

Greyscale Lithography with Photoresists



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Basics of Greyscale Lithography

In standard lithography, a "binary" behaviour of the photoresists is desired: The exposed resist have to be completely cleared during development, while the remaining resist features should have a rectangular cross-section with steep sidewalls.

The goal in greyscale-lithography is to transfer gradients of the exposure dose into a certain resist topography during development. The following sections describe which chemical and physical resist properties and process parameters hereby to be considered. Since almost all positive resists are generally suited for greyscale lithography, please consult the document [Photoresists, Developers, and Removers](#) for this purpose.

Greyscale Lithography with "Thin" Photoresists

In this context, "thin resist" means, that the penetration depth of light is higher than the resist film thickness. For standard positive resists and standard exposure wavelengths (g-, h-, i-line), this means a thickness of less than 2 μm . Hereby the resist film is exposed almost homogeneously from the surface towards the substrate from the very beginning of exposure, so it is not possible to attain a vertical exposure dose profile in the resist film. Therefore, the only mechanism which allows greyscale lithography is the dependency of the development rate from the exposure dose.

However, resists are generally optimized for high contrast. This means that they (almost) don't develop below a certain minimum exposure dose, and develop at a constant rate from a higher exposure dose on (green curve in the schema right-hand).

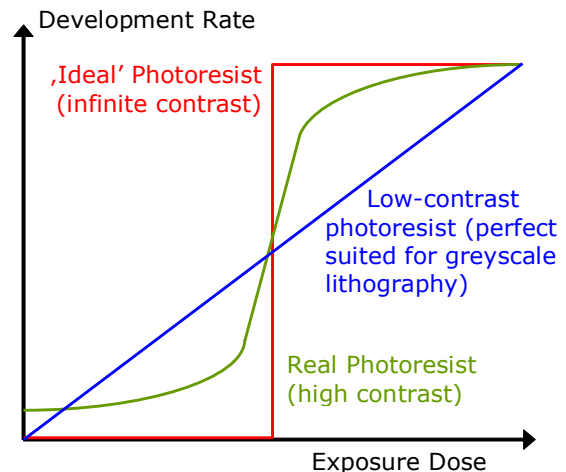
Since both doses are close together, there is only a small exposure dose window in which one can adjust the development rate. In order to make the process more reproducible, it is spread the curve towards an almost linear dependency between exposure dose and development rate. This can be attained via process parameters as described in the following:

A **short or/and cool softbake** (approx. 60-70°C for one minute per μm resist film thickness) keeps the concentration of the remaining solvent concentration high thus increasing the dark erosion in the developer and hereby lowering the contrast

Alternatively, a **hot or/and long softbake** (e. g. 120°C for a total of 5-10 minutes) decomposes a significant part of the photo active compound DNQ thus reducing the development rate and increasing the dark erosion at the same time (unexposed DNQ is a development inhibitor).

Additionally, a short **flood exposure** will cause an offset in the development rate.

A high developer concentration (e. g. AZ[®] 400K : H₂O = 1 : 3 ... 1 : 2) lower the selectivity of the developer which is equivalent to a lower contrast.



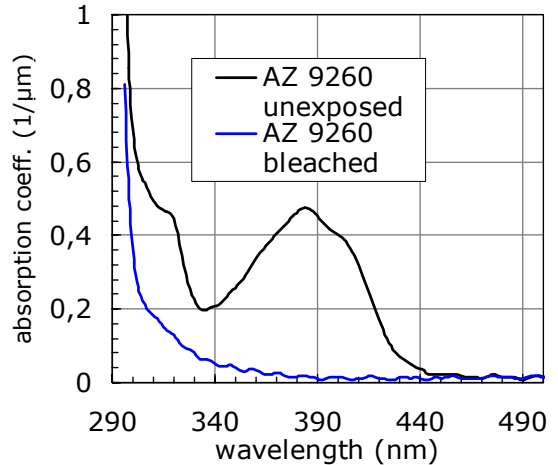
Greyscale Lithography with "Thick" Resists

"Thick resists" means, that the resist film thickness is much higher than the penetration depth of the exposure light. For standard positive resists and standard exposure wavelengths (g-, h-, i-line), this means a thickness of $> 5 \mu\text{m}$. (Of course, if small wavelengths with a very low penetration depth such as 310 nm are used, even a $1 \mu\text{m}$ resist film will be "thick" in this context).

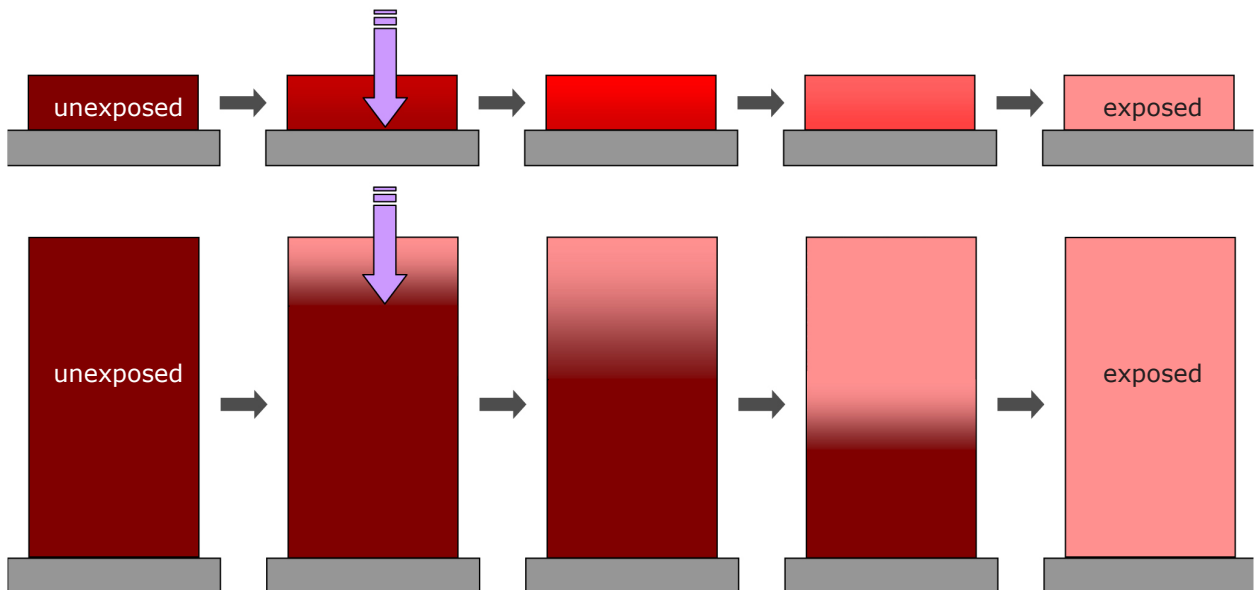
One would assume that under these conditions, the resist film cannot be completely exposed towards the substrate. However, the "trick" is the bleaching of the resist: As the plot right-hand shows, DNQ-based photoresists (= almost all AZ® positive resists) become UV-transparent during exposure.

Therefore, in the beginning of the exposure, light only penetrates the upper 1-2 μm of the resist film. This part of the resist film bleaches, so with the exposure going on, light will be able to penetrate the first 2-3 μm of the film, and so on (see schema below).

As a consequence, the exposed (and developable) resist film thickness goes approx. linear with the exposure dose. The transition exposed/unexposed is sufficiently sharp for reproducible greyscale lithography applications.



The absorption spectrum of AZ® 9260 before (black) and after (blue) exposure.



While "thin" resist films show a rather homogeneous illumination depth profile (top), 'thick' resist films bleach towards the substrate during exposure (bottom).

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