High-Resolution Photoresist Processing

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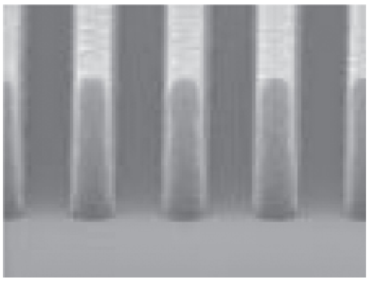
MicroChemicals

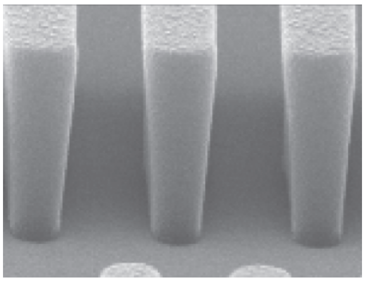
High Resolution Photoresists

Modern high-resolution AZ® resists allow feature sizes of 300 nm and below. This document explains which resists, process parameters, and equipment settings are required to attain a given resolution limit for a certain application. Hereby we focus on g-, h- and i-line resists, while e-beam and DUV resists are detailed in other documents.

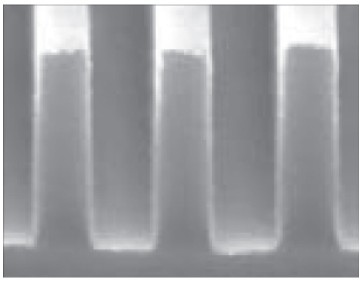
In order to achieve sub-µm features, a high-resolution resist is required. For dry etching we recommend the AZ® 701 MiR with its steep sidewalls and high softening point, for wet etching the AZ® ECI 3000 series with improved adhesion to most substrates. For lift-off processes, the negative AZ® nLOF 2000 resists allow a reproducible undercut. Please contact us for technical data sheets!



300 nm lines and spaces with the AZ® 701 MiR @ 0.8 µm



700 nm lines and spaces with the AZ® nLOF 2020 @ 2.0 µm



450 nm lines and spaces with the AZ® ECI 3012 @ 1.2 µm

Softbake

An important requirement to attain the maximum resolution of a resist is an maximized contrast: Only if the development rate of the exposed resist is sufficiently high, and the erosion rate of the unexposed resist as small as possible (vice versa in case of negative resists), the total dark erosion after development will not deteriorate smallest features.

The softbake parameters are important to attain the maximum contrast of a given positive resist. If the softbake is performed to short or/and cool, the high remaining solvent concentration in the resist film causes a high dark erosion rate. If the softbake has been applied too long or/and hot, a significant amount of the photo active compound will be thermally decomposed which lowers the development rate. For thin resist films around 1 µm, we recommend a softbake at 100-110°C for 1 minute on a hotplate. Detailed information on softbaking can be found in the document Softbake of Photoresists.

Rehydration

DNQ-based resists (= almost all AZ® positive and image reversal resist) require a certain water content during exposure in order to subsequently attain a high development rate. A high development rate is a requirement for a high contrast import for high resolution resist processes. However, after the softbake, the resist film is almost water-free.

Thus, an air humidity of > 40% is beneficial to allow the resist film to resorb enough water from air between softbake and exposure. The rehydration time to attain an equilibrium water concentration in the resist is diffusion-limited and increases quadratically with the film thickness: Thin (< 2 µm) resist films only need seconds for this process steps which makes an extra delay redundant (further details in the document Rehydration of Photoresists).

Exposure

The **exposure wavelength** limits the theoretical resolution limit: Small transparent features in the photomask act as slits causing an interference pattern on/in the resist film, which later transfers into the resist features after development.

As the figure right-hand shows, such a distribution of the light intensity differs from an ideal, sharply bounded rectangular distribution. Since the dimensions of the diffraction pattern increases with the exposure wavelength, smaller wavelengths improve the (theoretical) attainable resolution.

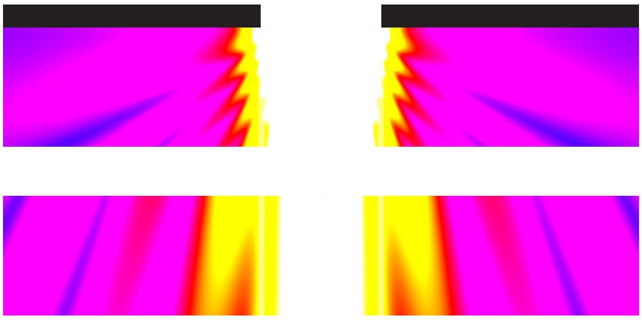
Cross-section of the modelled i-line (365 nm) exposure intensity distribution in a 1 µm thick resist film and a 1 µm slit in the photomask.

However, two points have to be considered in this context: The theoretical resolution limits only goes with the square root of the wavelengths, so the difference between g-line (435 nm), and i-line (365 nm), is less than 10 % resolution gain. Using smaller wavelength than i-line for g-/h-/i-line resists is not recommended, since the absorption of these resists is not matched to wavelengths < 340 nm where the resist absorption strongly increases. Therefore, comparable high exposure doses are required to through-expose a given resist film which also increases the intensity of scattered and diffracted light thus deteriorating the resolution.

A **Gap** between Photomask and resist surface extends the diffraction pattern and therefore deteriorates the resolution.

Possible (unintended) reasons for a gap > 0 are:

- **Particles** in the resist caused by either insufficient cleanroom conditions, contaminated substrates, or expired photoresist,
- **bubbles** in the resist film caused during dispensing, or an insufficient delay time after refilling/diluting/moving the resist,
- **mask contamination** by particles, or resist from previous exposure steps,
- rough, textured, or curved (strained) substrates,
- an **edge bead**, or a **mask** attached upside-down ☺.



Cross-section of the modelled i-line (365 nm) exposure intensity distribution in a 2 µm thick resist film and a 2 µm slit in the photomask with no (top) and 10 µm (bottom) proximity gap.

An optimized **Exposure dose** is another requirement for attaining the maximum resolution of a given resist: If the exposure dose is too low, the development time increases which increases the total dark erosion. Too high exposure doses cause an undesired exposure by scattering, diffraction and reflection of the part of the resist which should not be exposed making it soluble in the developer.

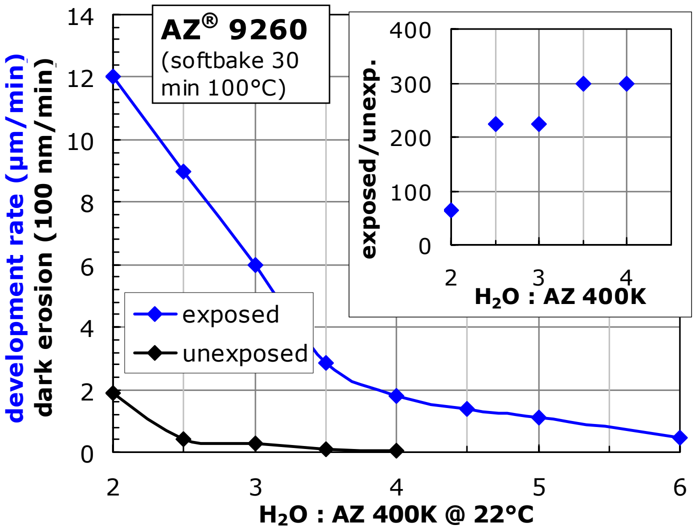
The optimum exposure dose can be determined with an exposure series which is very recommended for all new or changed processes: At a certain dose D_{opt}, the development starts to saturate and will not further increase towards higher exposure doses. For most processes, the optimum exposure dose is close to D_{opt}.

The **optical substrate properties** also impact on the attained resolution: Rough or textured substrates scatter or reflect light also into the resist which should not be exposed. Transparent substrates (glass or quartz), or substrates with transparent coating (e. g. thick SiO_2) laterally guide light which also exposes the resist. In this case, lowering the exposure dose might be beneficial.

Development

In the case of positive resists, the dark erosion (= dissolution rate of the unexposed resist in the developer) grows faster with the developer concentration than the development rate (= dissolution rate of exposed resist).

Therefore, a proper dilution is required for a high selectivity (= development rate : dark erosion ratio). For high-resolution photoresist processes, it can be beneficial to apply a higher developer dilution than usual: An AZ® 400K : H_2O or AZ® 351B : H_2O dilution ratio of 1 : 5 ... 1 : 6 (instead of typically 1 : 4), or a moderate dilution (2 : 1 ... 1 : 1) of MIF developers such as AZ® 326 or 726 MIF which are usually applied undiluted.



With increasing developer concentration, the dark erosion grows faster than the development rate resulting in a maximum selectivity for ‘standard’ developer concentrations.

In case of high resolution requirements, developers with an intrinsic high dark erosion should not be used: The AZ® 826 MIF, AZ® Developer, and AZ® 303 have a lower selectivity than the developers AZ® 400K, AZ® 351B or AZ® 326/726 MIF. The document Resists, Developers, and Removers explains which developers are recommended for certain resists.

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.