Using the PRISM Cleanroom Laboratory

How to do Lift-Off Process Right!

Lift-off

Metal *lift-off* is a microfabrication process for creating a pattern by depositing a thin metal film over the patterned photoresist with a specific lift-off profile (overcut) and removing the resist with solvent to leave behind the metal only in the patterned area, directly on the substrate.

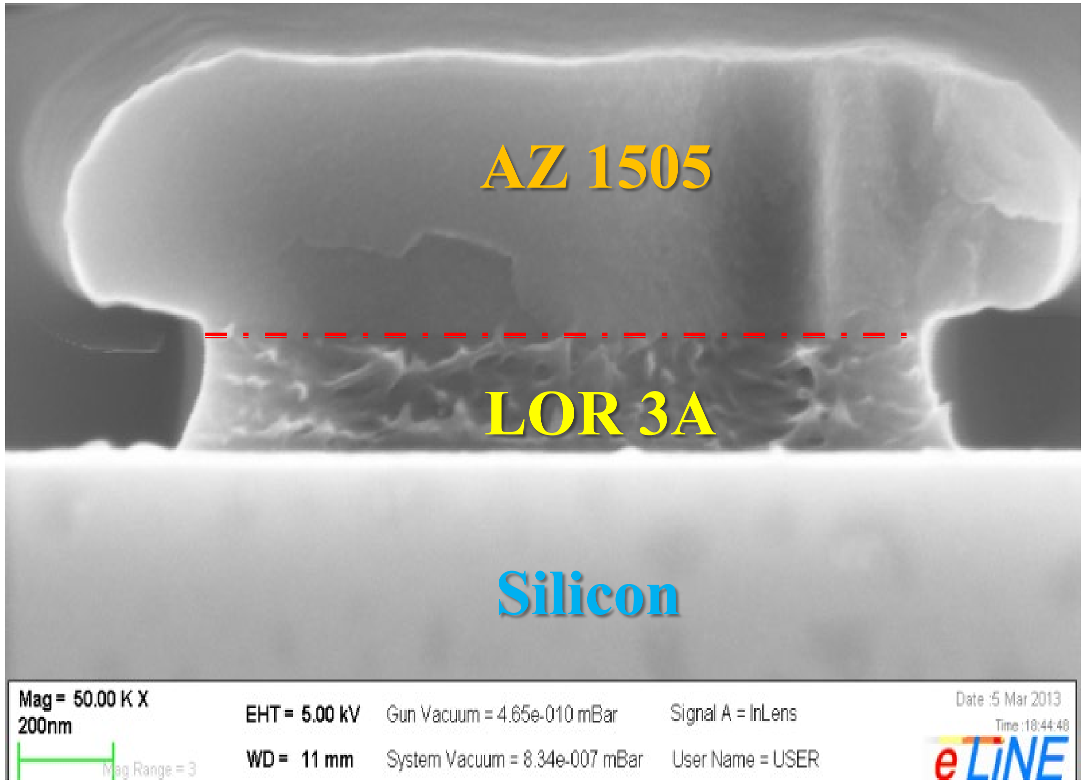
Methods for creating photoresist lift-off profile:

1) Double layer lift-off (or bi-layer lift-off)
2) Image reversal

Double layer lift-off (or bi-layer lift-off)

Double layer lift-off is using two different types of resist on top of each other, e.g. AZ 1500 series on top of LOR. Because of the chemical properties, the resists do not mix with each other. The top one can be precisely patterned and the bottom one undercut to form a lift-off profile.

Double layer LOR3A/AZ1505



Why double layer photoresists work?

- The positive imaging resists (e.g. AZ1500 series) consist of Novolak resin, the Photo active Compound (PAC) that belongs to the group of diazonaphtho-quinones (DNQ) and solvent. During exposure with UV-light the DNQ transforms into a carboxylic acid and its alkaline solubility increases. The exposed part become soluble in developers (e.g. AZ300MIF) and the unexposed areas remain on the substrate.
- LOR resists (e.g. LOR 3A) consist of polydimethylglutarimide (PMGI) that is virtually insoluble in typical photoresist solvents, so no intermixing occurs with the subsequent imaging resist coating from AZ1500 series.
- But, LOR resists are soluble in standard photoresist developers (e.g. AZ300MIF) and have highly controllable dissolution rate which allows to form an undercut and lift-off profile.

https://amolf.nl/wp-content/uploads/2016/09/datasheets_LOR_datasheet.pdf

Steps for double layer lift-off

1. Substrate preparation.

2. Coating and pre-baking LOR.

3. Coating and pre-baking imaging resist.

4. Exposing imaging resist.

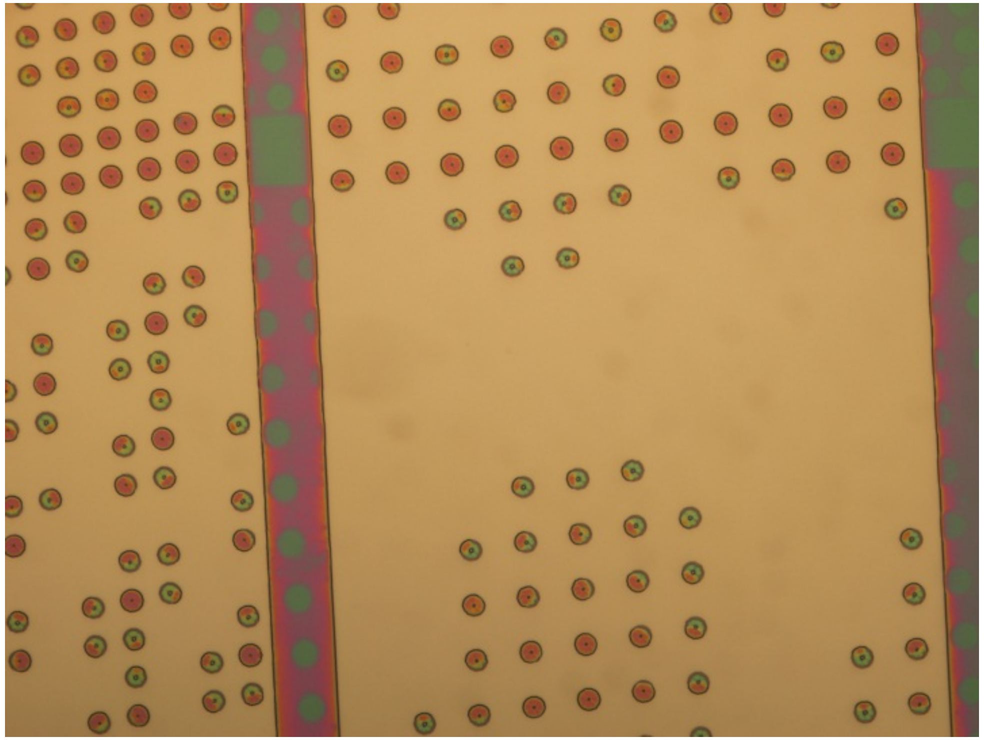
5. Developing imaging resist and LOR. LOR develops isotropically, creating a double-layer reentrant sidewall profile.

6. Depositing film. The re-entrant profile ensures discontinuous film deposition.

7. Lifting-off double-layer resist stack, leaving only desired film.

Substrate preparation

Examples of poor resist adhesion to Si wafer caused by organic residue and/or moisture on the substrate:



<u>Substrate should be dehydrated and primed before resist spin coating</u>

Substrate preparation: cleaning

Standard cleaning procedures for different circumstance:

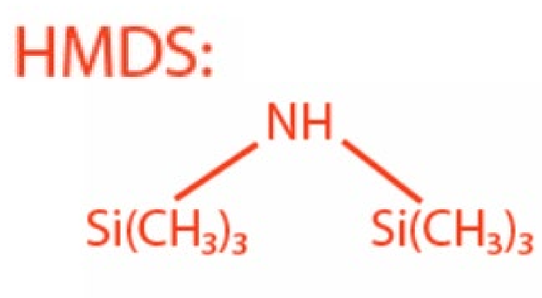
- In order to remove particles → rinsing in isopropanol
- For substrates contaminated with organic impurities → acetone followed by isopropanol
- In the case of stronger organic impurities → two acetone and isopropanol steps following each other (acetone vessel I → acetone vessel II → isopropanol vessel I → isopropanol vessel II)
- More aggressive organic residue removal → Piranha solution (H_2O_2 : H_2SO_4 = 1 : 3)
  - SiO_2 grows on the Si that can be removed in 1-5% HF dip
- RCA cleaning before high-temperature processes (not desired before resist coating)
  - RCA-1 (NH_4OH : H_2O_2 : H_2O = 1 : 1 : 5) at 75-80°C for 10 minutes
  - Optionally followed by a dip in 1-5% HF to remove the grown SiO_2
  - RCA-2 (HCl : H_2O_2 : H_2O = 1 : 1 : 8) at 75-80°C for 10 minutes
  - Optionally followed by a dip in 1-5% HF to remove the grown SiO_2

Substrate preparation: dehydration

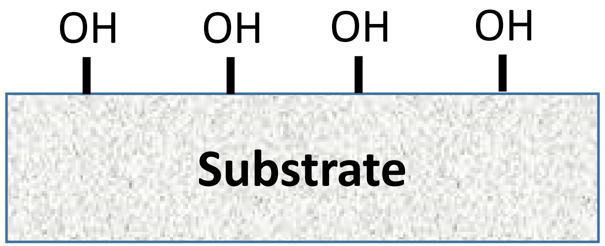
Dehydration :

- Bake out clean substrate at approx. 120°C for a few minutes for the desorption of water molecules usually adsorbed on surfaces exposed to air humidity
- Oxidized surfaces (native or thermally oxidized Si, quartz, glass, most metals) should be baked out at temperature above 140°C to remove the OH bonds generally present on oxidized surfaces exposed to air humidity
  - Resist coating should be carried out as soon as possible after baking out, but not before cooling of the substrate down to room temperature
- **Dehydrate and prime clean substrate in YES oven at 148 °C with HMDS vapor** (recommended)

Substrate preparation: priming with Hexamethydisilazine (HMDS)

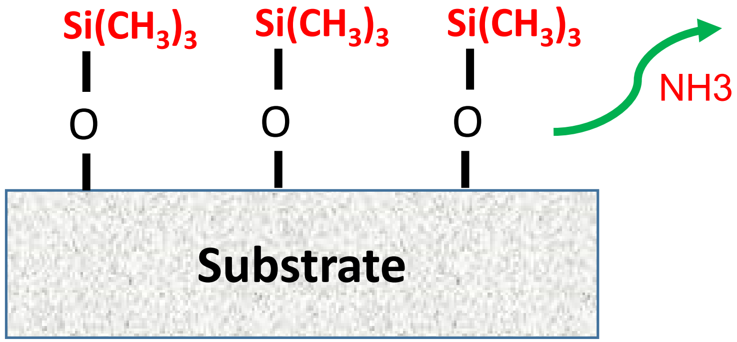


Wafer surface with adsorbed water, especially on oxide surfaces



HMDS priming in Yield Engineering Systems (YES) Oven

Wafer surface dehydrated and vapor HMDS primed in YES oven



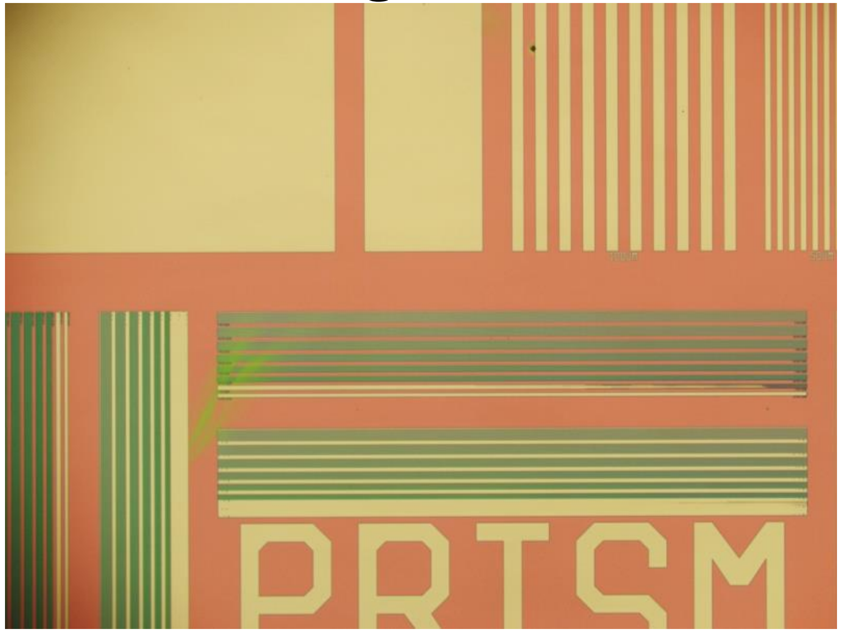
Silane compound (from HMDS) is bonded to the substrate to promote the chemical adhesion of an organic compound (photoresist) to a non-organic substrate (wafer).

https://www.yieldengineering.com/Products/HMDS-Prime-Ovens
https://www.microchemicals.com/technical_information/substrate_cleaning_adhesion_photoresist.pdf

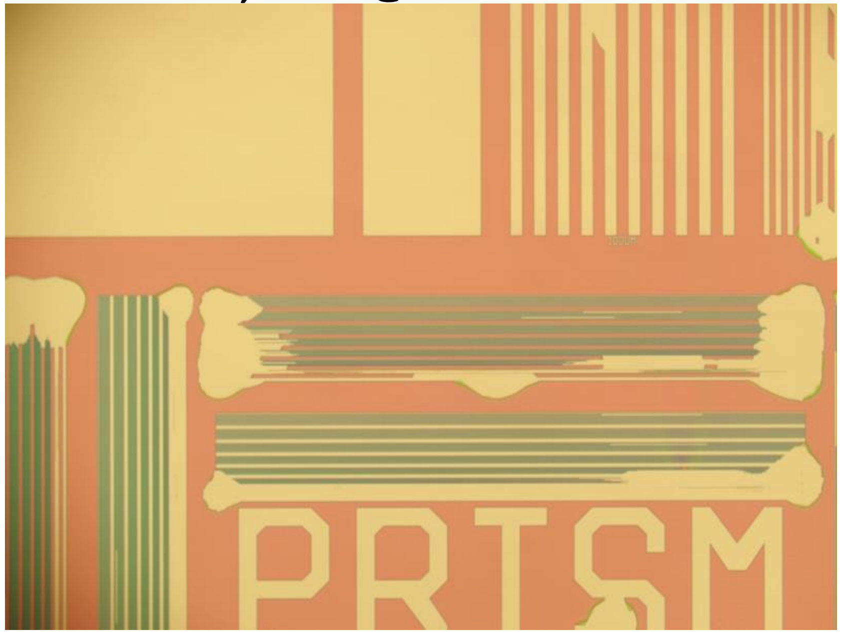
HMDS priming in YES oven – see the difference!

The difference with/without HMDS surface priming is shown in the pictures below. Both wafers are coated with LOR3A/AZ1505. The wafer on the left is primed with HMDS at 148 °C in the YES oven; the one on the right is only baked at 170 °C for 20 min (NO HMDS). Both wafers went through identical lithography process.

HMDS Prime @ 148 °C in YES oven



No HMDS, bake @ 170 °C for 20min

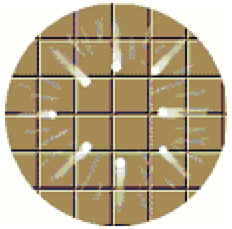


Spin coating

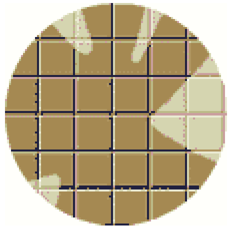
Clean, dehydrated and primed wafer is covered with photoresist by spin coating.

<u>Common problems:</u>

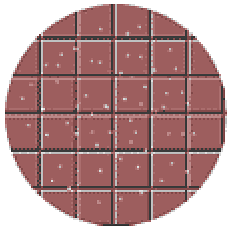
- Comet pattern
  - Particles exist on substrate surface prior to dispense
  - Resist sits on wafer too long prior to spin
  - Spin speed and acceleration setting is too high



- Uncoated Areas
  - Insufficient resist volume
  - Fluid is not being dispensed at the center of the substrate surface
  - Spinner not leveled



- Pinholes
  - Air bubbles
  - Particles in fluid
  - Particles exist on substrate surface prior to dispense



https://www.costeffectiveequipment.com/service-support/technical-resources/spin-coating-theory/

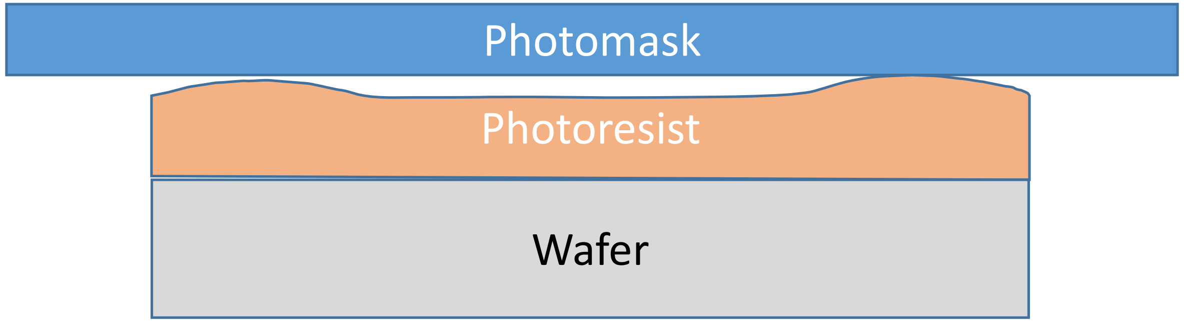
Spin coating and the edge bead formation

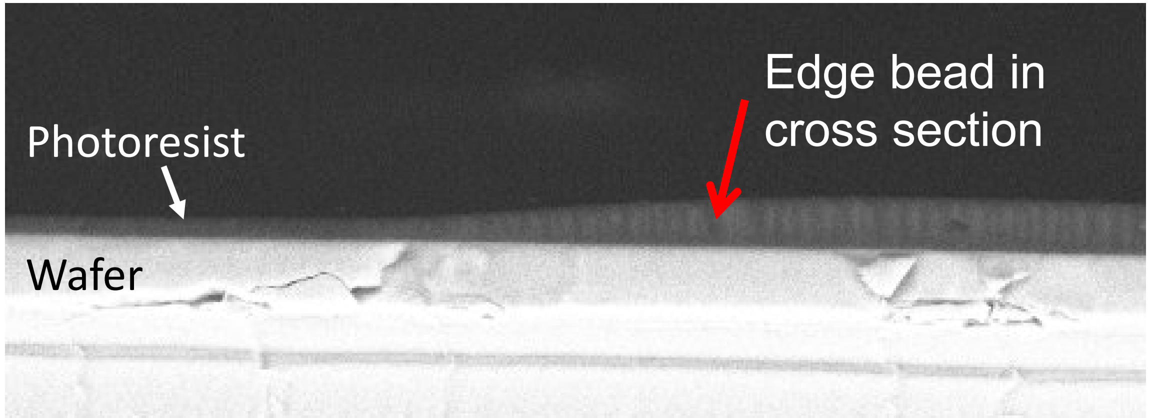
Edge bead forms especially during the coating of thick resist films and square substrates, or very small samples

<u>Consequences of the edge bead formation:</u>

- Features may not completely clear in thick regions
- Gap between mask and resist surface forms, reducing resolution
- Solvent may not be completely removed in thick regions

If possible use an automatic edge bead removal, or wipe the edge bead with a solvent-soaked swab.

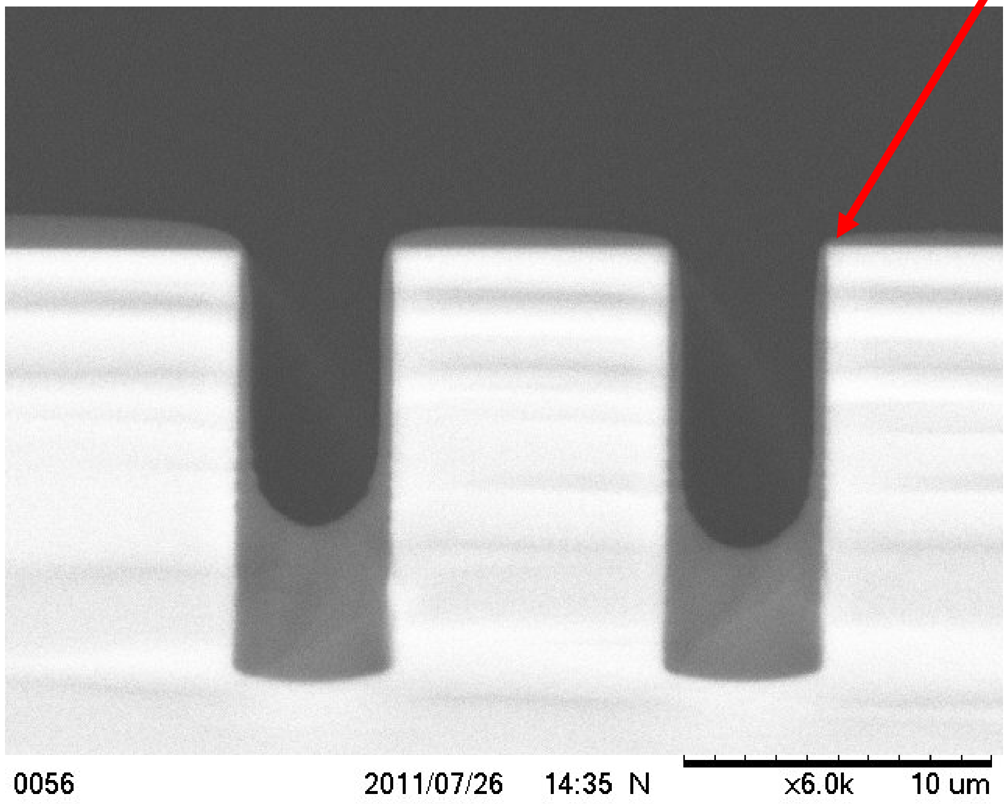


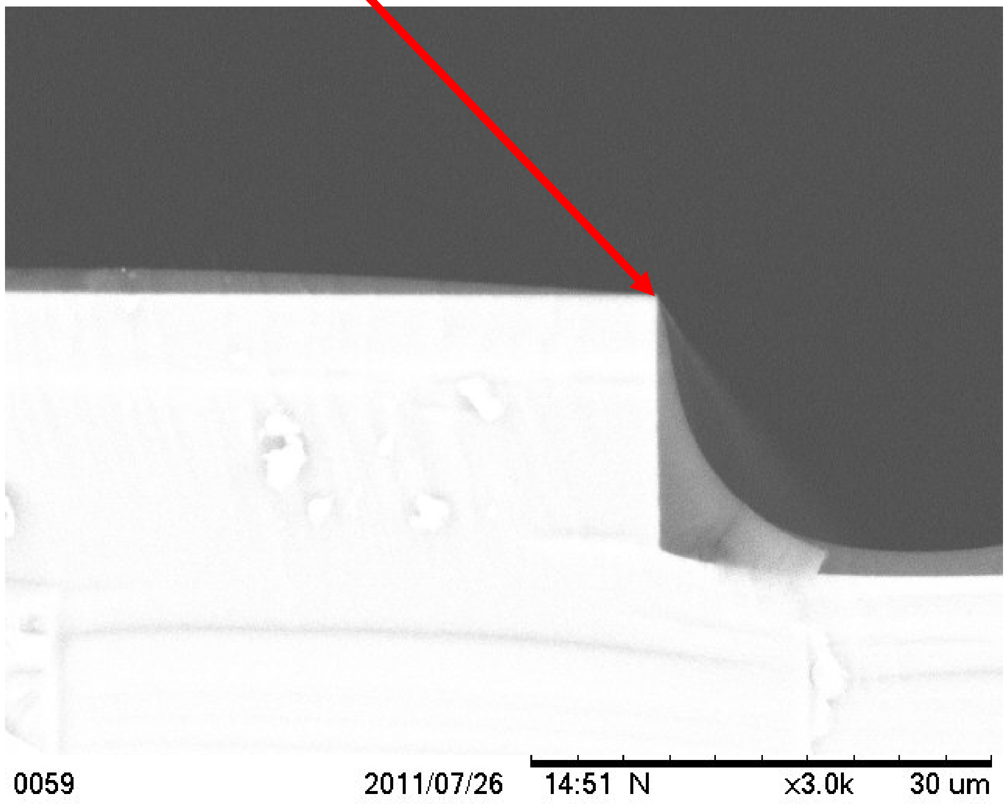


https://www.microchemicals.com/technical_information/spin_coating_photoresist.pdf

Difficulties in coating topography

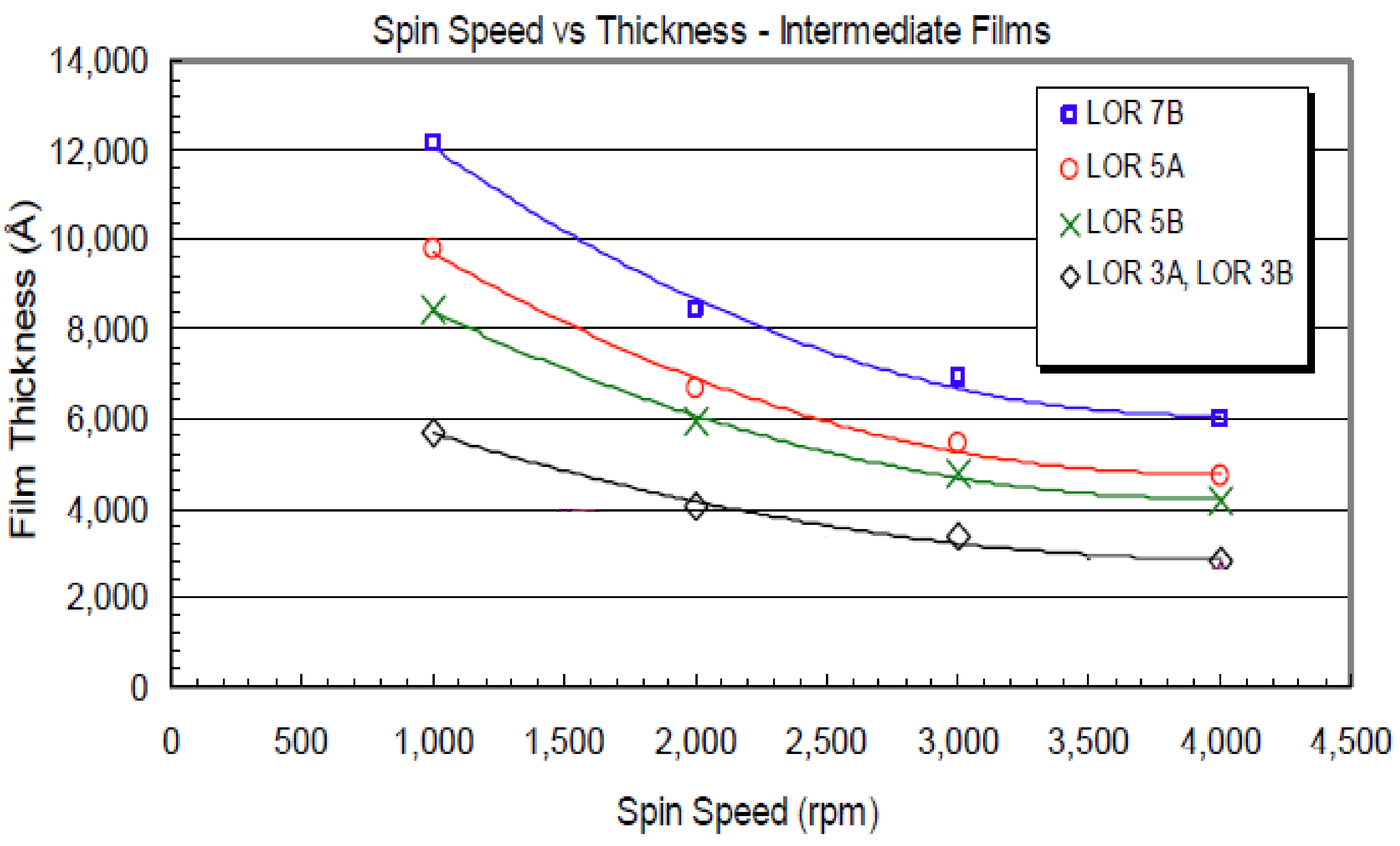
Resist is VERY thin here and may not survive processing





Wafer coating with LOR

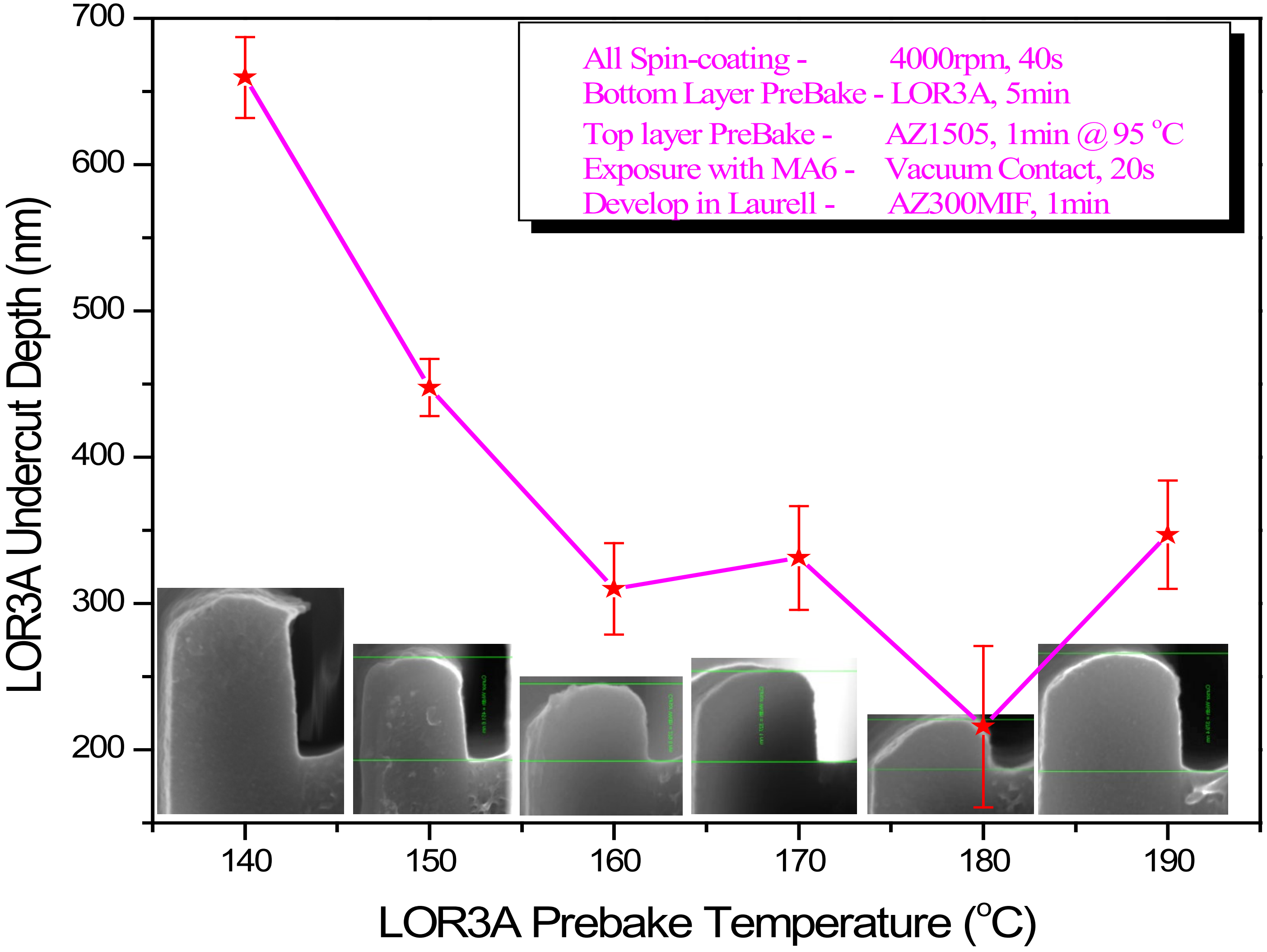
LOR resists are designed to produce broad range of film thicknesses using a variety of spin-coat conditions. For clean lift-off processing, the LOR film should be thicker than the metal deposition thickness, typically **1.2 to 1.3 times** the thickness of the metal film.



https://amolf.nl/wp-content/uploads/2016/09/datasheets_LOR_datasheet.pdf

LOR prebake

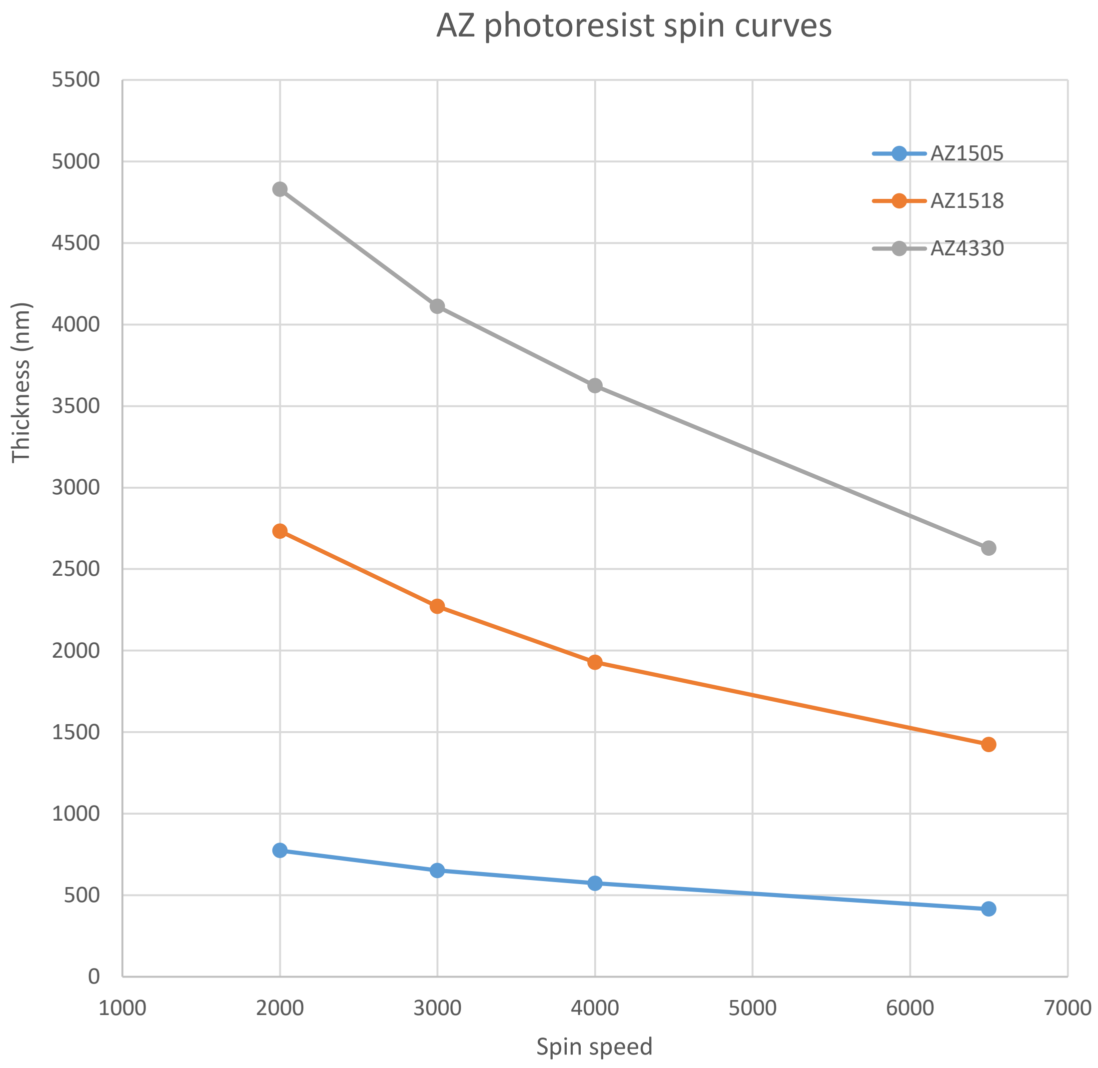
After spin coating, the photoresist is baked to drive off solvents and to solidify the film. In case of LOR, the prebake process is also the parameter with influence on undercut rate. Once the exposure and development processes have been defined, design of the prebake process enables precise control of undercut. Exposure dose of the imaging resist, and develop time are also influential.



https://amolf.nl/wp-content/uploads/2016/09/datasheets_LOR_datasheet.pdf

Spin coating of the imaging resist

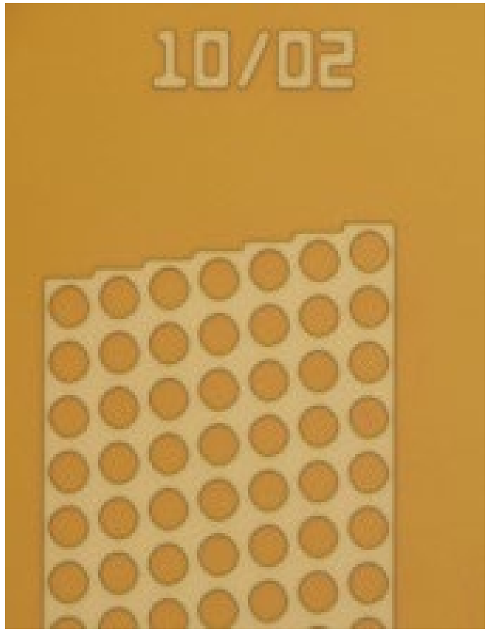
After LOR prebake, the imaging resist, e.g. AZ resist is spin coated. Film thickness of AZ 1500 series resists depends on spin speed and usually ranges within 0.5 - 3 µm. Note that these resists were optimized for substrate adhesion in wet etch process environments.



Exposing imaging resist

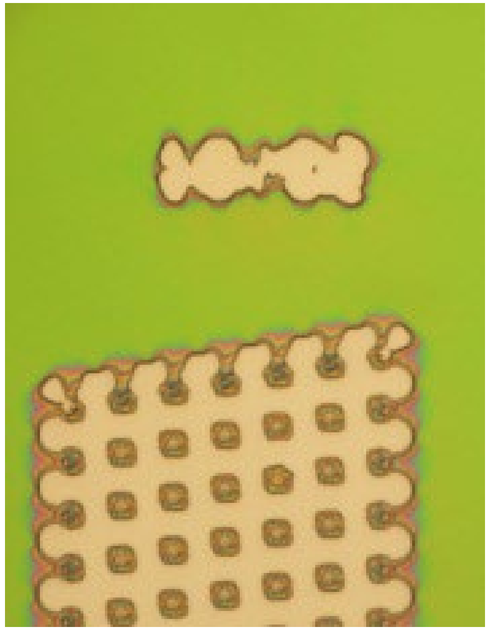
After spin coating the imaging resist on top of LOR, it must be exposed to transfer pattern into the photoresist. Using a mask aligner MJB4 or MA6 you can expose the resist using different exposure modes and gaps between the photomask and wafer: vacuum, hard, soft and proximity. The lower the exposure gap from mask to wafer, the higher the resolution but contact printing can damage the mask and fragile wafers.

Vacuum exposure mode



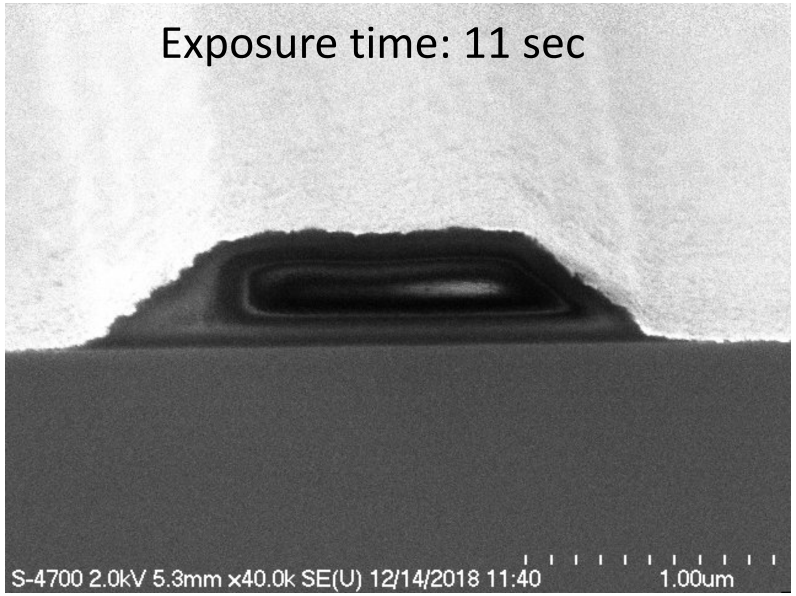
Hard exposure mode

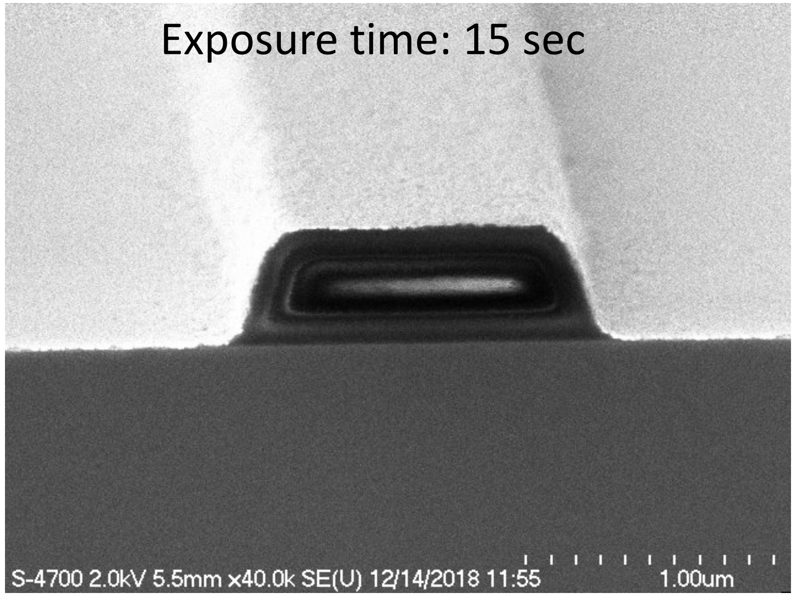
Soft exposure mode

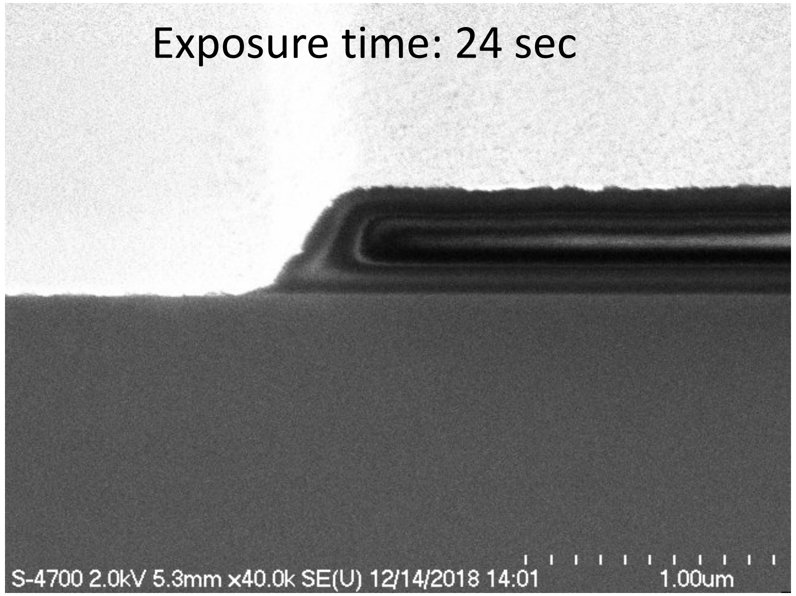


Effect of exposure time on positive tone resist

A positive photoresist profile has a positive slope of 75 - 85° depending on the process conditions.

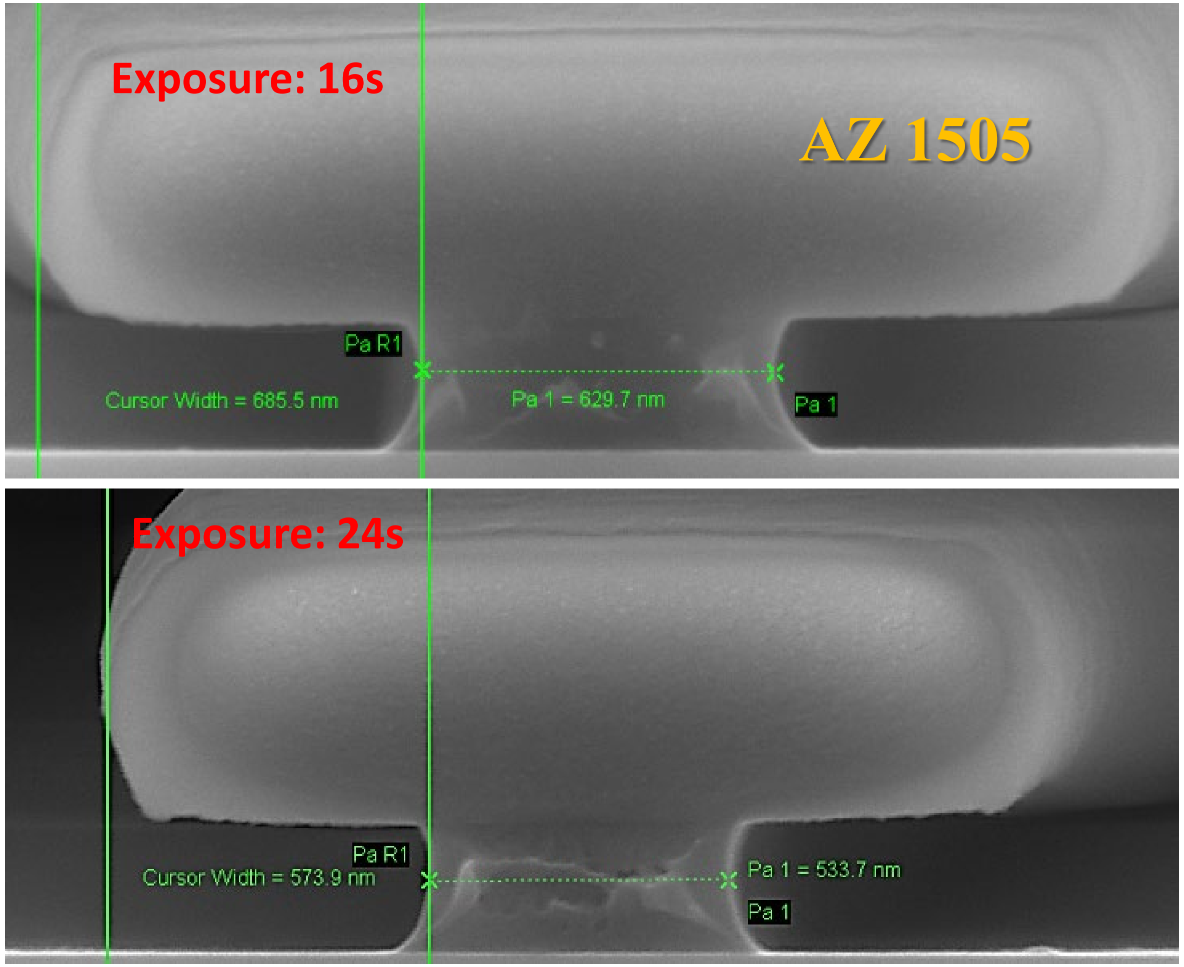






AZ1505, 4000rpm, 40s
Bake: 1min @ 95 °C
Exposure: MA6, hard contact: 11, 15, and 24 sec
Develop: 300MIF for 30 sec

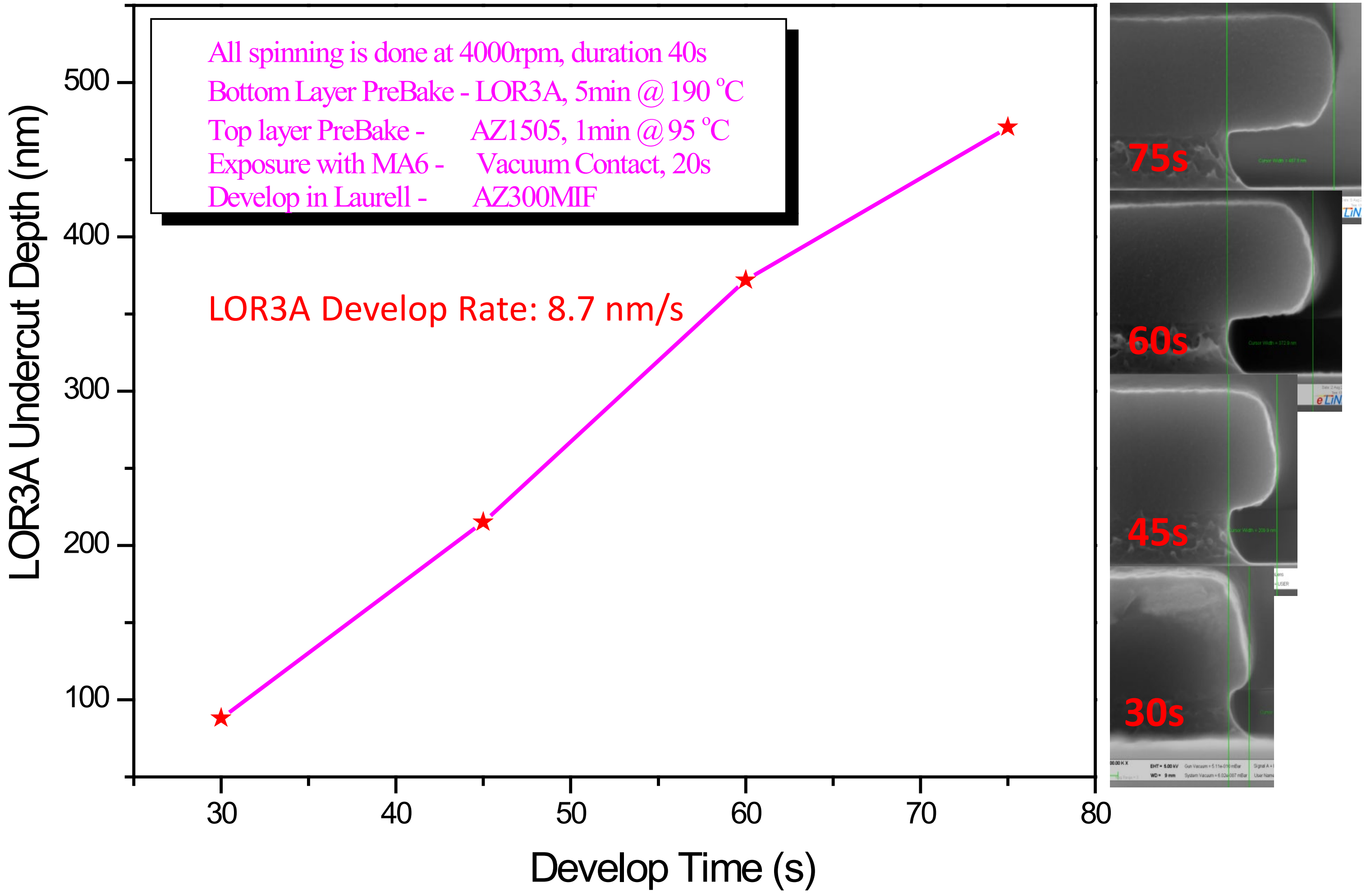
Effect of exposure time on double layer profile



Bottom Layer:
LOR3A, 4000rpm, 40s
Bake 5min @ 190 °C
Top Layer:
AZ1505, 4000rpm, 40s
Bake 1min @ 95 °C
Develop:
60s in AZ300MIF
Laurell Spin Processor

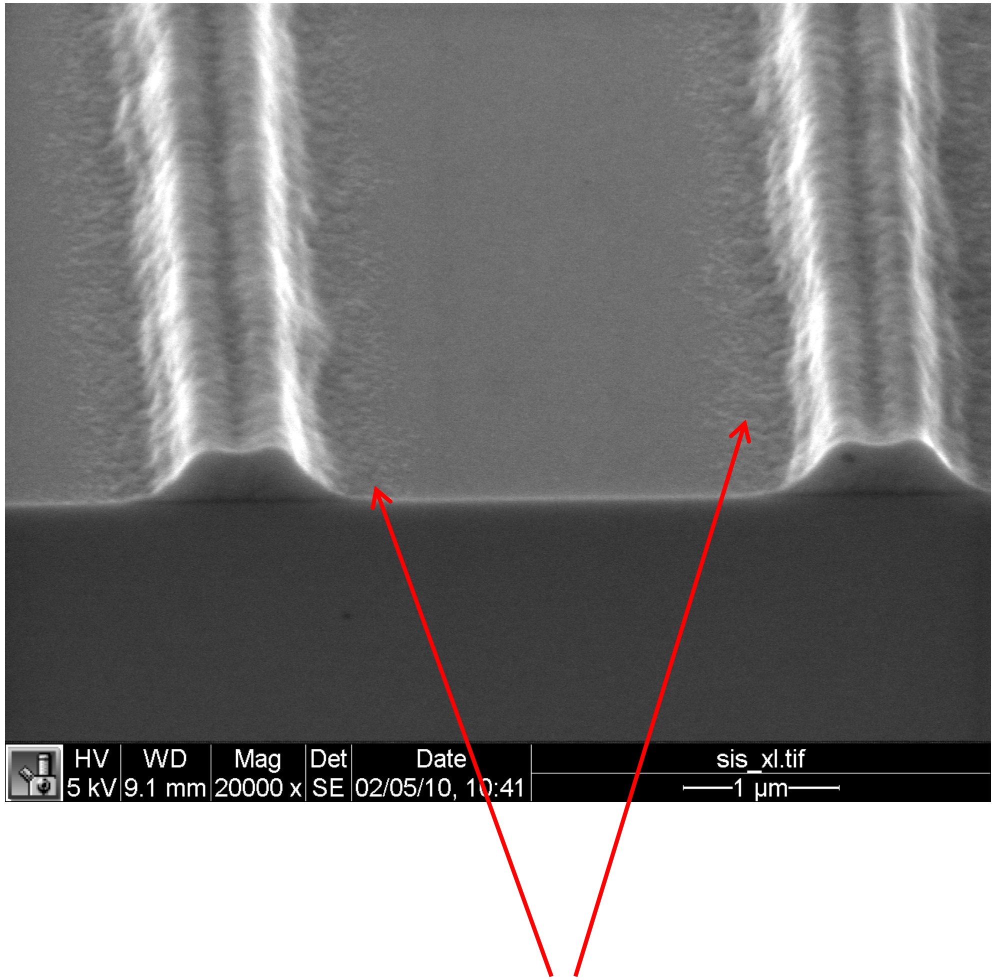
Effect of develop time

After exposure, the double layer resists are developed. Here, effect of different develop time (30s, 45s, 60s and 75s) on the undercut depth is presented. The plot shows the undercut depth increases with develop time.



“Descum" process

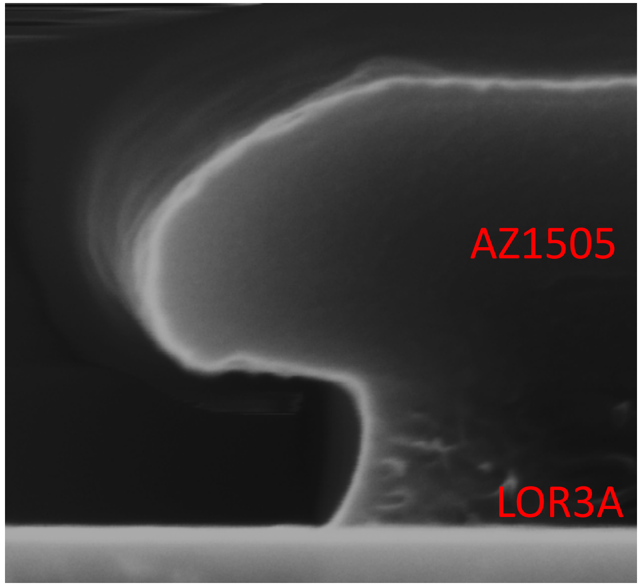
The "descum" process (e.g. in Tepla ML4 etcher) is a short, gentle oxygen plasma treatment that removes residual photoresist in the patterned area. Tepla ML4 etcher creates a remote “gentle” oxygen plasma that decomposes organic materials such as photoresist residue which could cause poor metal adhesion or contact.



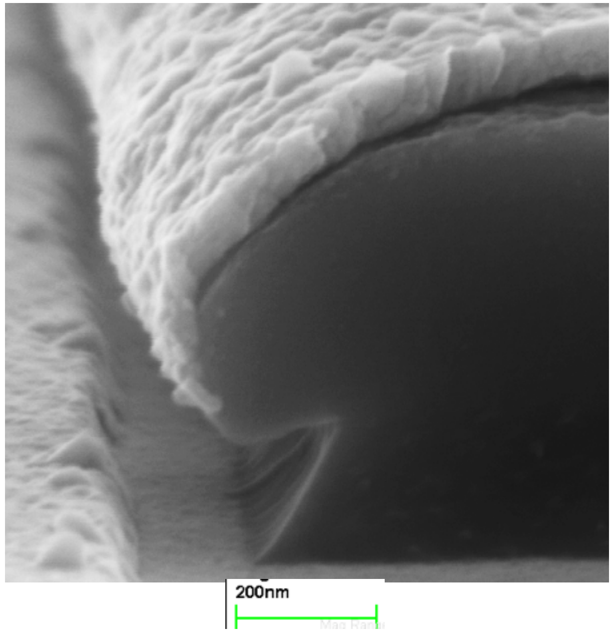
Photoresist residue that can be cleaned by descum process

After metal deposition

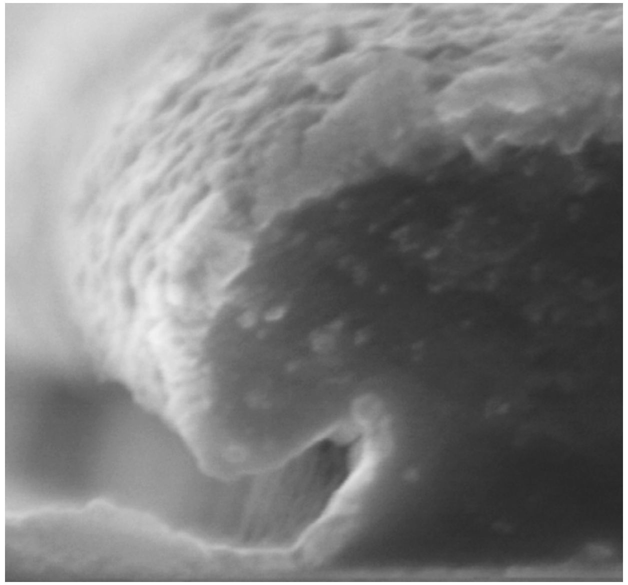
Here, two metal deposition methods are compared: evaporation vs. sputtering. The cross-section images show that, evaporation is directional, while sputtering is conformal. For metal lift-off process, it's preferred to deposit metal with evaporation.



Double-layer resists



After evaporating 100nm Al



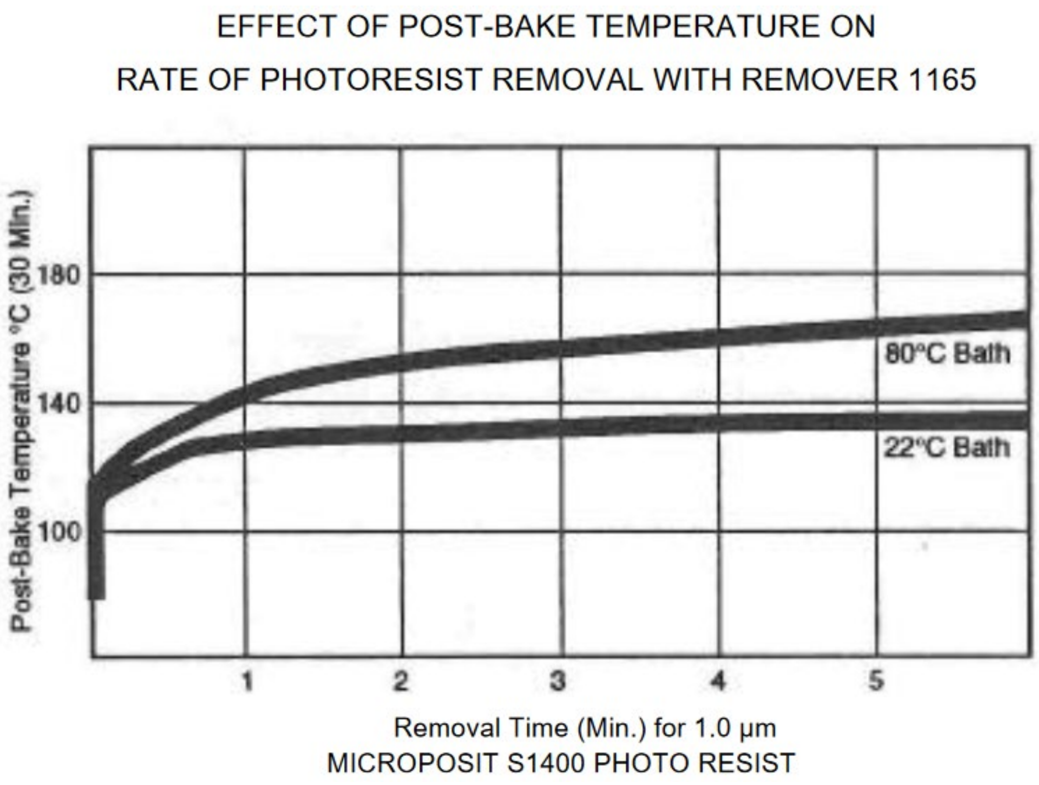
After sputtering 100nm Al

Removing photoresist

MICROPOSIT REMOVER 1165 is a mixture of organic solvents mainly N-methyl-2-pyrrolidine suitable for removing photoresist layers. A two-bath system is recommended: the first bath to remove the bulk of the photoresist, the second bath to remove any remaining traces of photoresist.

MR 1165 may be used at temperatures up to 80°C using cautions pertaining to combustible liquids in order to be able to remove even more cross-linked photoresist films.

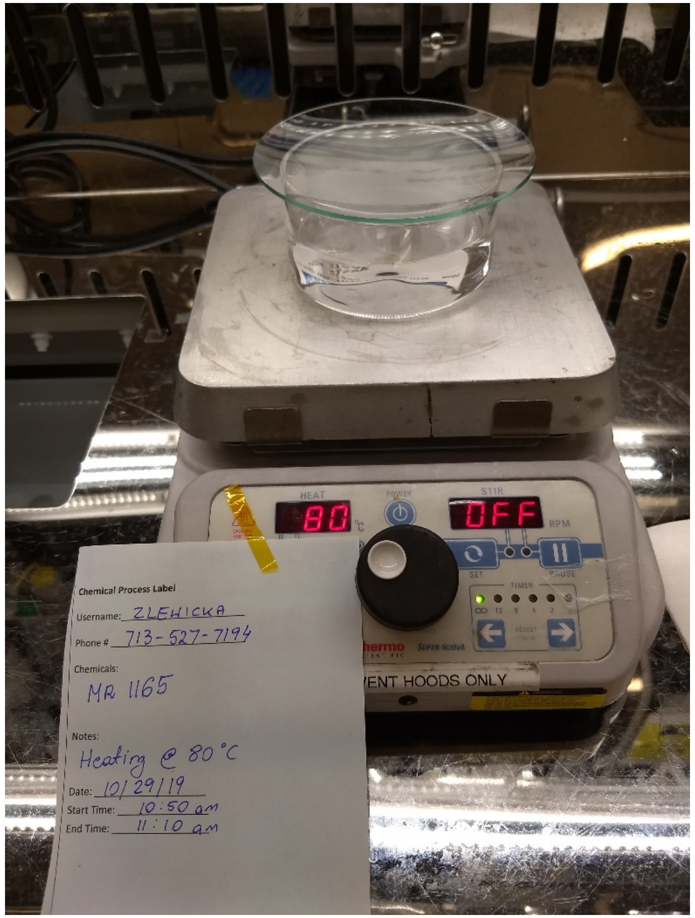
Acetone is not recommended for the removal of photoresist films because of its high vapor pressure. Furthermore, LOR will precipitate in the presence of acetone. Remember, do not heat the acetone to increase the solubility because of the high risk of fire due to its high vapor pressure.



http://micromaterialstech.com/wpcontent/dow_electronic_materials/datasheets/1165_Remover.pdf

When doing the lift-off

- Use the borosilicate glass beaker and fill it half way with MR 1165
- Insert the wafer into the solvent, and heat it on a hotplate in Wet-Stripping Fume Hood. A front panel setting of 80 C on the hotplate should be used. DO NOT HEAT ABOVE 80 C!!!
- Leave the wafer in the remover 1165 until the liftoff is complete.
  - If doing a long soak make sure the glass cover is on the beaker or the remover may evaporate away.



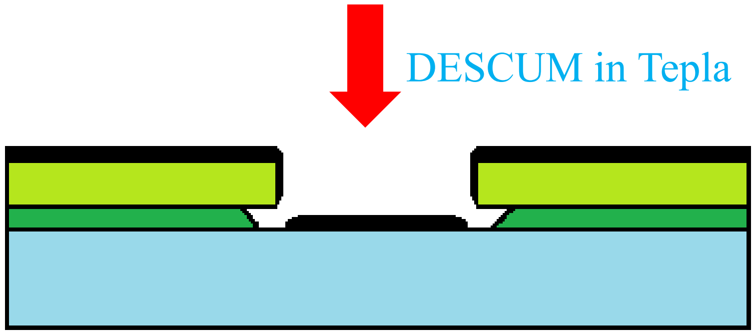
Typical bi-layer photoresists process - summary

(1). Clean surface and prime with HMDS in YES oven. Spin coat LOR3A at 4000rpm for 40s, bake on a hotplate for 5min @ 160-190 °C.

(2). Spin coat AZ1505 at 4000rpm for 40s, bake on a hotplate for 1min @ 95 °C

(3). Perform vacuum contact with Karl Suss MA6 aligner, exposure time: 20s.

(4). Develop using AZ300MIF (e.g. with Laurell spin-processor for 60s)

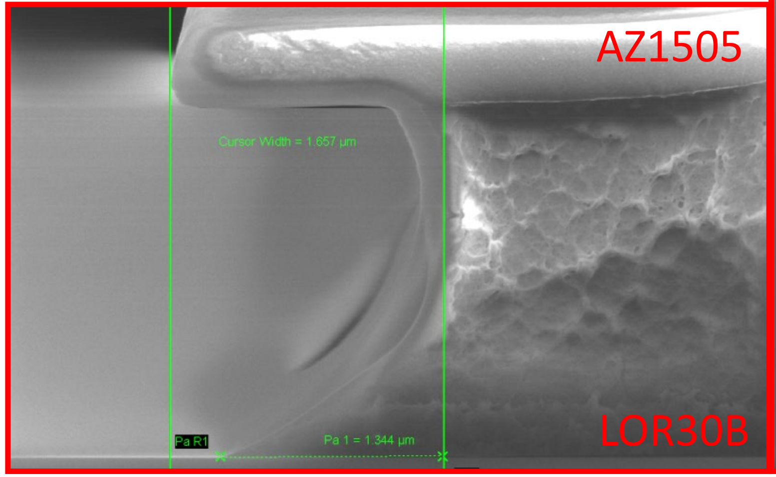


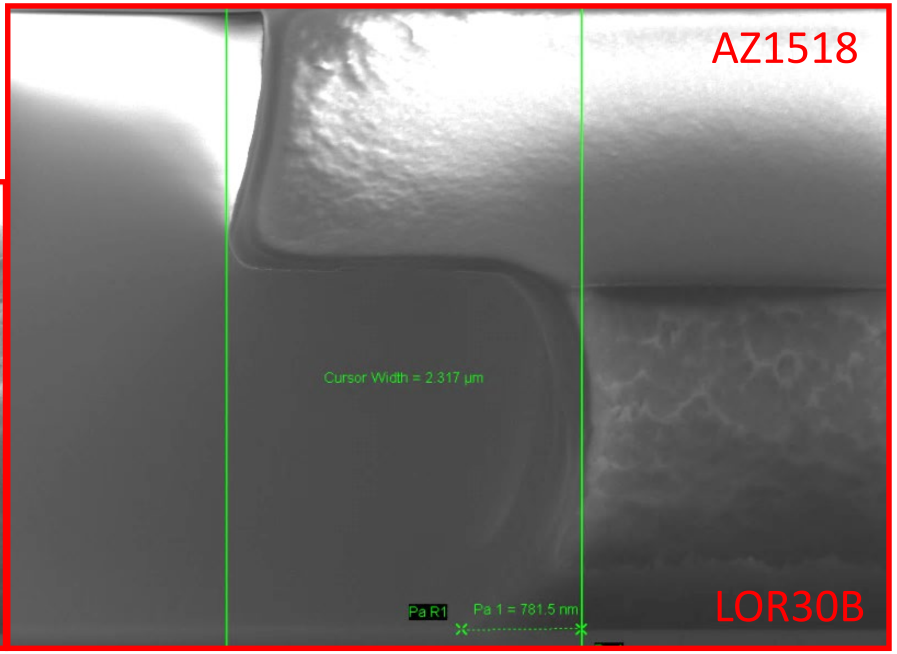
(5). Evaporate metal (e.g. 100 nm Al) onto the substrate with e-beam evaporator

(6). Lift off in MR1165 (heated max up to 80 °C) for 15 minutes (don’t lift off in Acetone).

Other double-layer structures

with LOR30B as the bottom layer, use AZ1518 & AZ1505 as the top layers





Bottom Layer:
LOR30B, 4000rpm, 40s
Bake 5min @ 190 °C
Top Layer:
AZ1505, 4000rpm, 40s
Bake 1min @ 95 °C

Exposure:
Suss MA6: 20s
Develop:
45s in AZ300MIF
Laurell Spin Processor

Bottom Layer:
LOR30B, 4000rpm, 40s
Bake 5min @ 190 °C
Top Layer:
AZ1518, 4000rpm, 40s
Bake 1min @ 95 °C

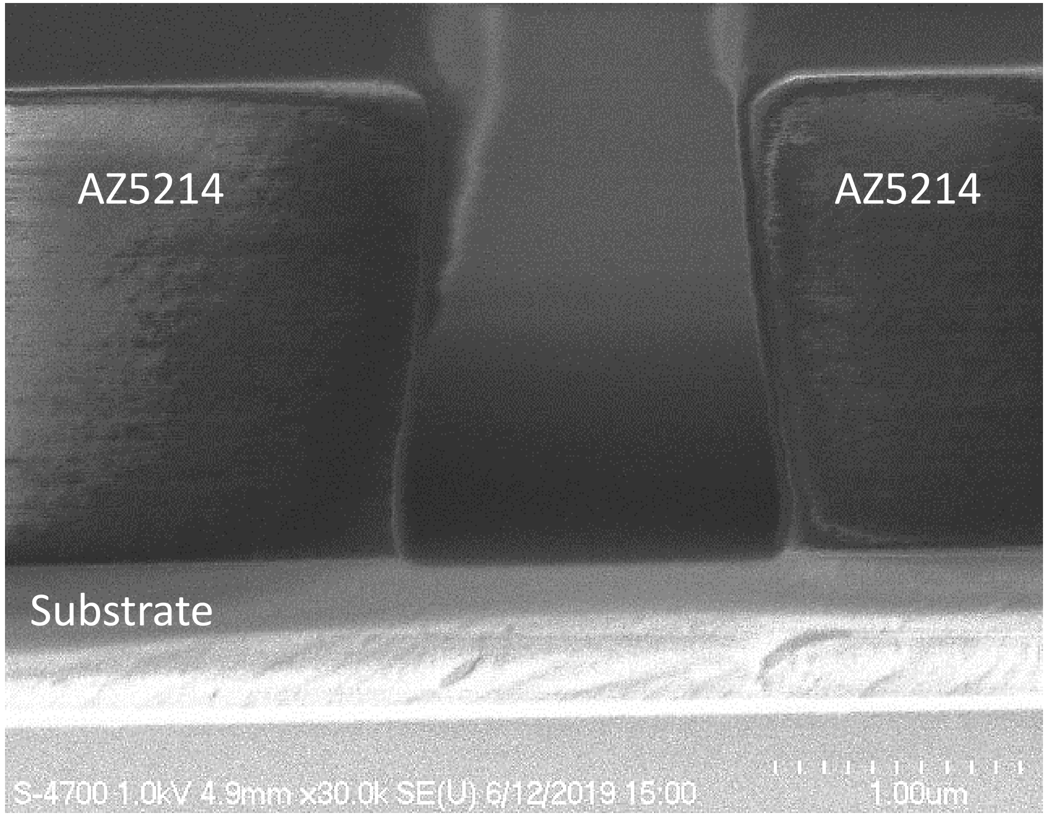
Exposure:
Suss MA6: 20s
Develop:
60s in AZ300MIF
Laurell Spin Processor

Image reversal

Image reversal uses photoresists capable of image reversal (IR) resulting in a negative pattern of the mask for lift-off techniques.

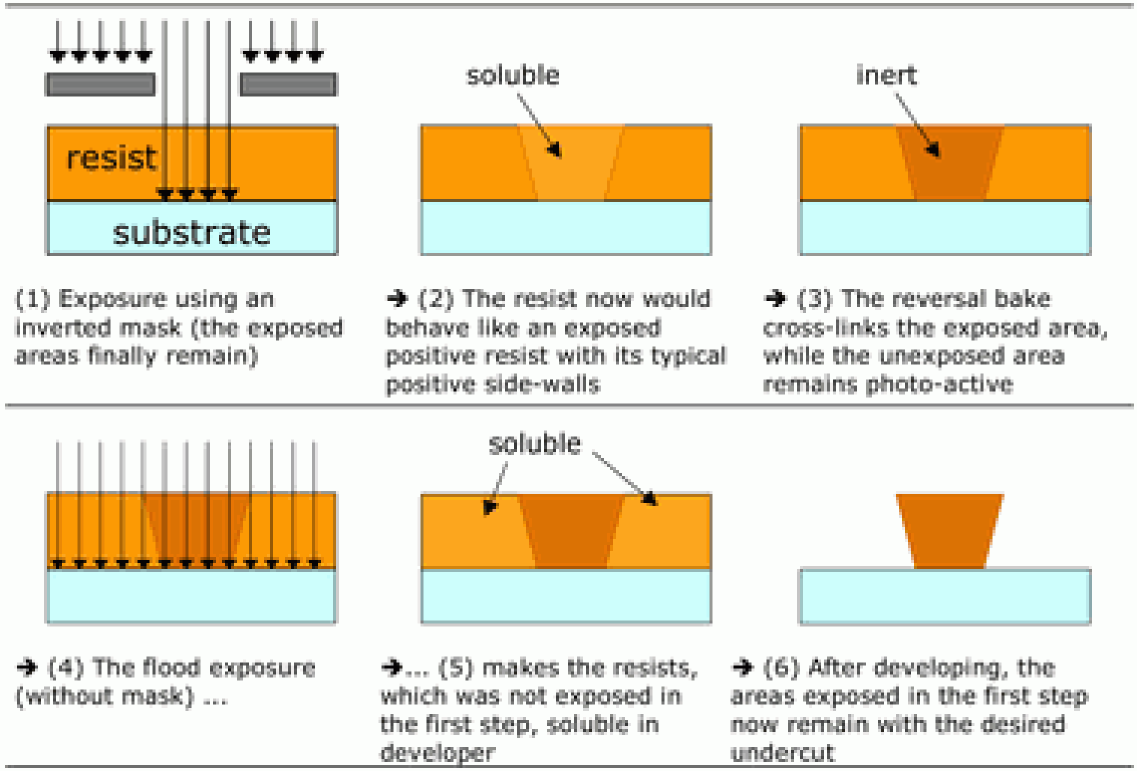
For example, AZ5214 when processed according to the general protocol for positive resists it works like a normal positive tone resist. But with the additional process steps “reversal bake” and “flood exposure”, the material provides a negative resist image with undercut ideal for lift-off.

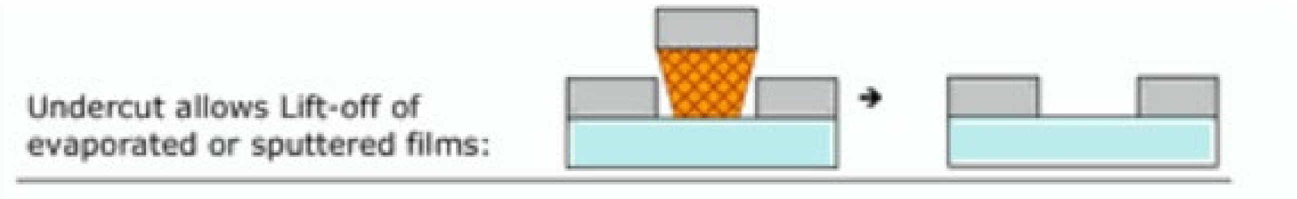
Negative AZ5214 resist image



https://www.microchemicals.com/products/photoresists/image_reversallift_off.html

Steps for 5214 image reversal





http://www.imicromaterials.com/index.php/technical/az-5200-image-reversal-recipe
https://www.microchemicals.com/products/photoresists/image_reversallift_off.html
https://microchemicals.com/micro/tds_az_5214e_photoresist.pdf

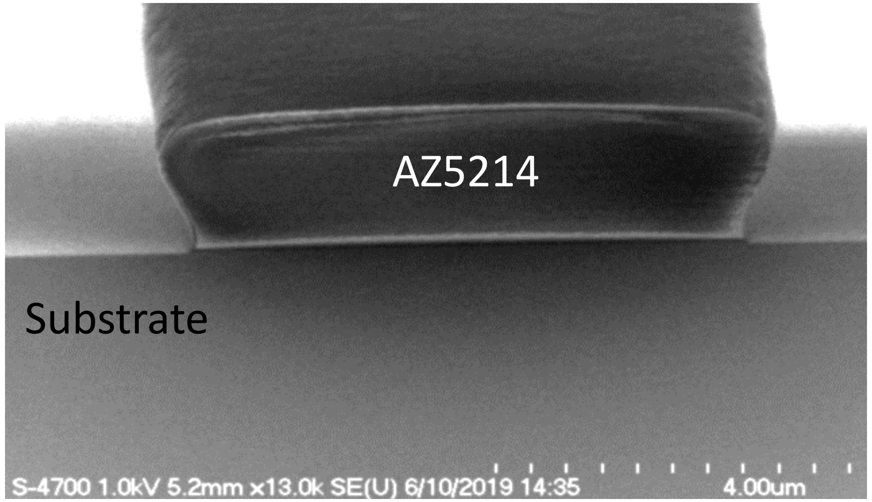
AZ5214 positive photoresist formulation consists of a special crosslinking agent which becomes active at temperatures above 110°C only in UV exposed areas of the resist.

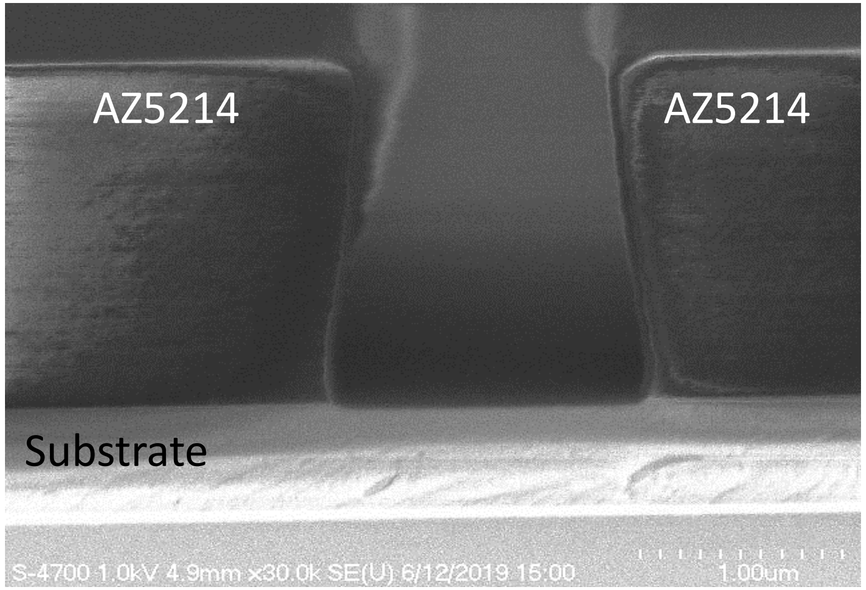
FILM THICKNESS [µm] as FUNCTION of SPIN SPEED (characteristically)

spin speed [rpm]	2000	3000	**4000**	5000	6000
AZ 5214E	1.98	1.62	**1.40**	1.25	1.14

Example of 5214 image reversal process

- Wafer cleaning and priming
- Spincoat at 4000 RPM for 40 sec
- Softbake on a hotplate at 110C for 60 sec
- Exposure on MJB4 for the specified amount of time (e.g. 2 sec when on SiN/Si substrate)
- Reversal bake on a hotplate at 120C for 2 min
- Flood exposure on MJB4 (no mask) 60 sec
- Develop with AZ 300MIF for 60 sec





Photoresist selection - summary

Name	Thickness range	Bake conditions	Notes
AZ 1505	0.35 – 1 micron	95C, 60 sec	
AZ 1518	1.5 – 2.5 microns	95C, 60 sec	
AZ 5214	1.2 – 2 microns	95C, 60 sec (positive tone)	Can be thermally image reversed
AZ 4330	3 – 5.5 microns	110C, 60 sec	Double spun up to 15 microns thick
LOR 1A	100 nm	160 to 200C, 5 min	Non-photosensitive lift off material
LOR 3A	300 nm	160 to 200C, 5 min	Non-photosensitive lift off material
LOR 10A	1 micron	160 to 200C, 5 min	Non-photosensitive lift off material
LOR 30B	3 microns	160 to 200C, 5 min	Non-photosensitive lift off material

Above are presented baseline processes that results may vary depending on the conditions such as e.g. substrate type and size so it is always recommended to optimize the process for your specific sample.