EE669: VLSI Technology

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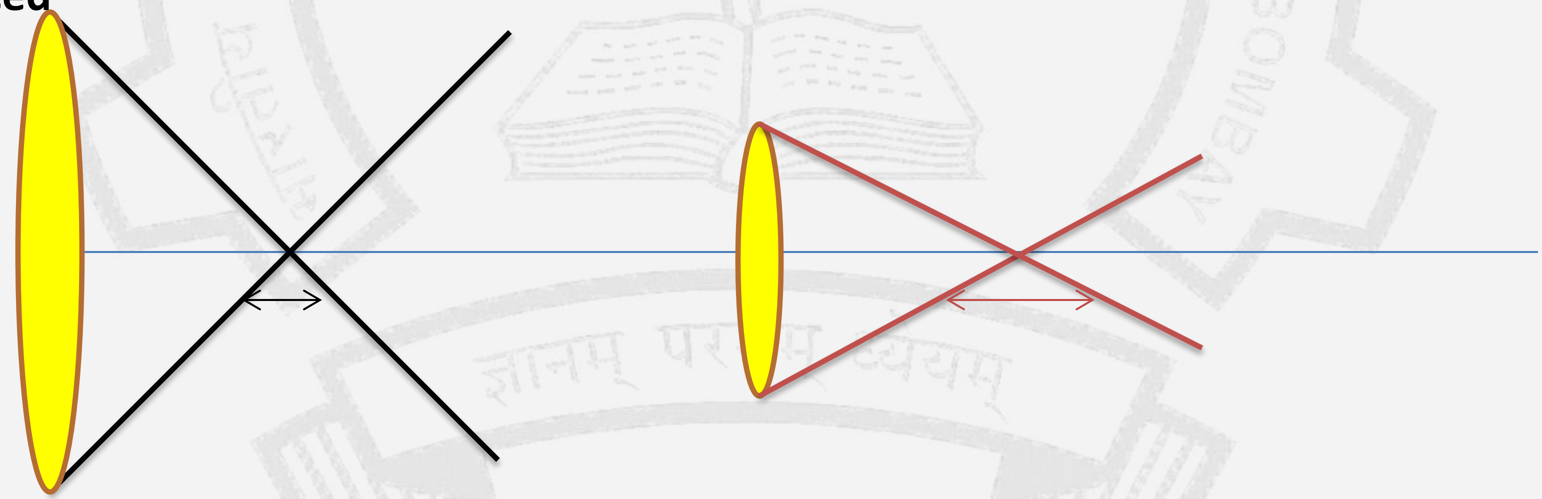
Office hour: Friday 10:00 – 11.00 AM, EE Annex, Room: 104

Rayleigh criterion for depth of focus

$$DOF = \delta = \pm k_2 \frac{\lambda}{(NA)^2}$$

$$R = k_1 \frac{\lambda}{NA}$$

- Larger NA = smaller DOF
- True for photographic camera. A cheap camera takes photos that are always in focus, no matter where the object is. It is because, it has small lenses.
- This is of course, works against resolution where larger NA gives much higher resolution
- In order to improve the resolution without impacting DOF too much, λ should be reduced



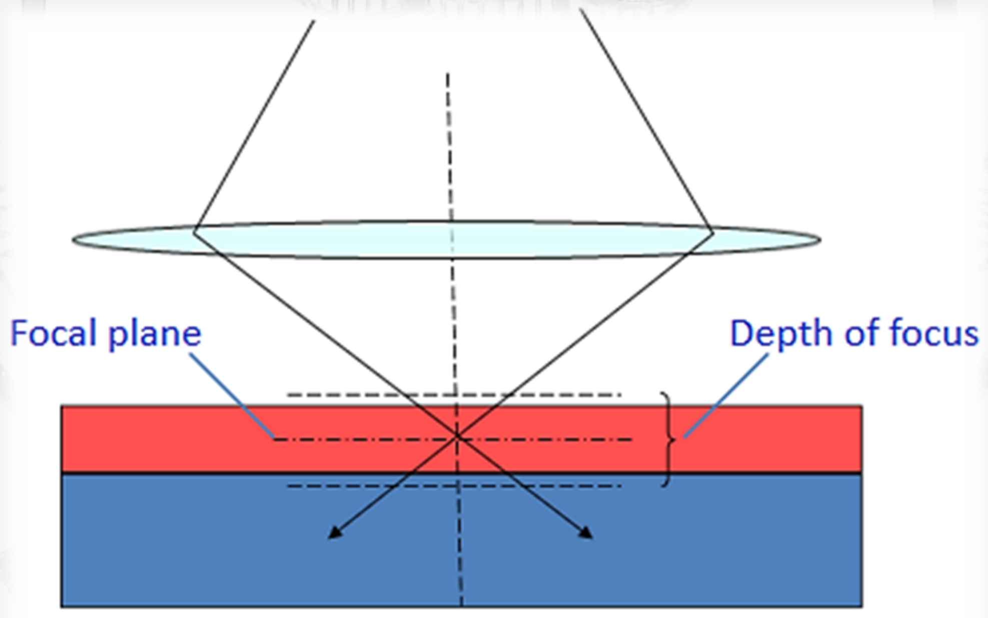
Large Lens (Large NA), small DOF

Small Lens (Small NA), Large DOF

Optimal focal plane in lithography

- Light should be focused on the middle point of the resist wafer layer
- In IC, DOF is <<1μm, tricky to focus, if wafer is not extremely flat
- We are concerned about higher resolution, however, DOF could be a bigger concern than R

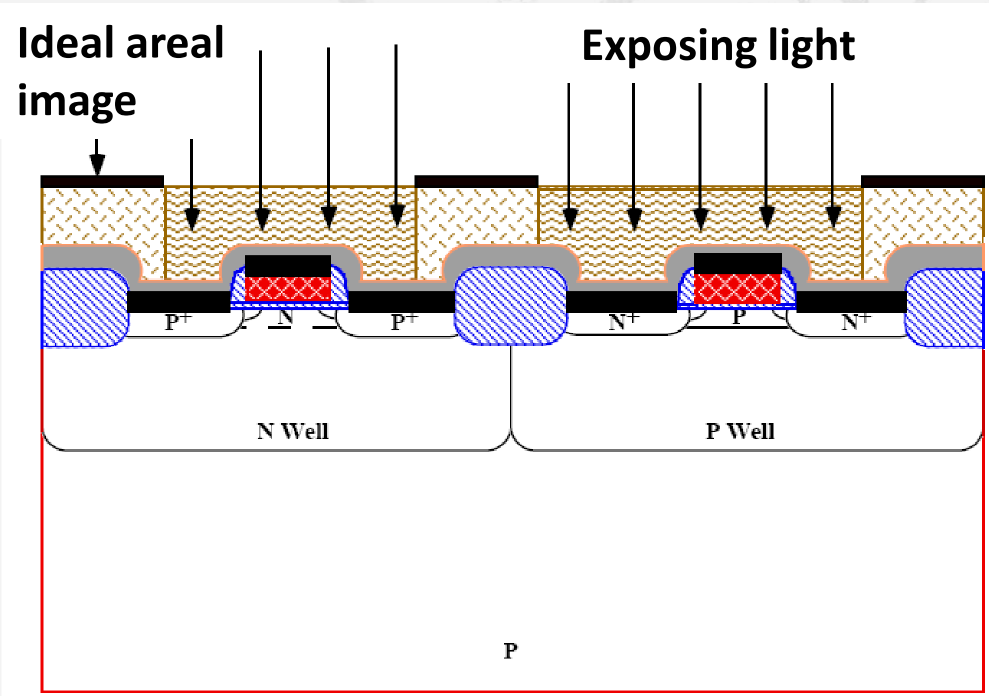
e.g. λ=248 μm, NA= 0.6, R≈ 0.3μm (k1=0.75) DOF ≈ ± 0.35μm (k_2=0.5)



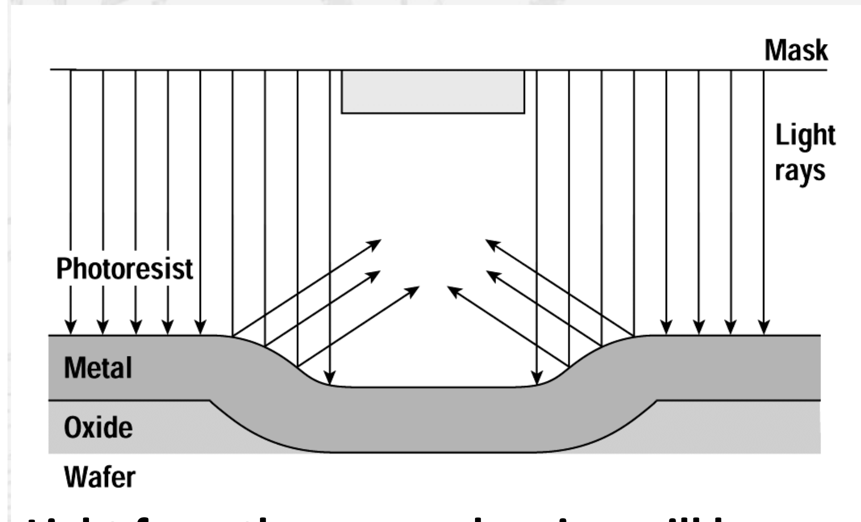
Other lithography issues: none-flat wafer, standing wave

Exposure on patterned none-flat surface

This leads to random reflection/proximity scattering, and over or under-exposure.



Proximity scattering

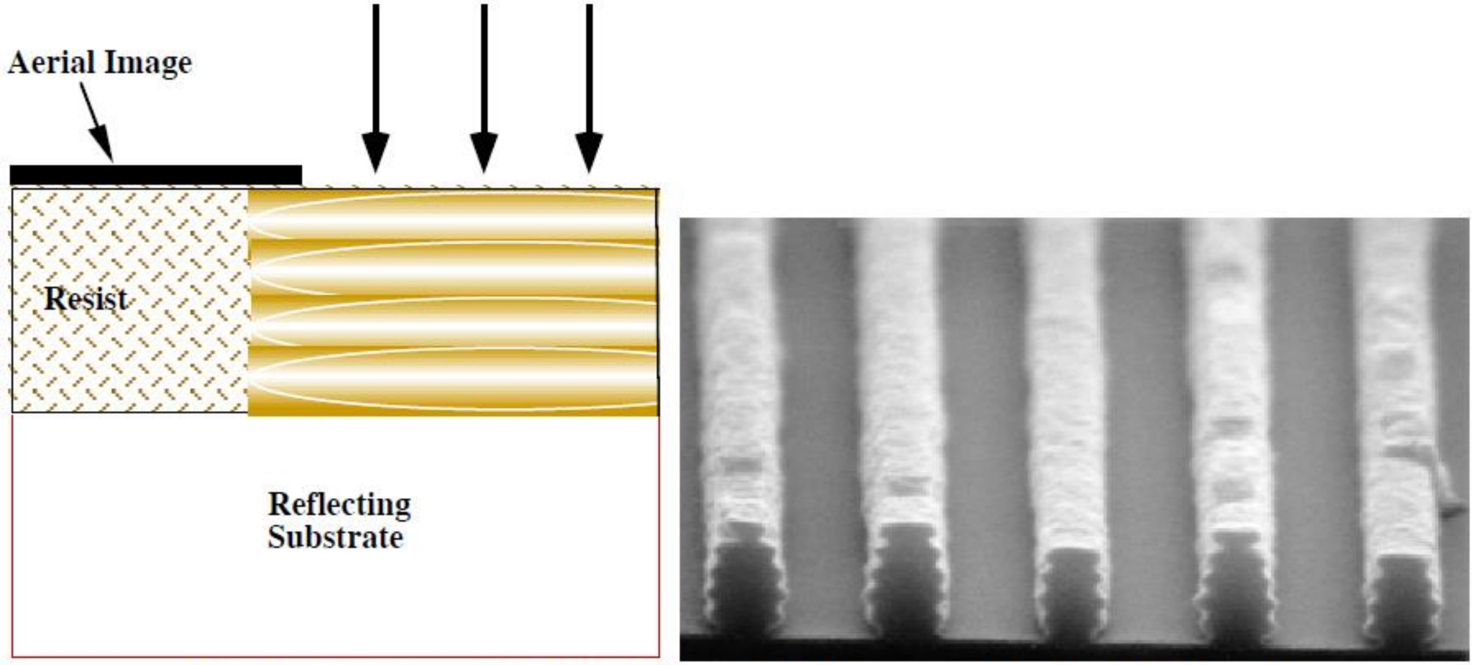


Light from the exposed region will be reflected by wafer topology and be absorbed in the resists in the unexpected regions

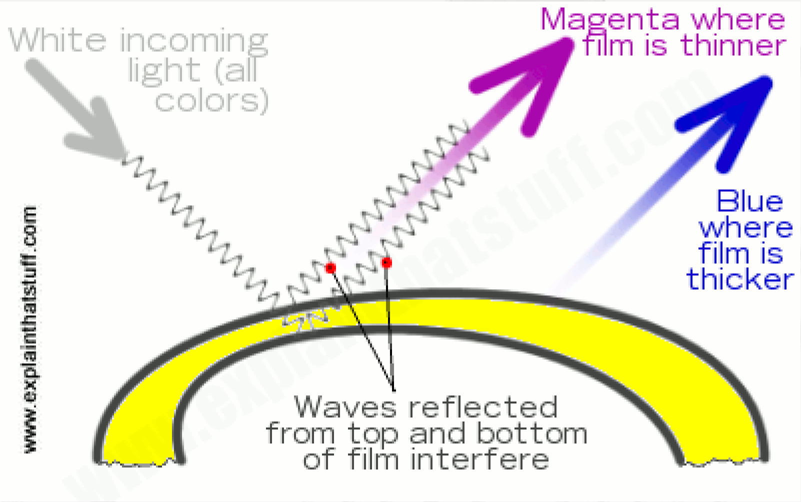
Both problems would disappear if there is no reflection from substrate.

Surface reflection and standing wave

- Resist is partially reflective, so some light reaches resist bottom and is reflected.
- Constructive and destructive interference between incident and reflected light results in a periodic intensity distribution across the resist thickness.
- Use of anti-reflecting coating (ARC) eliminates such standing wave patterns.
- Post exposure bake also helps by smoothing out the zigzag due to resist thermal reflow.



(Photo courtesy of A. Vladar and P. Rissman, Hewlett Packard.)


White incoming light (all colors)
Magenta where film is thinner
Blue where film is thicker
Waves reflected from top and bottom of film interfere
www.explainthatstuff.com

Exposure on patterned none-flat surface

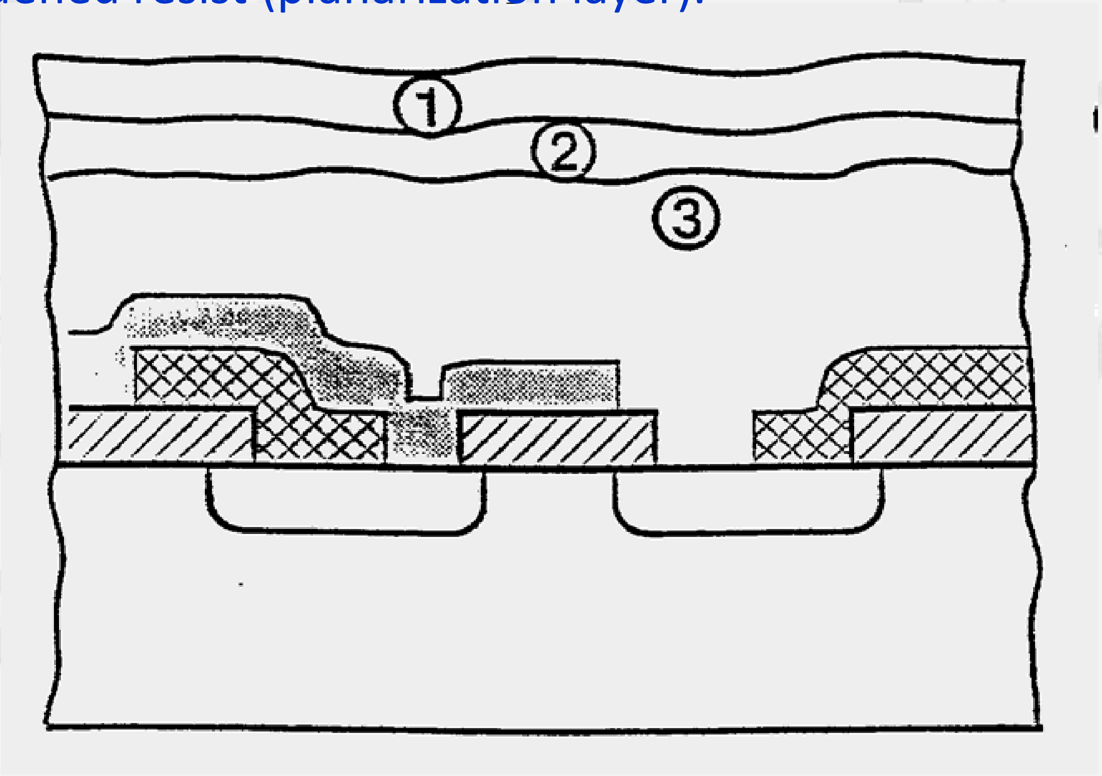
To reduce the problem, one can:

- Use absorption dyes in photoresist, thus little light reaches substrate for reflection.
- Use anti-reflection coating (ARC) below resist.
- Use multi-layer resist process (see figure below)

  1) thin planar layer for high-resolution imaging (imaging layer).

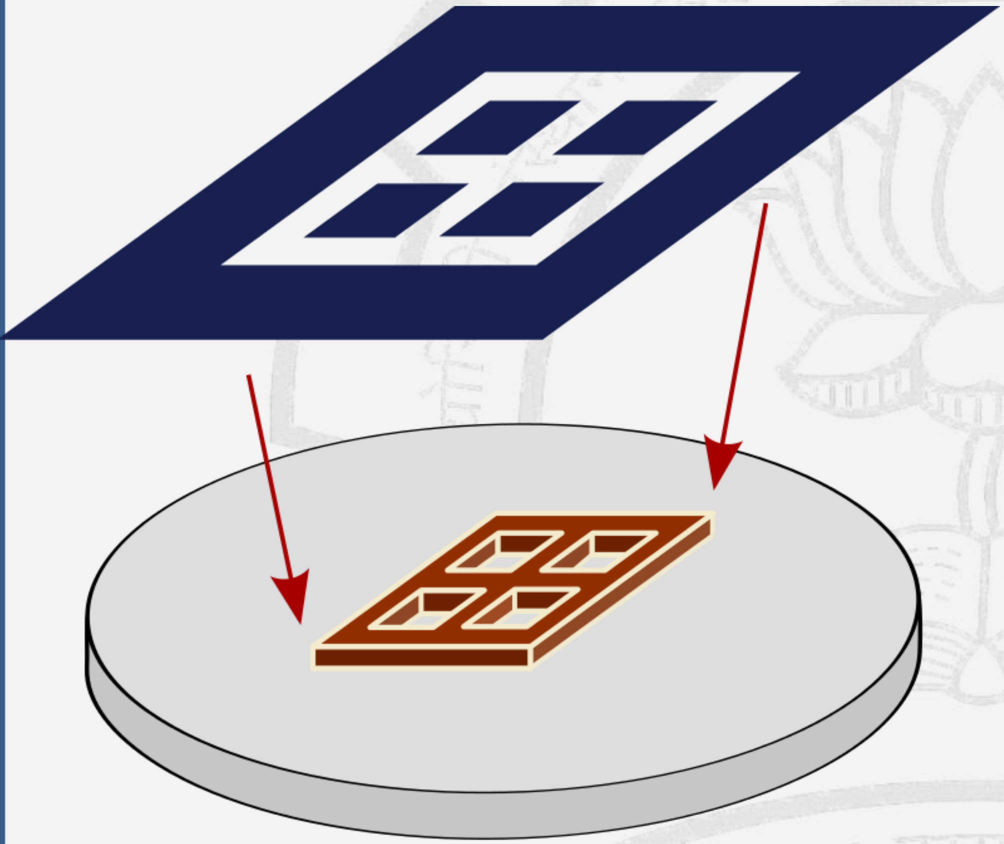
  2) thin develop-stop layer, used for pattern transfer to 3 (etch stop).

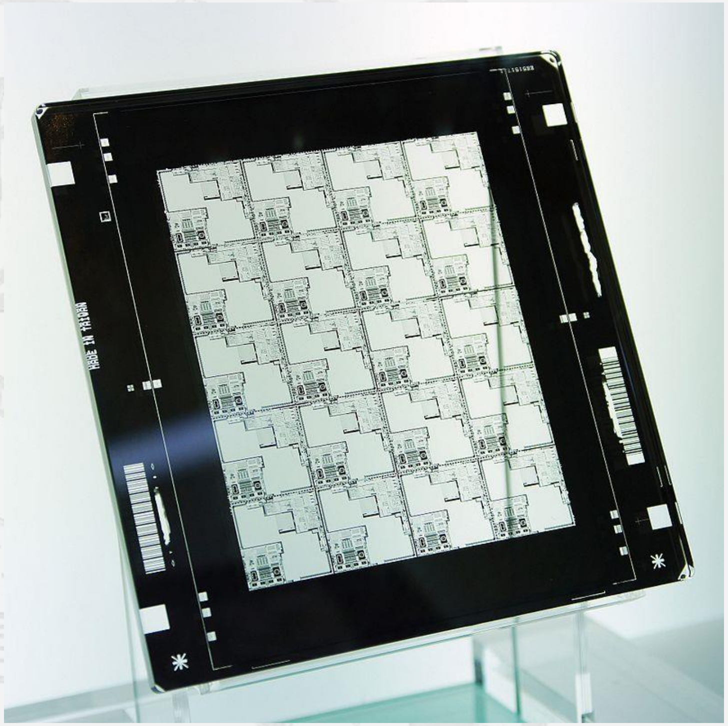
  3) thick layer of hardened resist (planarization layer).



Photomask

A photomask is an opaque plate with holes or transparent regions that allow light to pass through in a defined pattern.





- **Lithographic photomasks: Typically transparent fused silica blanks covered with a pattern**
- **Patterns are defined with a chrome metal-absorbing film.**

- **Photomasks are used at wavelengths of 365 nm, 248 nm, and 193 nm**

Photolithography: Detailed Process flow

Photolithography consists the following process steps:

- **Adding adhesives and removing moisture from the surface**
- **Resist coating**
- **Stabilization of the resist layer**
- **Exposure**
- **Development of the resist**
- **Curing of the resist**
- **Inspection**
- **Resist removal**

Photoresist

Photoresists are polymers that are sensitive to light, and other higher energy sources of radiation such as electron beams and X-rays.

Typically it consists of 3 components:

Binder **Sensitizer** **Solvent**

Type of PR

Positive photoresist

A *positive photoresist* is a type of photoresist in which the portion of the photoresist that is exposed to light becomes soluble to the photoresist developer. The unexposed portion of the photoresist remains insoluble to the photoresist developer.

Negative photoresist

A negative photoresist is a type of photoresist in which the portion of the photoresist that is exposed to light becomes insoluble to the photoresist developer. The unexposed portion of the photoresist is dissolved by the photoresist developer

Photoresist: Differences between positive and negative resist

Characteristic	Positive	Negative
Adhesion to Silicon	Fair	Excellent
Relative Cost	More expensive	Less expensive
Developer Base	Aqueous	Organic
Solubility in the developer	Exposed region is soluble	Exposed region is insoluble
Minimum Feature	0.5 µm	2 µm
Step Coverage	Better	Lower
Wet Chemical Resistance	Fair	Excellent

Source: *Madou, Marc (2002-03-13). Fundamentals of Microfabrication. CRC Press.* ***ISBN 978-0-8493-0826-0***.

Photoresist: Chemical composition

Photoresists are composed of adhesive agents, sensitizers and solvents.

- **Binders (20%):** As a binder **Novolac (***phenol-formaldehyde*)is used, which is a synthetic resin to control the thermal characteristics of the resist.

- **Sensitizer (10%):**Sensitizers define the photosensitivity of the resist. Sensitizers are composed of molecules which affect the solubility of the resist if it is exposed to energetic radiation. Thus the lithography has to take place in areas with ambient light which has a low energy

- **Solvents (70%):**Solvents determine the viscosity of the resist. By annealing, the solvent is vaporized and the resist is stabilized

A resist, as it is provided from vendors, has a defined surface tension, density and viscosity. For this reasons the thickness of the resist layer in wafer fabrication depends on the temperature and the rpm of the coating tool

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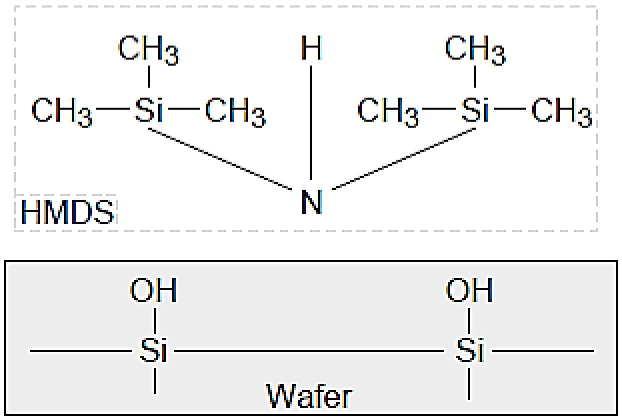
Adhesives

- All the wafers are cleaned and annealed (pre-bake) to remove adhesive particles and adsorbed moisture.
- If the wafer surface is hydrophilic and has to be hydrophobicbefore deposition of the photoresist.
- An adhesives, hexamethyldisilazane (HMDS) in general, are added to the surface.
- The wafers are exposed to the vapor of this liquid and are dampened.

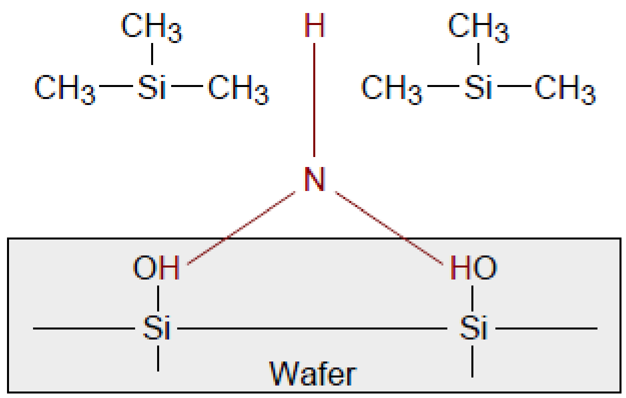
Because of the moisture in the atmosphere even after the pre-bake there are hydrogen H or hydroxyl groups OH–attached to the surface

The HMDS decomposes into trimethylsilyl groups Si−3 CH_3 and removes the hydrogen by forming ammonia NH_3

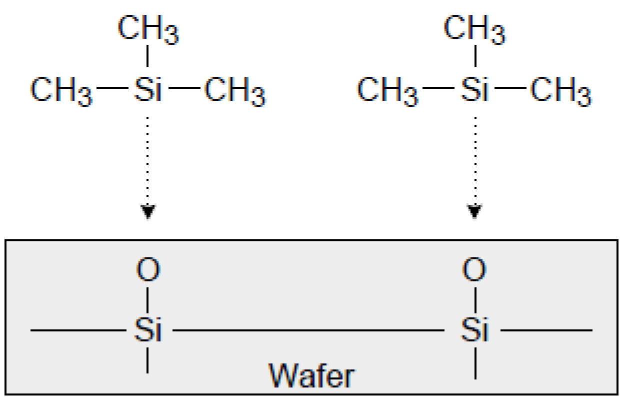
Pretreatment of Si surface



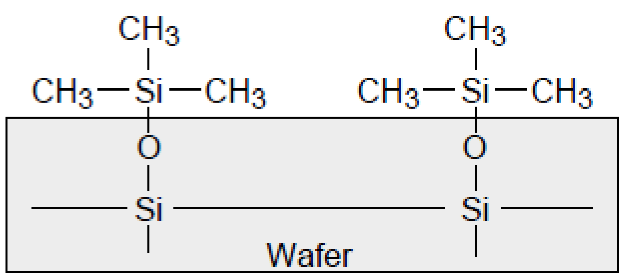
(a)



(b)



(c)



(d)

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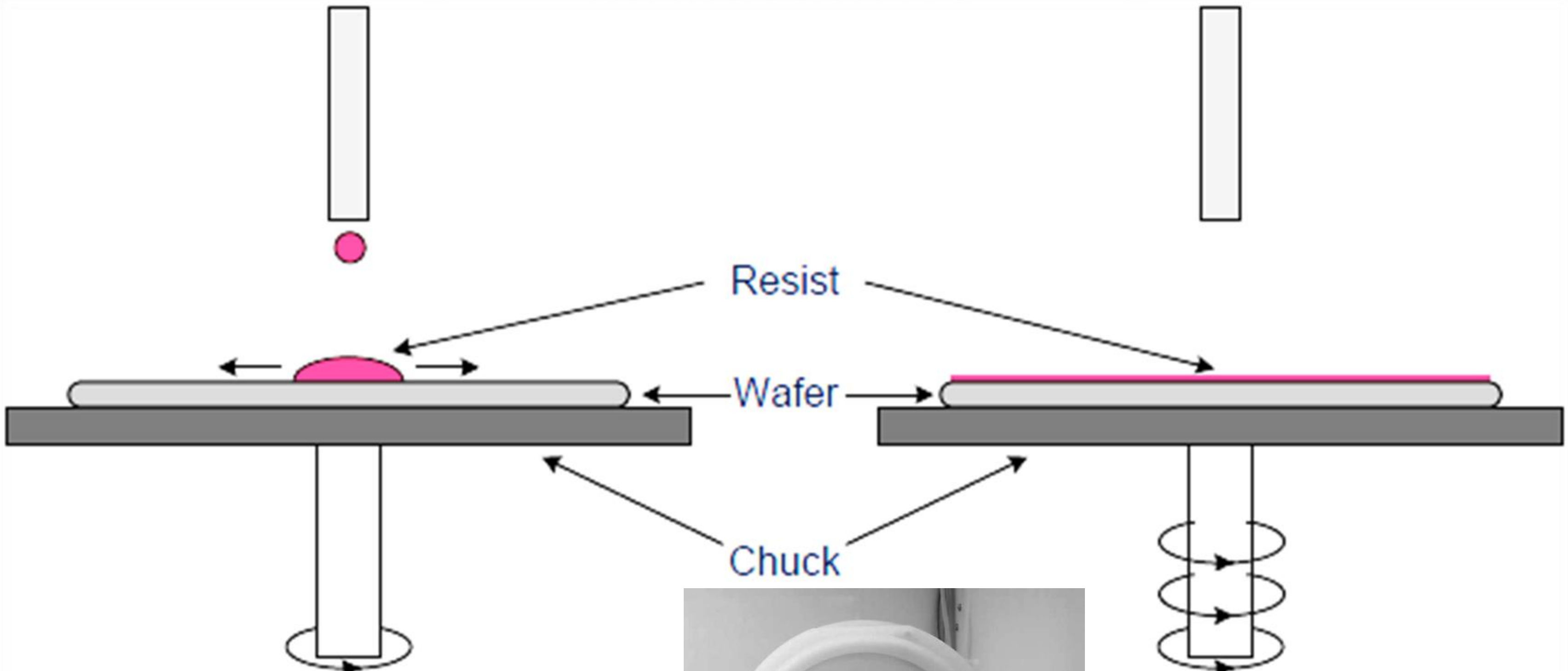
Coating and stabilizing of photoresist



Rotational speed 4000 to 6000 rpm.

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Stabilizing PR: Softbake

After coating, the resist film contains a remaining solvent concentration depending on the resist, the solvent, the resist film thickness and the resist coating technique.

The softbake reduces the remaining solvent content in order to:

- Avoid mask contamination and/or sticking to the mask,
- Prevent popping or foaming of the resist by N2 created during exposure,
- Improve resist adhesion to the substrate,
- Minimize dark erosion during development,
- Prevent dissolving one resist layer by a following multiple coating,
- Prevent bubbling during subsequent thermal processes (coating, dry etching).

Recommend a softbake at 100°C on a hotplate for 1 minute per µm resist film thickness.

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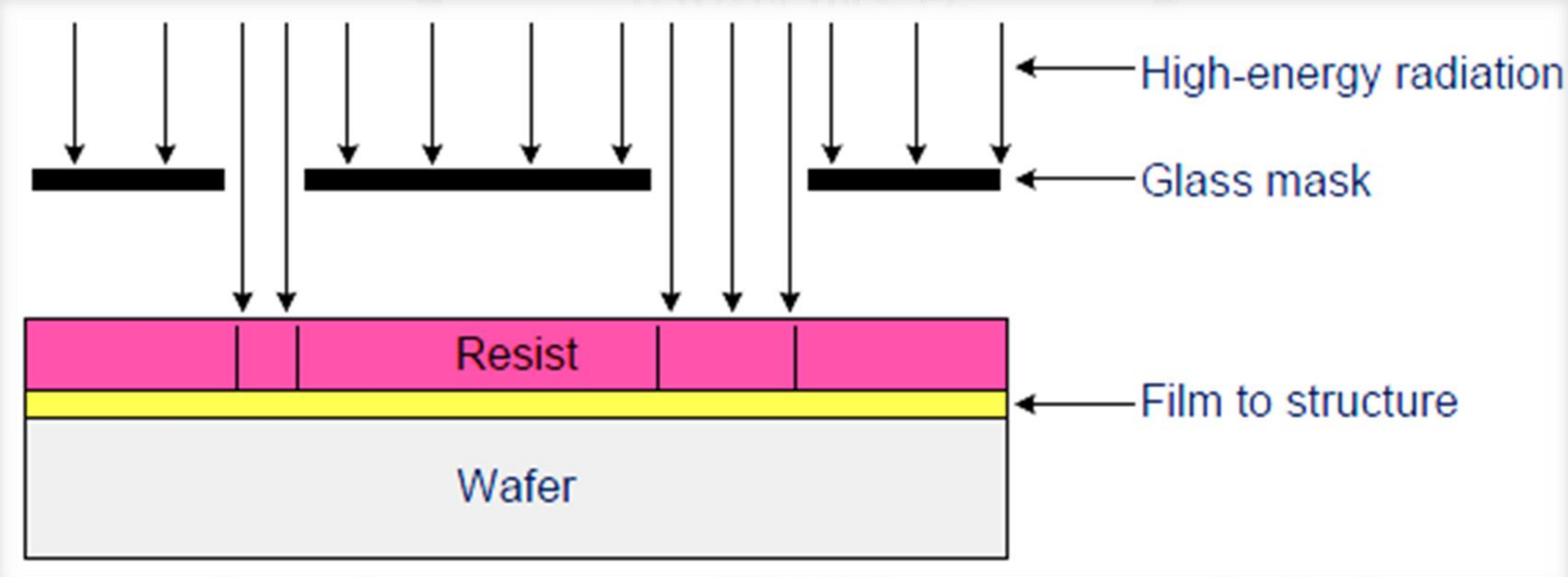
Exposure



- Depending on the type of the resist, exposed areas become soluble or insoluble.
- With a wet-chemical developer the soluble parts are removed, so that a patterned resist layer remains.
- The exposure time is a very important parameter to achieve the correct dimensions of the structures

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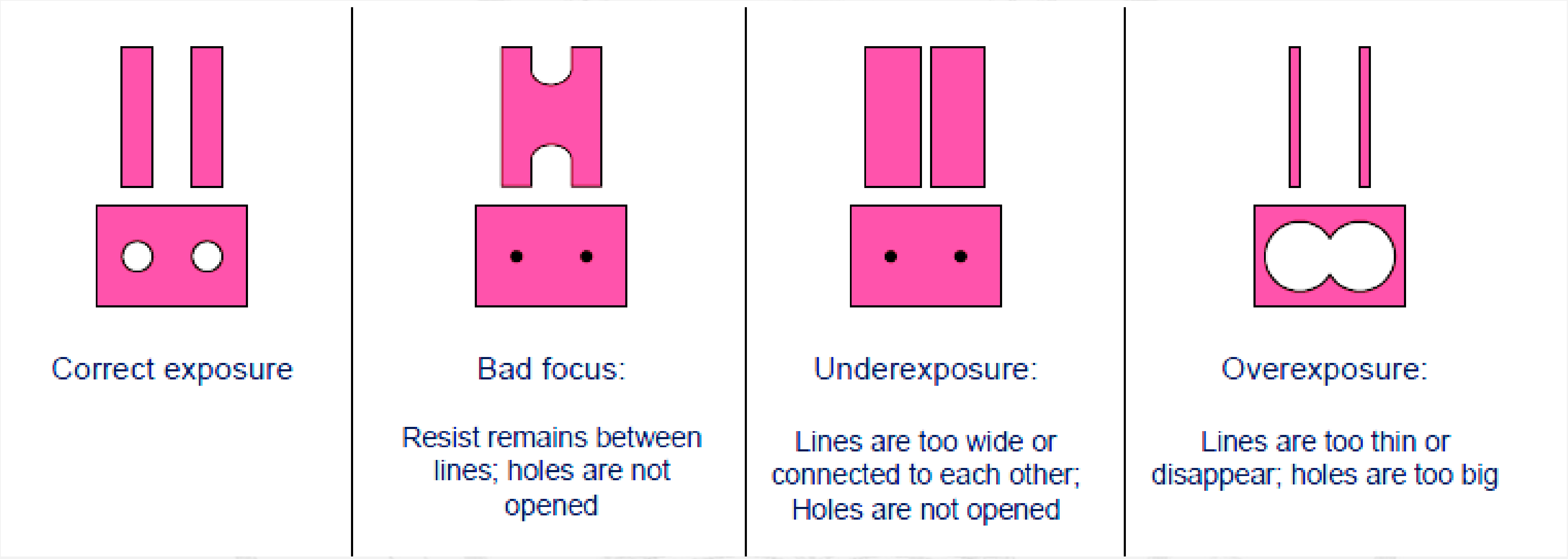
Exposure time

- The longer the wafers are exposed to the radiation, the larger the radiated area is
- Due to fluctuating ambient temperatures a precise determination of the correct exposure time has to be investigated with <u>one or more dummy wafers</u>
- Because the characteristics of the resist can change with temperature, an overexposure causes smaller resist patterns, and therefore smaller structures beneath, in contrast VIAs will be enlarged
- Too short exposure time, the VIAs are not opened correctly, conductors are too wide or even in contact to each other (short circuit).
- A bad focusing leads to unexposed areas, so that vias can not be opened and conductors are in contact as well.

VIA: Vertical Interconnect Access)

Bad exposure due to focus issues, over exposure, or under exposure



- Depending on the subsequent process, the width of the resist patterns or the diameter of the vias, respectively, should be adjusted.
- In isotropic etch processes (etching in vertical and horizontal orientation) the resist mask is not transferred 1:1 into the layer beneath.

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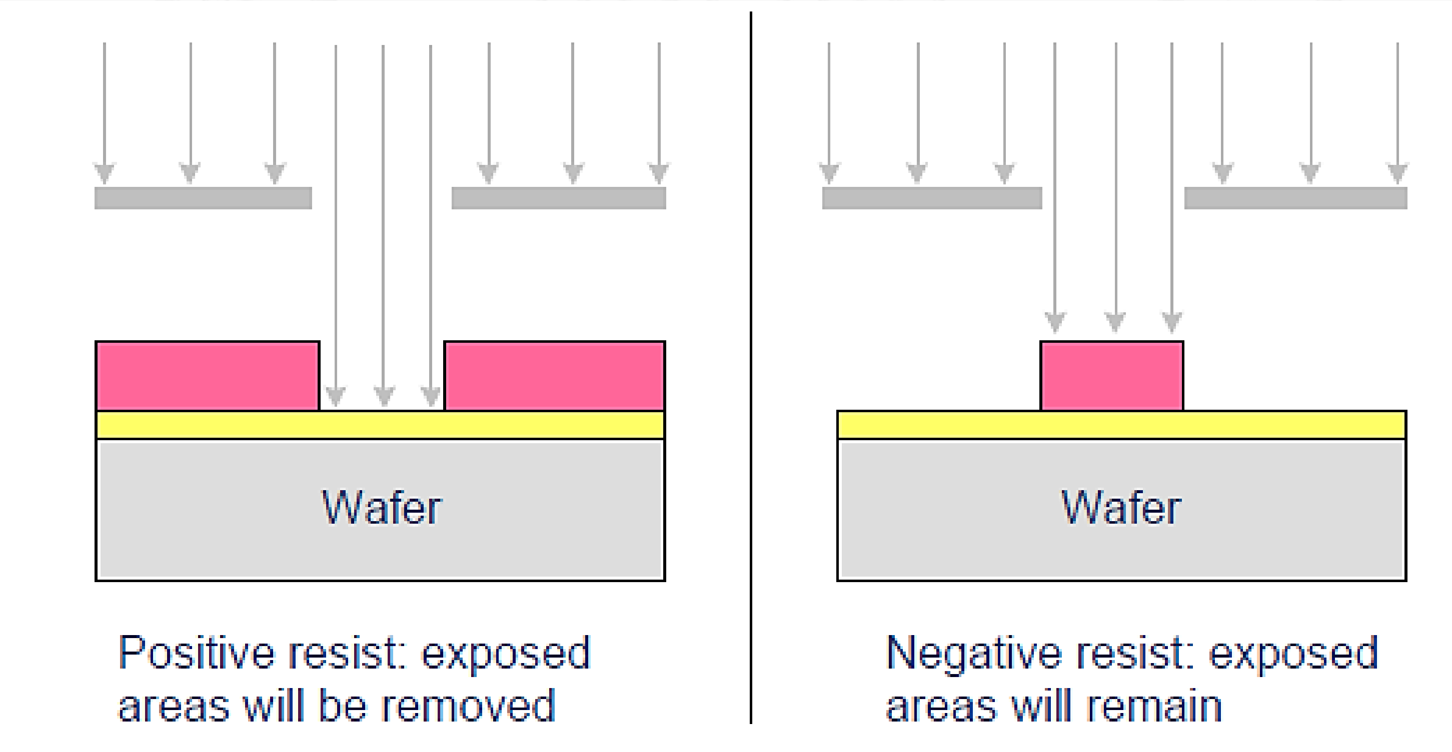
Development and inspection

Development

- The exposed wafers are developed in dipping baths or in spray processes
- Dipping baths allow the development of multiple wafers at a time,
- in spray development one wafer is processed after another



Photolithography: Detailed Process flow

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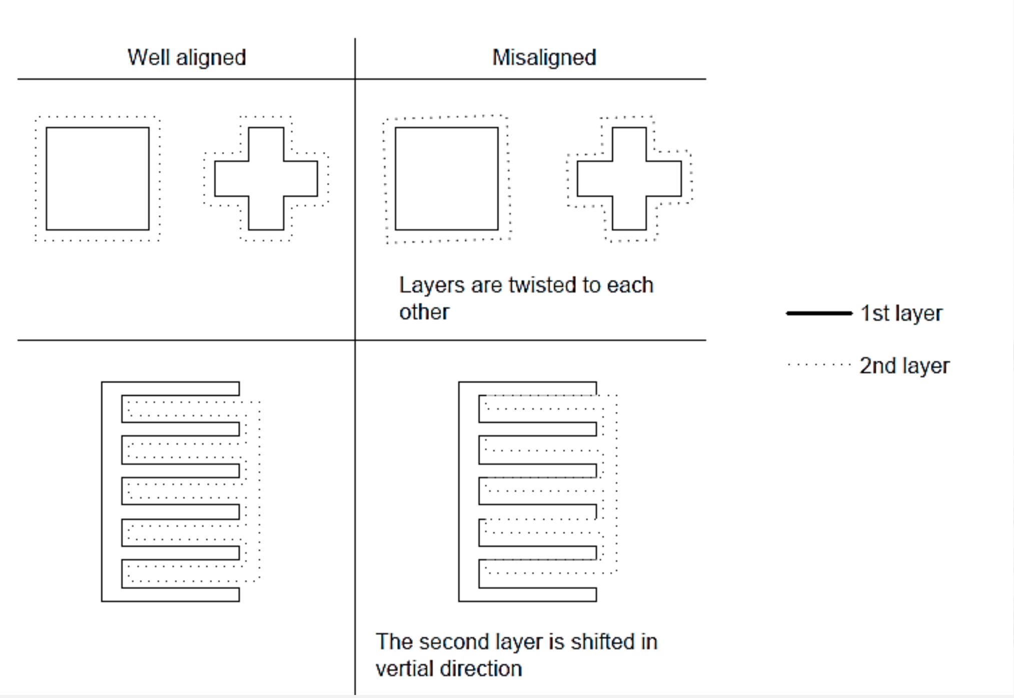
- Curing of the resist
- **Inspection**
- Resist removal

Inspection

- The resist layer must be inspected afterwards
- In angular incidence of light the uniformity of the layer can be inspected as well as bad focusing or agglomeration of resist
- If structures are too thin or too wide the resist has to be removed and the process has to be repeated.
- The resist pattern has to be adjusted precisely to the layer beneath or the process has to be repeated as well.



Resist removal

This is done with abrasive chemicals (remover), in a dry etch step or with solvents

As solvent acetone can be used since it does not corrode other layers on the wafer.

Due to a dry etch process or ion implantation the resist could be hardened, so that solvents can't remove it.

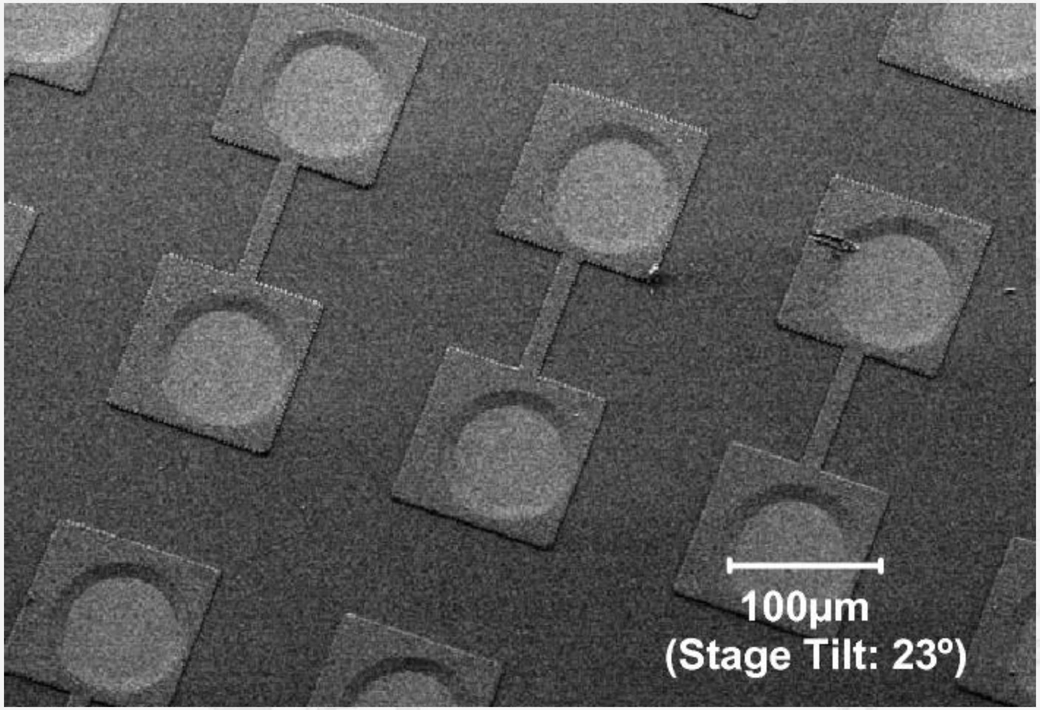
In this case the resist can be removed with a remover dilution at about 80 C in a dipping bath. If the resist has been hardened, heating above 200 C even can't remove it***. In this case the resist has to be removed in an ashing process.***

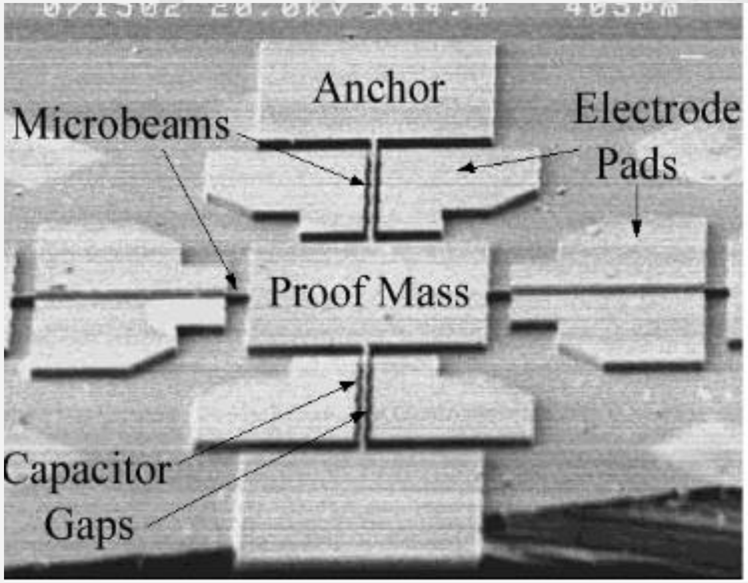
Solvents as Removers

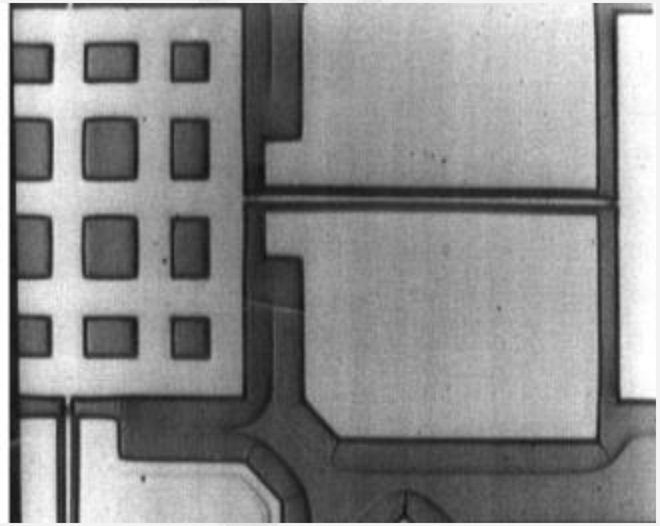
Acetone: Acetone is generally not recommended for the removal of photoresist films because of its high vapor pressure. If acetone is to be used, it is advisable to rinse the acetone contaminated with resist with iso-propanol before the acetone evaporates and forms streaks.

NMP: NMP (1-methyl-2-pyrrolidone) is a generally suitable solvent for removing photoresist layers. The very low vapour pressure of NMP allow heating to 80°C in order to be able to remove even more cross-linked pho-toresist films.

AZ® 100 Remover: AZ® 100 Remover is an **amine / solvent mixture** and a standard remover for AZ® and TI photoresists. To improve its performance, AZ® 100 Remover can be heated to 60 - 80°C to improve its performance


100µm
(Stage Tilt: 23º)


Anchor
Microbeams
Electrode
Pads
Proof Mass
Capacitor
Gaps



Good luck for you MIDSEM