

- SCOPE: This document overviews the mask aligner and its use in semiconductor photolithography.

What is a mask aligner?

A mask aligner is a precision machine tool used in the semiconductor manufacturing process to transfer a pattern onto a wafer or substrate; these patterns are micro and nano in scale.

The patterns (structure) are created using a shadow transfer method, where the pattern (photomask) to be printed is placed between a light source and the substrate to be patterned (wafer). The substrate being patterned is first coated with a photosensitive material (photoresist), this material then reacts to the light projected from the shadow image. The resultant pattern is then developed using specific chemicals.

This process is commonly known as photolithography, more details of this micro-fabrication technique are covered in a separate document [Lithography Basics](#).

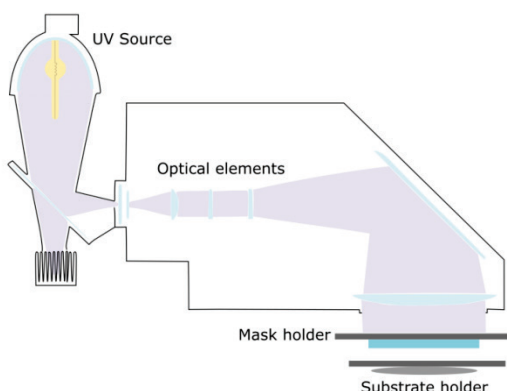
Mask aligners enable photolithography to be used to produce semiconductor devices, such as transistors, sensors and medical components, etc.

Along with a method to uniformly coat the substrate with photoresist, a mask aligner is crucial to the photolithography process. A mask aligner is used to both precisely align the coated substrate to the photomask containing the structure to be patterned, and for then exposing the substrate with light to transfer the desired pattern onto the substrate.

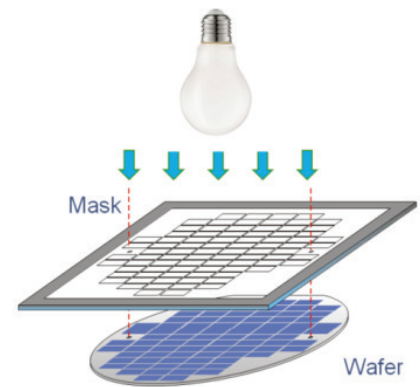
In order to enable this complex process to take place and to produce structures with features down to 250nm, the mask aligner must be a precision engineered instrument. As these structures are so small, the wavelength of light used is also a factor in determining the final feature size.

The key components of a mask aligner include the following:

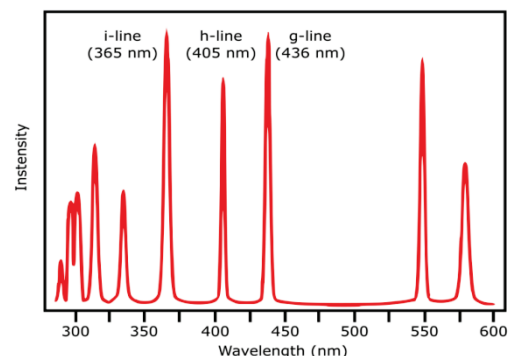
- Ultraviolet light source
- Optical elements
- Mask holder
- Substrate holder
- Microscope



Schematic of a mask aligner's key components
(microscope not shown)



Pictorial representation of Shadow Lithography



Emission Spectrum of a typical mercury lamp

Ultraviolet light source:

A mask aligner would not be able to expose a substrate to light in a controllable manner, if it does not have a high-quality source of light. Traditionally, this has been a broadband mercury bulb, which provides a spectrum of light, an example of which is shown in the graph above. Despite two wavelengths being outside the specific UV spectrum (100-400nm), mask aligner light sources are commonly referred to as being UV, as the bulb also transmits in this range.



SUSS Mask Aligner with LED Light Source

Dependent upon the photoresist used, the light should be transmitted in either the broadband range, or in a specific spectrum G: 436nm, H: 405nm or I: 365nm.

An alternate option to a mercury lamp is to use a UV LED array. These contain a number of LEDs that emit light at the G, H or I line wave-lengths, or a combination of all three to produce a similar broadband spectrum to that of the mercury bulb.

UV LEDs have seen advances in quality and performance in recent years, enabling them to replace the traditional mercury bulb. The introduction of the UV LED has brought a number of advantages. The first of these is a reduction in the power consumption of mask aligners, which brings with it a reduced running cost. In addition, the removal of mercury from the production facility brings health and safety benefits to the operator, plus there is a reduction of the volumes of mercury that must be safely disposed of when lamps reach the end of their lifetime. Other benefits include reduced maintenance, as the LED's are only illuminated during the exposure period; thus no shutter mechanism is required, plus simplified facility requirements, since no additional cooling or extraction are needed with LED light-

Optical elements:

After the UV source the light passes through a number of optical elements. These optical elements are used to shape the beam of light so that there is uniform illumination across the substrate to be processed.

Typical optical elements include:

- Ellipsoidal Mirror
- Cold Light Mirror
- Heat Sink
- Shutter
- Fly's Eye
- Condenser Lens
- Filter Plates
- Front Mirror
- Front Lens

The quality of these optical components is critical to the resolution achievable by the mask aligner. Without high quality lenses and mirrors that are kept in good condition and free of scratches or contamination, the resulting lithography will not be homogeneous over the whole substrate. There will be changes in the critical dimensions (CD), under or over exposed photoresist and overall a loss in the yield of functional devices.

Mask holder:

The mask holder is the component that holds in place the photomask containing the pattern to be transferred to the substrate. The mask holder must not allow the photomask to move whilst alignment and exposure are taking place.

Substrate holder:

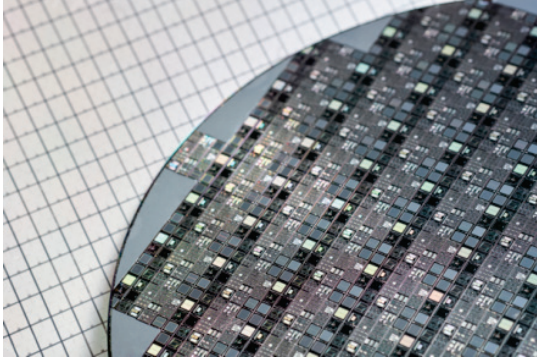
The substrate holder, often referred to as the wafer chuck, holds the substrate in position within the mask aligner. The substrate is usually held in place by applying a slight vacuum to the chuck and with alignment pins used to mark the rough placement. The substrate holder can then be moved around relative to the mask holder, this allows the precise alignment of features on the mask to existing features on the substrate.

The substrate holder also compensates for any wedge or slope on the surface of the substrate through a process called Wedge Error Compensation (WEC). The WEC is crucial to ensure uniform results across the whole substrate. WEC is the process of ensuring the top surface of the wafer is parallel to the photomask and so the optical path travelled by the UV light is the same regardless of position on the wafer.

Microscope:

The microscope system within the mask aligner allows the user to view the photomask and the substrate and to align the relevant features to one another. Typically, there are two microscope arms which are used to locate the alignment targets on the substrate and the mask, and to then move the substrate on the wafer chuck into position.

Summary:



Example Semiconductor Wafer Lithography

The quality of these five components outlined above will determine the resolution and alignment accuracy of the lithographic process.

Critical to the final resolution of the features being printed are a well-defined UV source and optics that reduce optical diffraction limitations and ensure uniformity of the light across the whole wafer.

The mask holder and substrate holder together are critical to the alignment accuracy, this is key when fabricating complex devices with many layers which must be aligned to one another.

If employed in a production environment, all elements of the mask aligner can be automated using pattern recognition to detect alignment targets and to correctly orientate the substrate and the mask, in addition to wafer and mask handling systems, to automate the loading and unloaded processes.