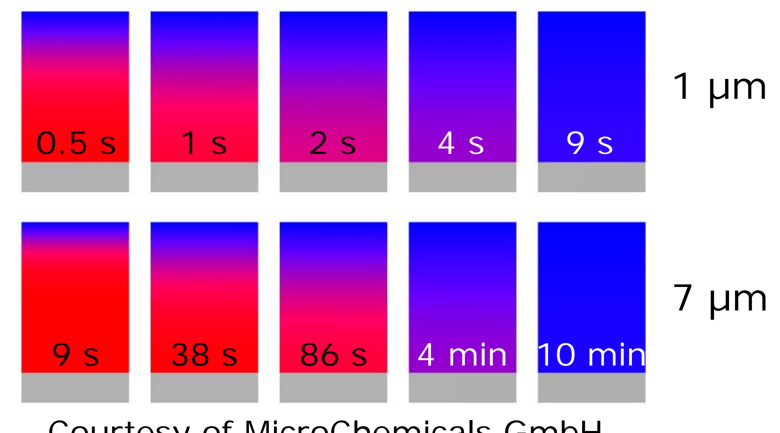
- DNQ lowers the solubility of the resin in the developer, while the carboxylic acid increases the solubility

  → positive tone resist



# Photoresist: photo-chemistry, consequences

- After softbake, the resist has to rehydrate in order to enable exposure
  - 1µm rehydrates in 10s
  - 10µm requires at least 10 minutes
  - Thicker films may require hours to rehydrate
  - Insufficient rehydration leads to under-development and/or non-straight sidewalls

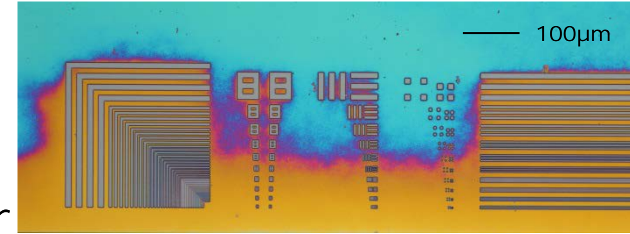


Courtesy of MicroChemicals GmbH

- After exposure, the $N_2$ has to outgas before any thermal process in order to prevent bubbles from forming
  - Before image reversal bake (5214E), and possibly PEB (MiR 701)
  - 1µm outgasses in ~1 minute, 3µm in ~10 minutes, while a 10µm film may require hours to outgas
  - Thick resist should be exposed in intervals with delays in between
- AZ nLOF 2020 and SU-8 both have a different PAC, and do not require rehydration or outgassing

# Development: effects

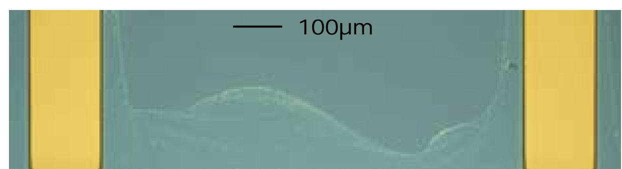
- **Under-development**: resist remaining between pattern
  - Increase development time
  - Increase exposure dose (positive tone)



Under-developed resist

- **Dark erosion**: pattern attacked by the developer
  - The resist becomes thinner
  - Resist lines become narrower; gaps become wider
  - Minimize development time
  - Optimize softbake parameters (positive) / increase dose (negative)

- **Scumming**: resist residues left behind on the substrate
  - Substrate and developer dependent

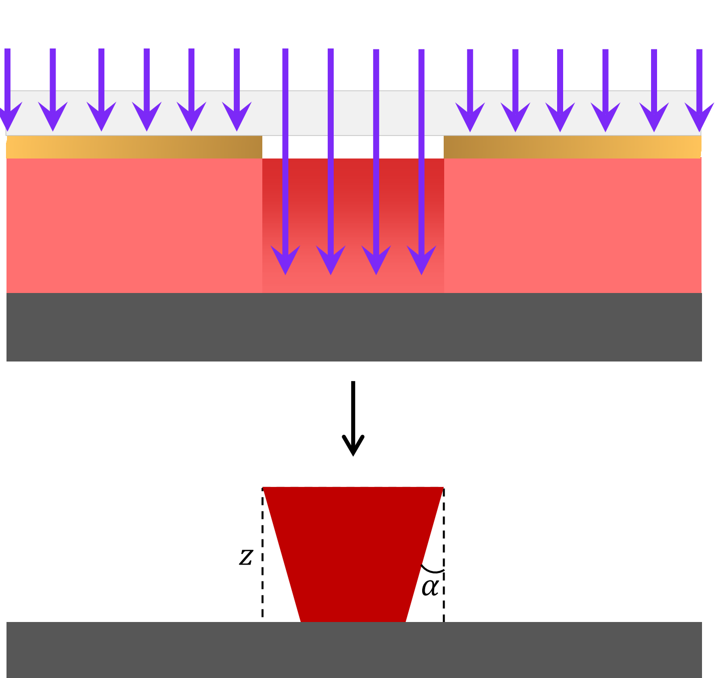


Scumming on $SiO_2$. Courtesy of Sonny Massahi

- **Forgetting PEB** leads to
  - under-development of positive tone resist
  - full development (no pattern) for negative tone resist

# Sidewall angle in negative resist

- In a cross-linking, negative tone resist, erosion of the exposed resist in the developer depends on the density of cross-links in the resist
- Due to absorption during exposure, the cross-link density is often lower at the substrate, compared to at the top of the resist film (especially for AZ nLOF which doesn't bleach)




- This gives rise to a higher erosion rate of the resist near the substrate, resulting in a sloped resist sidewall, or negative resist profile, after development

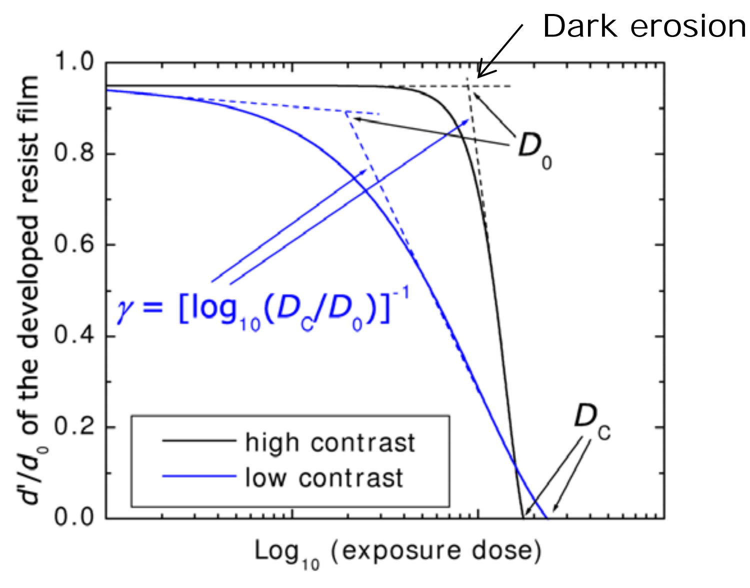
- Sidewall angle usually limits the resolution in contact printing of negative tone resist

$$R = 2z \tan\alpha \ \ (+c)$$

# Photoresist: contrast

- Ideally, at least for high resolution, the response of a resist to exposure should be a step function, i.e. no development below a threshold dose; full development above the threshold dose
- In reality, development starts at a dose, $D_0$, but finishes at a higher dose, $D_C$ (dose to clear), leading to the definition of **contrast, γ,** as the slope of the transition:

$\gamma = \frac{1}{log\left(\frac{D_C}{D_0}\right)}$, for a positive tone resist



Courtesy of MicroChemicals GmbH

- What does the contrast curve look like for a negative tone resist?

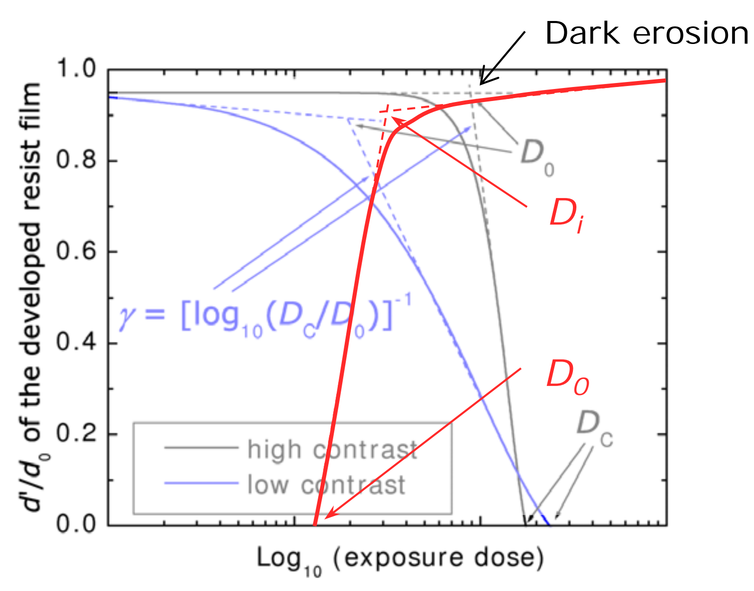
# Photoresist: contrast

- Ideally, at least for high resolution, the response of a resist to exposure should be a step function, i.e. no development below a threshold dose; full development above the threshold dose
- In reality, development starts at a dose, $D_0$, but finishes at a higher dose, $D_C$ (dose to clear), leading to the definition of **contrast, γ,** as the slope of the transition:

$$\gamma = \frac{1}{log\left(\frac{D_C}{D_0}\right)},$$ for a positive tone resist

- For a negative resist, the curve is reversed
- Complete development stops at a dose, $D_0$, and development stops a higher dose, $D_i$ ("fully insoluble dose"), leading to:

$$\gamma = \frac{1}{log\left(\frac{D_0}{D_i}\right)},$$ for a negative tone resist



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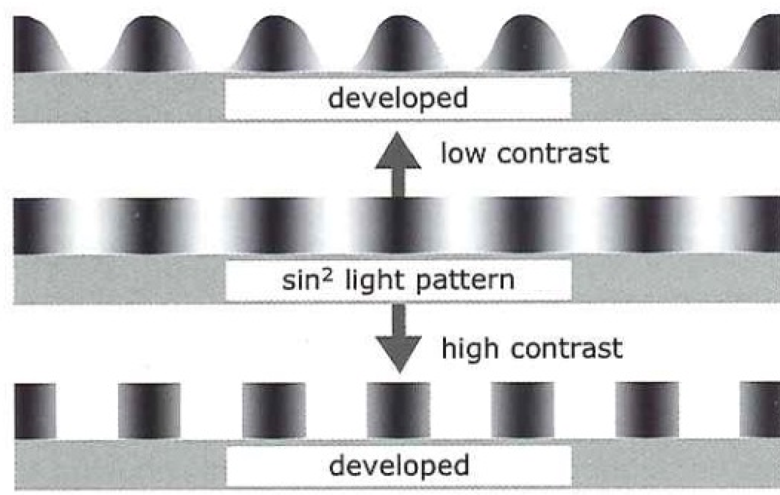
# Photoresist: contrast, low vs. high

- Contrast determines how the image from the exposure transfers to the resist pattern
- In most cases, e.g. for dry etch, a high contrast is desired

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- Contrast depends on many factors:
  - Developer chemistry, concentration, and temperature
  - Resist type and thickness
  - Softbake parameters (due to dark erosion)
  - etc.