Semiconductor Technology from A to Z

Photolithography

Exposition methods

Overview

Depending on the type of irradiation, photolithography can be divided into different processes: optical lithography (photolithography), electron beam lithography, x-ray lithography, and ion beam lithography.

In optical lithography, patterned photomasks (reticles) are used. Exposure with UV light or gas lasers is carried out either at a scale of 1:1 or in a reducing scale, for example 4:1 or 10:1.

Today, optical lithography splits into two technically completely different branches:

- DUV (deep ultraviolet, 248 and 193 nm): the mask is transparent, imaging is done through a lens system, and the tool operates either in air or with a film of water between the lens and the wafer.
- EUV (extreme ultraviolet, 13.5 nm): since this radiation is absorbed by every material, the tool operates under vacuum, images via mirrors, and the mask is not a transparency but a mirror.

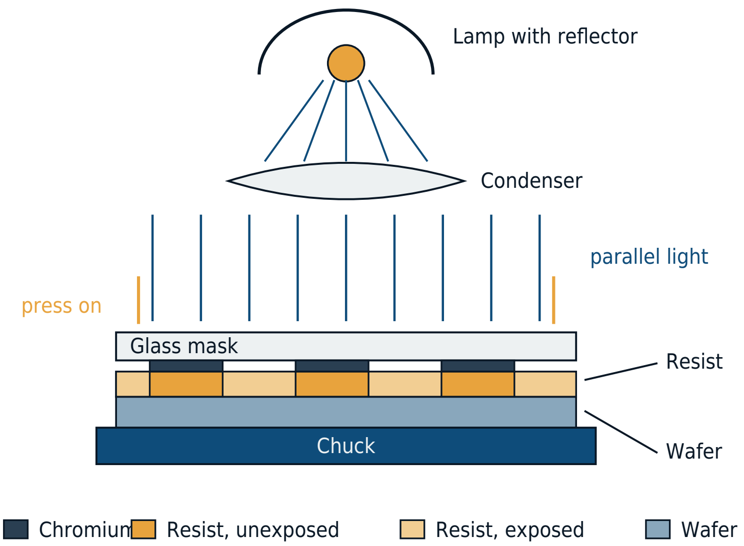
The exposure methods described below are arranged in order of increasing resolving power. Contact and proximity exposure are found today only in micromechanics, in research, and in education; chip manufacturing exclusively uses reducing projection exposure.

Contact exposure

Contact exposure is the oldest method used. Here, the mask is pressed directly onto the resist layer, and the structures are transferred at a scale of 1:1. Resolution-limiting scattering and diffraction effects of the light occur only at the edges of the structures. However, the achievable feature widths with this method are small. Since all chips are exposed at once, wafer throughput with this technique is very high, and the construction of the exposure tools is relatively simple.

Contact Exposure

The mask sits directly on the resist, transfer is 1:1



Because mask and resist touch, diffraction effects occur only at the feature edges. The setup is simple and exposes all chips at once. In return, the mask gets dirty and scratched, since it is pressed onto the resist.

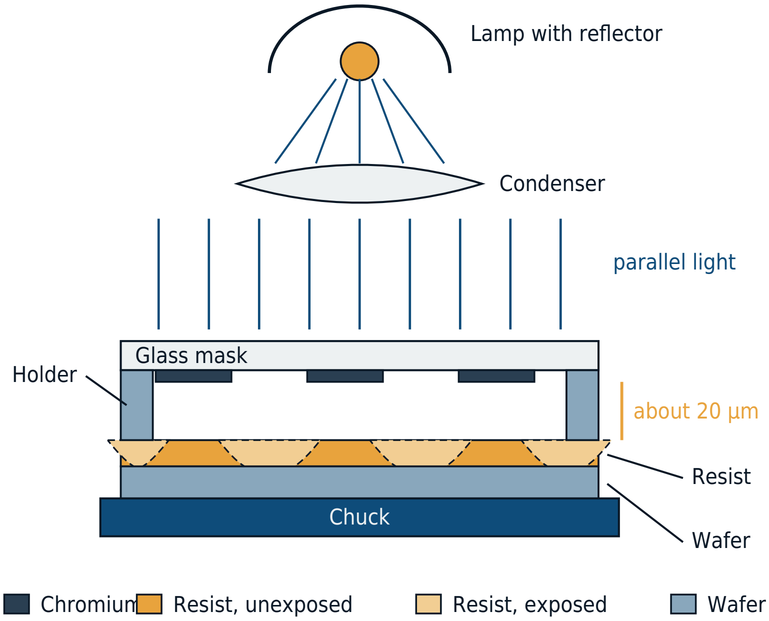
The disadvantages, however, are obvious: because the mask is pressed onto the resist, it becomes contaminated quickly, or can be scratched, as can the resist. If particles are present between the wafer and the mask, the resulting gap between mask and wafer degrades the image.

Proximity exposure

In proximity exposure, contact between the mask and the wafer is avoided by means of a spacer (about 20 µm). In this case, however, only a shadow image of the mask is projected onto the wafer, which offers a significantly worse resolution of the structures.

Proximity Exposure

Spacers hold the mask above the resist – a shadow image results



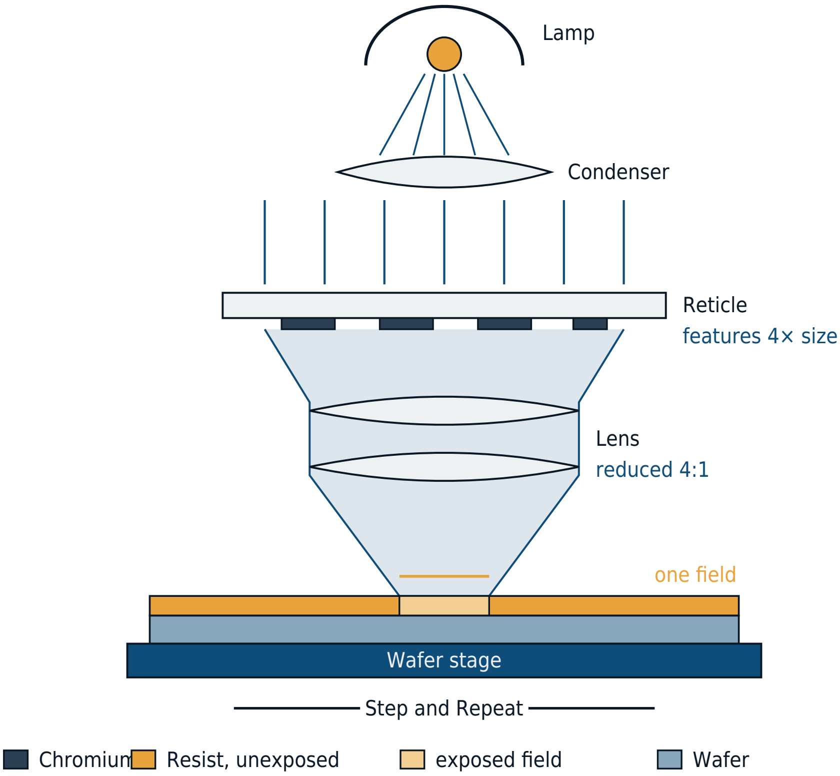
The gap protects mask and resist from scratches and from particles in between. In return, only a shadow image falls onto the wafer: the light diffracts at the chromium edges, so the features widen and their edges become blurred.

Reducing projection exposure

This is the only exposure method still used in chip manufacturing. The step-and-repeat technique is commonly used for this method. A single die – or, for small enough dies, several at once – is imaged onto the wafer via a reticle. In this way, the entire wafer surface is exposed die by die.

Reduction Projection Exposure

The lens images the reticle onto the wafer at reduced scale



Because the features on the reticle are four to ten times larger, particles and mask defects are also scaled down and often fall below the resolution limit. Exposure proceeds field by field, with the wafer stage moving between.

At high resolution, the field is no longer exposed as a whole; instead, the mask and wafer are moved synchronously in opposite directions beneath a narrow slit of light (step and scan). Only in this way can the lens be kept optically corrected across the entire field. The advantage of this method is that the structures depicted on the reticle are enlarged by a factor of 4 (by a factor of 8 in one axis for High-NA EUV tools). When the image is reduced onto the wafer, not only the structures but also any defects, such as particles, are likewise reduced in size, or even fall below the resolution limit; the resolution itself is improved by this method.

Since not the entire mask is used for a single layer, several layers can be placed on one glass plate, which reduces mask costs.

In addition, a pellicle – a thin film with an aluminum frame – can be attached to the mask, which keeps particles away from the mask. These then lie outside the depth of focus and are not imaged.

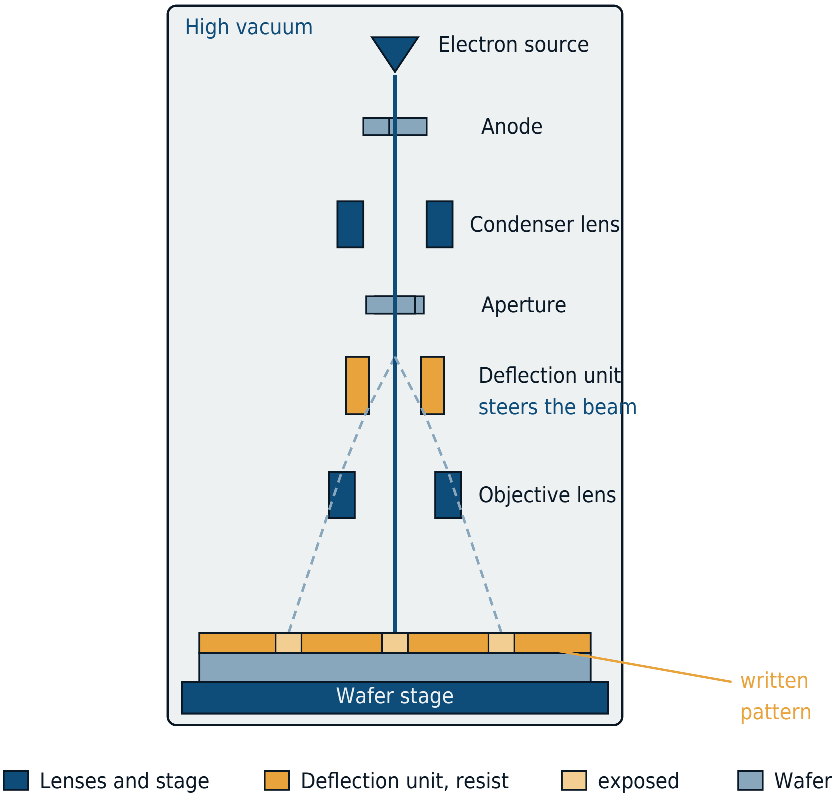
There is also mirror projection exposure (1:1), in which the wafer is exposed through a complex system of mirrors. Because mirrors are used, no chromatic aberrations occur, as they do with lens systems, and in addition, thermally induced expansion of the wafer during processing can be compensated for. However, mirror systems produce distorted/curved images. Furthermore, due to the 1:1 imaging, the resolution is strongly limited.

Electron beam lithography

As in photomask manufacturing, a focused electron beam is scanned across the resist-coated wafer. This scanning can be carried out line by line using the raster-scan method or using the vector-scan method. However, here too every structure has to be written individually, which is very time-consuming. The advantage is that no masks are required, which saves costs. The entire apparatus is housed under high vacuum.

Electron Beam Lithography

A focused beam writes the pattern directly – no mask needed



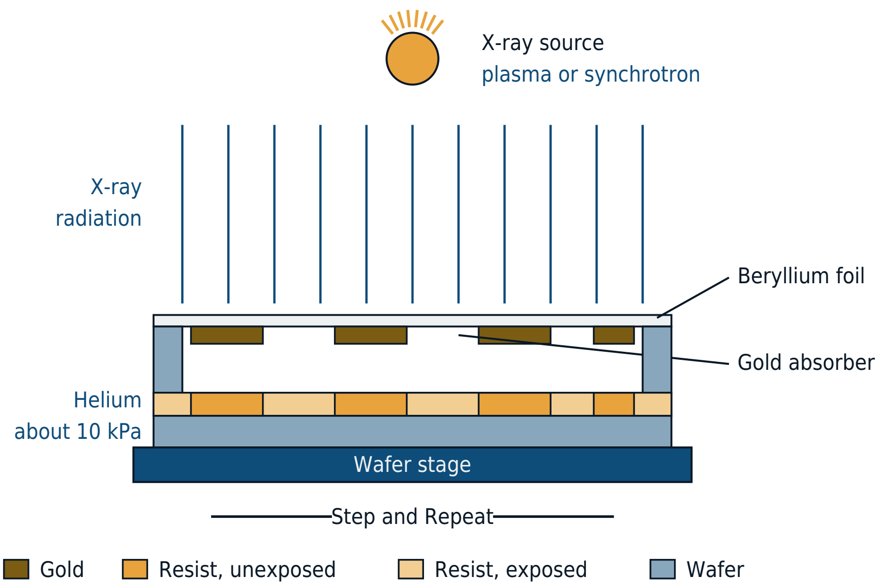
The beam scans the pattern point by point – row by row in raster scan or targeted in vector scan. This takes time but saves the mask, which is why it is mainly used for prototypes and for making the masks themselves.

X-ray lithography

The resolution limit of x-ray lithography is about 40 nm. Imaging is carried out using the 1:1 step-and-repeat method via shadow projection, and is performed either at atmospheric pressure in air or at slightly reduced pressure in a helium atmosphere (about 10,000 Pa). The x-ray source can be either a plasma source or synchrotron radiation.

Instead of chrome-coated glass masks, thin, mechanically stable foils made of beryllium, and in some cases silicon, are used. To absorb the x-radiation, the foils are coated with heavy elements such as gold. Both the equipment and the masks are very expensive.

X-Ray Lithography
1:1 shadow casting – there are no lenses for X-rays



X-rays cannot be focused with lenses, so the pattern is transferred directly as a shadow – one to one, field by field. The resolution reaches down to about 40 nm, but the equipment and masks are very expensive.

Additional methods

Another possibility for lithography is irradiating the wafer with ions. With ions, the wafer can be patterned either through a mask or directly, as described for the electron beam method. The achievable resolution here is not limited by the wavelength: at 100 keV a hydrogen ion reaches a de Broglie wavelength of about 0.0001 nm, far below anything optically possible. What limits the process instead is the scattering of the ions within the resist and the mutual repulsion of the charges within the beam. With other elements, direct doping without masking is also conceivable.