Lift-off Processes with Photoresists

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Lift-off - Basic Questions and Criteria

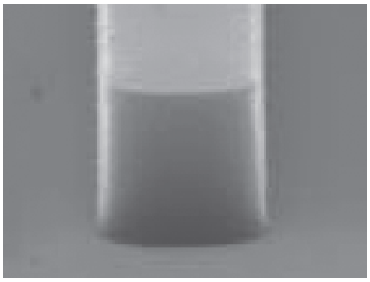
Beside wet or dry etching, lift-off is a common technique to pattern metal or dielectrica films in the µm or sub-µm range. The main criteria for the choice of a photoresist best-suited for a certain lift-off process are:

- The thickness of the coated material
- The coating technology (evaporation, sputtering, CVD, ...) and the maximum temperature the resist film has to stand during coating
- The required resolution
- The availability of positive or negative photomasks
- The available exposure wavelengths (g-, h-, i-line)

After these questions have been answered, it's time to look for a resist meeting the requirements of your lift-off process(es) as described in the following sections.

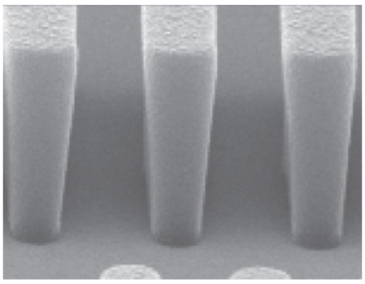
Which Resist for Lift-off?

Positive resists are suitable for lift-off processes to only a limited extent for two main reasons: Positive resists do not cross-link which keeps the softening point to values of 110-130°C. Since these temperatures often occur during typical coating processes, the resist features will rounden and become coated overall making lift-off hard or impossible. Even if the resist features do not soften, positive resists allow only positive or - in best case - 90° sidewalls which also promotes the coverage of the sidewalls during coating. If the existing mask-design requires positive resists for lift-off, it is recommended to use resists with i) a high thermal stability, and ii) resist sidewalls as steep as possible. Both demands are met with the AZ® 6600-series (resist film thickness range approx. 1-4 µm), or the AZ® MiR 701 (< 1 µm resist film thickness).



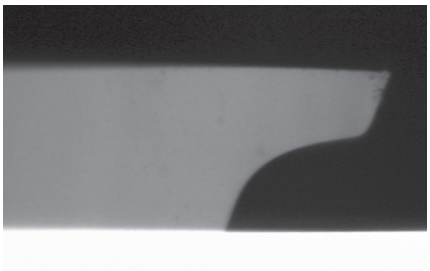
An AZ® MiR 701 resist pattern after a baking step at 130°C. Due to the high softening point of approx. 135°C, no roundening becomes visible.

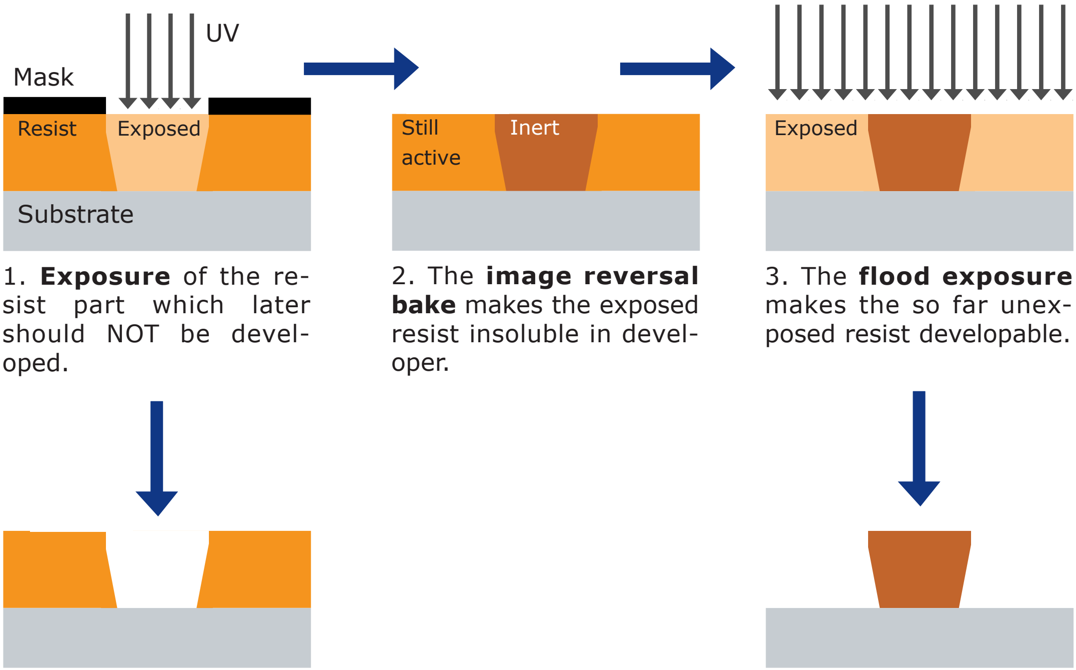
Negative resists are generally the best choice for lift-off processes: On the one hand, negative resists designed for lift-off attain a reproducible undercut. Such an undercut helps to prevent the resist sidewalls from being coated, which makes the subsequent lift-off easier. On the other hand, the crosslinking of the resin of common negative resists maintains the undercut even at very high coating temperatures, which helps to maintain the undercut during coating. For stable lift-off processes in the µm and sub-µm range, we recommend the AZ® nLOF 2000 series for resist film thicknesses in the range 1-20 µm. This resist series is i-line sensitive and can be developed in aqueous alkaline solutions (such as MIF developers).



Left: 300 nm lines and spaces with the AZ® nLOF 2020 negative resist at 2.0 µm resist film thickness.

Right: Progressive undercut with AZ® nLOF 2070 (resist film thickness 22 µm). The limited penetration depth of light concentrates the crosslinking to the upper. 5-10 µm of the resist film.





1. **Exposure** of the resist part which later should NOT be developed.

2. The **image reversal bake** makes the exposed resist insoluble in developer.

3. The **flood exposure** makes the so far unexposed resist developable.

After exposure, the image reversal resist can be developed as any positive tone resist.

4. After **development** a resist profile with the typical undercut remains.

Image reversal resists can either be processed in the positive or negative (image reversal) mode. Compared to the positive process, the image reversal mode requires an additional image reversal bake after the exposure, and a subsequent flood exposure without mask. Hereby, the resist sidewalls show a more or less pronounced undercut which makes the lift-off easier to realize. However, image reversal resists generally do not cross-link. Hence, from approx. 120-130°C on, the resist structures start to soften, and the features rounden making them less suited for lift-off. If an image reversal resist shall be used, we recommend the AZ® 5214E (1-2 µm resist film thickness), or the TI 35ES (3-5 µm resist film thickness).

The document Photoresists, Developers, and Removers gives a detailed overview on the processing and typical fields of application of the above-mentioned resists.

When Using Positive Resists for Lift-off ...

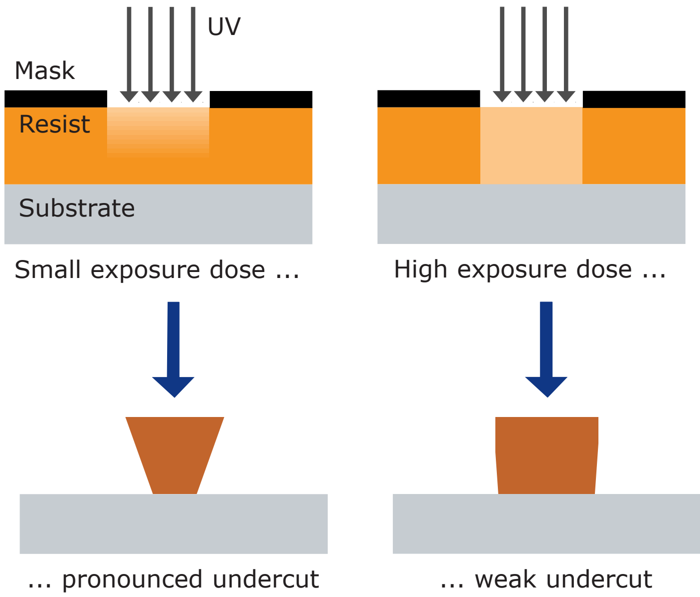
Steep sidewalls become less coated during deposition than positive sidewalls, which helps to make the lift-off easier. In order to make the resist sidewalls as steep as possible using positive resists, we recommend the following points:

- The usage of resists designed for steep sidewalls such as the AZ® MiR 701 (< 1 µm resist film thickness), the AZ® 6600-series (1-4 µm), or the thick resist AZ® 9260 (> 5 µm)
- The usage of resists with a high softening point maintaining the steep sidewalls during deposition at elevated temperatures (AZ® MiR 701, or the AZ® 6600 resists)
- A close contact between resist surface and photomask during exposure (no proximity gap)
- Optimized softbake parameters (approx. 100°C hotplate for 1 minute/µm resist film thickness)
- A sufficient rehydration (for details please consult the document Rehydration of Photoresists)
- An optimized exposure dose
- A developer (-concentration) for high selectivity (e. g. AZ® 400K or AZ® 351B in a 1 : 4 dilution, or the AZ® 326 or 726 MIF)

When Using Image Reversal Resists for Lift-off ...

The (First) Exposure

The first, structure-defining exposure is done with a photomask exposing the resist areas remaining on the substrate after development. As compared to a mask for positive resists, a mask for image reversal resists is inverted.



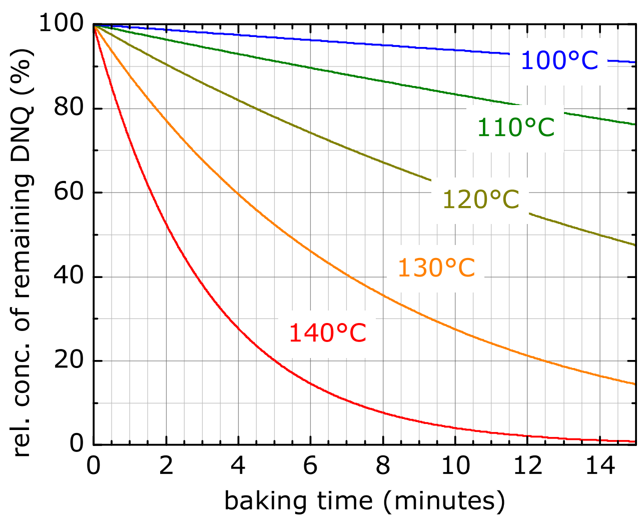
The exposure dose strongly impacts the attained resist profile. Low exposure doses keep the substrate-near resist rather unexposed and therefore maintain a high development rate thus achieving a pronounced undercut. High exposure doses homogeneously expose the resist film towards the substrate, the resist profile shows almost no undercut.

If the exposure dose is too low, the reversal bake cannot convert even the surface-near resist. Thus, the erosion of the exposed resist during development is rather high, the resist starts thinning. An exposure dose too high also illuminates nominal dark resist areas via scattering, diffraction, or reflection. As a consequence, the resist structures remaining after development are much larger than determined by the photomask. The development of narrow spaces will become more and more difficult.

The Image Reversal Bake

During the image reversal bake, the exposed resist areas are converted and become insoluble in the developer, while the resist so far unexposed remains 'virgin' and can be exposed in the next step. The optimum reversal bake parameters depend on the resist and the required resist profile. Typical values are 110-130°C for a few minutes.

Low bake temperatures (or/and -times) mainly convert the strongly exposed surface-near resist, thus resulting in a rather pronounced and progressive undercut. High bake temperatures (-times) also convert the weakly exposed part of the resist film, making the undercut less pronounced, and the resist profile more steep.



During the image reversal bake, a certain amount of the photoactive compound is thermally cracked, depending on the reversal bake temperature and -time.

Too low bake temperatures (-times) cannot convert even the highly-exposed surface-near part of the resist film, causing a strong erosion of also the exposed resist in the developer. Too high bake temperatures (-times) thermally decompose a significant part of the photo active compound (Fig. right-hand), thereby strongly lowering the development rate.

Bubble formation during the reversal bake (sometimes not visible before development) probably stems from nitrogen, which is generated during the first exposure. If the N_2 did not have enough time to outgas from the resist film before the reversal bake, it will form bubbles or even foam the resist film during the reversal bake which softens the resist film. The required delay between exposure and reversal bake to outgas the nitrogen depends on the resist and especially the resist film thickness. As a rule of thumb, 1 minute for a 1 µm film, and 10 minutes for 3 µm film are required. At moderately elevated temperature (40 ... 60°C), this delay can be shortened. Hereby, care has to be taken that the temperature keeps below the value where bubble formation will occur.

The Flood Exposure

The entire resist film is exposed without a mask, making the resist areas up to now unexposed developable. The exposure dose needs to be high enough to completely expose the substrate-near resist. Since there is no upper limit for this parameter, therefore we recommend a flood exposure dose at least twice as high as would be required to expose the resist in positive mode.

The resist film is water-free after the reversal bake, but needs a certain amount of water during exposure as every DNQ-based positive resist does. Therefore, rehydration (= delay between reversal bake and flood exposure) is important to keep the development rate at a reasonably high value. For details on this topic, please consult the document Rehydration of Photoresists.

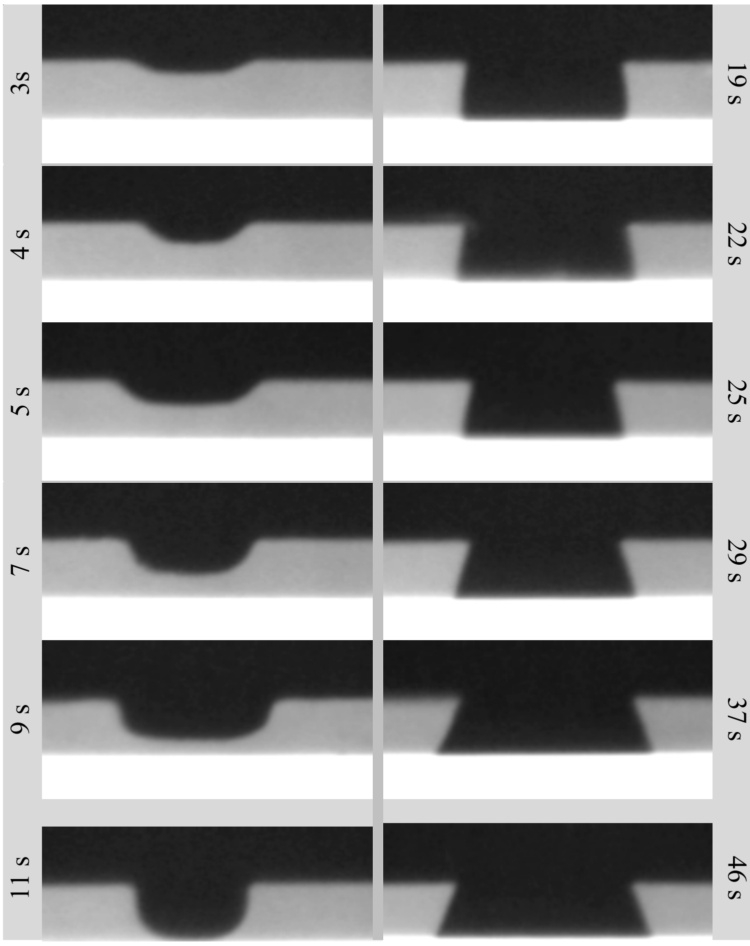
Development

The development rate attained depends on the resist, and especially on the reversal bake parameters. A hot, long reversal bake will decompose a higher amount of the photo active compound thus reducing the development rate. A value of > 1 µm/min in typical developers should be attained, but is not obligatory.

The degree of over-development (the development time after the substrate is free-developed in relation to the development time until now) impacts the undercut:

The cross-section image series right-hand shows how the undercut becomes more and more pronounced after the substrate is already cleared. An over-development of 30 % is a good starting point for your own optimizations.

In case of high aspect ratios, one has to take care that the undercut does not 'short-circuit' small/narrow resist structures and thereby lift them from the substrate.



A series of cross-sections of an image reversal resist in different stages of development. The undercut develops mainly after the substrate is already cleared. The time specification given refers to the development start.

When Using Negative Resists for Lift-off ...

The Exposure Dose

Generally, the exposure dose has a similar effect on image reversal resists and negative resists: The lower the exposure dose, the more the crosslinking or later reversal process concentrates on the upper part of the resist film making the undercut more progressive. High exposure doses make the undercut less pronounced, and the developed resist pattern wider.

The Post Exposure Bake (PEB)

This baking steps cross-links the exposed resist areas which hereby become insoluble in the developer. If the PEB temperature is too low, the degree of crosslinking keeps at a low level, and the erosion during development is comparable high. High PEB temperatures also weakly exposed resist areas, so the dimensions of the developed resist pattern becomes larger. Very high PEB temperatures thermally cross-link also unexposed resist, so the development rate drops, or development even does not work anymore.

The Development

As depicted in the same-titled section in „When Using Image Reversal Resists for Lift-off ...", the undercut forms out in the final stage of development. Thus, an over-development of 20-30% is recommended.

While image reversal resists remain soluble in organic solvents, negative resists can be developed in e. g. PGMEA which is compatible to alkaline-sensitive substrate materials.

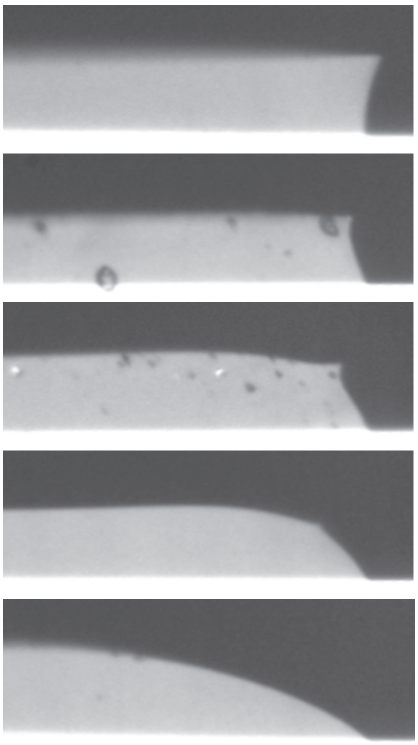
Deposition: Frequent Problems

Thermal Softening

During coating (evaporation of metals, sputtering, CVD), the resist film may be heated by the evaporation source radiation, the condensing heat of the growing film, or the kinetic energy of the ions, above its softening point (110 - 130°C for most positive tone and image reversal AZ® resists). Therefore, the resist profile starts rounding (Fig. below) allowing the coating material to cover also the resist profile side-walls. As a consequence, subsequent lift-off worsens or becomes impossible.

Possible work-arounds are

- an optimized heat coupling of the substrate to its holder (e. g. some turbo pump oil for proper heat transfer from strained, curved substrates),
- a sufficiently high heat buffer (massive substrate holder construction) or
- heat removal (e. g. black anodized aluminium as rear infrared radiator) from the substrate holder,
- a reduced deposition rate or/and a multistage deposition with cooling interval(s) in between,
- DUV-hardening or
- a reduced deposition rate or/and a multistage deposition with cooling interval(s) in between,
- a thermally stable photoresist (e. g. AZ® 701 MiR or AZ® 6600 series in positive mode or TI 35ES in image reversal mode), or AZ® nLOF negative resist for highest thermal stability.



Beyond the softening point of the resist, the resist structures stat to rounden. The temperature increases from top to bottom.

Evaporation of Solvent or Water from Resist

An insufficient softbake (too short/too cool) may cause the evaporation of the remaining solvent from the resist forming bubbles. In this case, the softbake time should be increased.

Water in the resist volume originating from development may also evaporate during coating. In the second case, a baking step after development at approx. 80-100°C (below the resist softening point) helps to reduce the water concentration.

N_2-Formation

A further reason for bubbling can be the undesired exposure of the enclosed (under the growing coated film on top of it) resist film during evaporation/sputtering by thermal or recombination UV-radiation through the partially UV-transparent layer with N_2 formation as a consequence (photoreaction).

One work-around is the usage of image reversal resists in image reversal mode, which do not contain a significant amount of the photo active compound (N_2-source) after development.

Alternatively, a flood exposure (without mask) of developed positive resist structures with a certain delay to outgas the N_2 formed, thereby preventing the creation of N_2 during coating.

Using a resist without gas formation during (undesired) UV-exposure such as AZ® nLOF 2000 negative resist is also a good alternative.

Lift-off: Frequent Problems

„Fences" after Lift-off

If the resist sidewalls have been coated during deposition, lift-off occurs at a more or less random location. As a consequence, fence-like structures keep on the substrate after lift-off.

In this case, the following work-arounds might help:

- Thermal evaporation instead of sputtering makes the deposition much more directed, and the resist sidewalls are not or less coated.
- Using resists with steep sidewalls, or process parameters allowing the realization and maintenance of steep sidewalls - please consult the recommendations listed on page 2.
- If image reversal or negative resists are used, a strong undercut (via a low exposure dose, a high resist film thickness, and a sufficiently long development) helps to prevent the coating of resist sidewalls.
- If the resist features are not cross-linked, care has to be taken that no softening occurs during deposition. In order to keep the temperature below the softening point of the resist, a reduced deposition rate, or an optimized thermal coupling during deposition of the substrate to the substrate holder will be helpful.

Re-deposition of Lifted Material

Using solvents with a high vapour pressure, such as acetone, as a lift-off medium, sometimes promotes the re-adsorption of material already lifted onto the substrate. We recommend NMP or DMSO (both supplied by us) as a lift-off medium, which can be heated up to 80°C if required.

If necessary, ultrasonic treatment assists the lift-off process.

Lift-off Does Not Work

If the resist sidewalls are coated with a thickness of more than 200-300 nm, lift-off becomes hard or impossible. The above section "Fences after Lift-off" gives recommendations how to prevent the sidewalls from being coated during deposition.

If the resist is strongly cross-linked, lift-off becomes impossible. Strong thermal crosslinking might occur during deposition at elevated temperatures. Positive or image reversal resists start to cross-link from 150°C on, negative resists also increase the degree of crosslinking towards higher temperatures. In order to keep the deposition temperature as low as possible, a reduced deposition rate, or an optimized thermal coupling during deposition of the substrate to the substrate holder will help.

Disclaimer of Warranty

All information, process guides, recipes etc. given in this brochure have been added to the best of our knowledge. However, we cannot issue any guarantee concerning the accuracy of the information.

We assume no liability for any hazard for staff and equipment which might stem from the information given in this brochure.

Generally speaking, it is in the responsibility of every staff member to inform herself/himself about the processes to be performed in the appropriate (technical) literature, in order to minimize any risk to man or machine.