Lecture 8

Microfabrication
– Pattern Transfer (I)

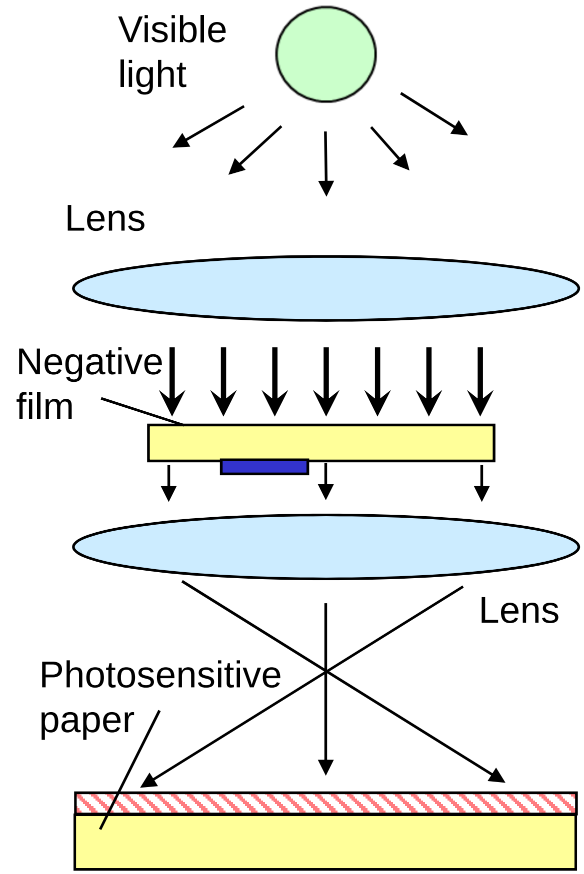
- Pattern Transfer
- Optical Lithography
  - Photographic Process
  - Negative and Positive Photoresists
  - Projection Step-and-Repeat Lithography
  - Scanning 1:1 Projection Aligner
  - Systemic Errors
  - Random Errors

Pattern Transfer

- Pattern transfer consists of two parts:
- (1) Photo-process: the desired pattern is photographically transferred from an optical plate to a photosensitive film coating the wafer.
- (2) Chemical or physical process of either removing or adding materials to create the pattern.
- Most processes are subtractive, removing material by etching unwanted material away chemically.
- A few processes are additive, such as doping or plating.
- Another additive is called lift-off.

Photographic Process

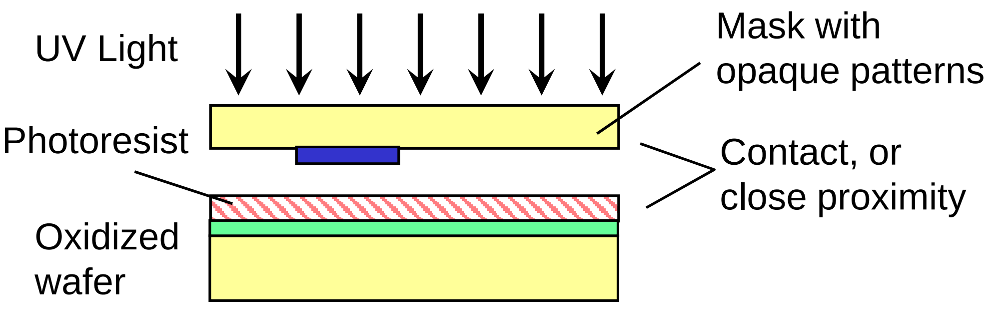
- Much like the photographic process of producing a print from a negative.
- Contact prints are made when the negative is placed directive onto a sheet of photosensitive paper.
- When light is shined through the negative onto the surface of the paper, the varied light intensity reaching the paper exposes the image, which is then made visible through a chemical development process.
- Enlargement or reductions are made by interposing suitable lenses between the negative and the photosensitive paper.
- Both methods are used optical lithography.



Schematic drawing of photographic enlarging system

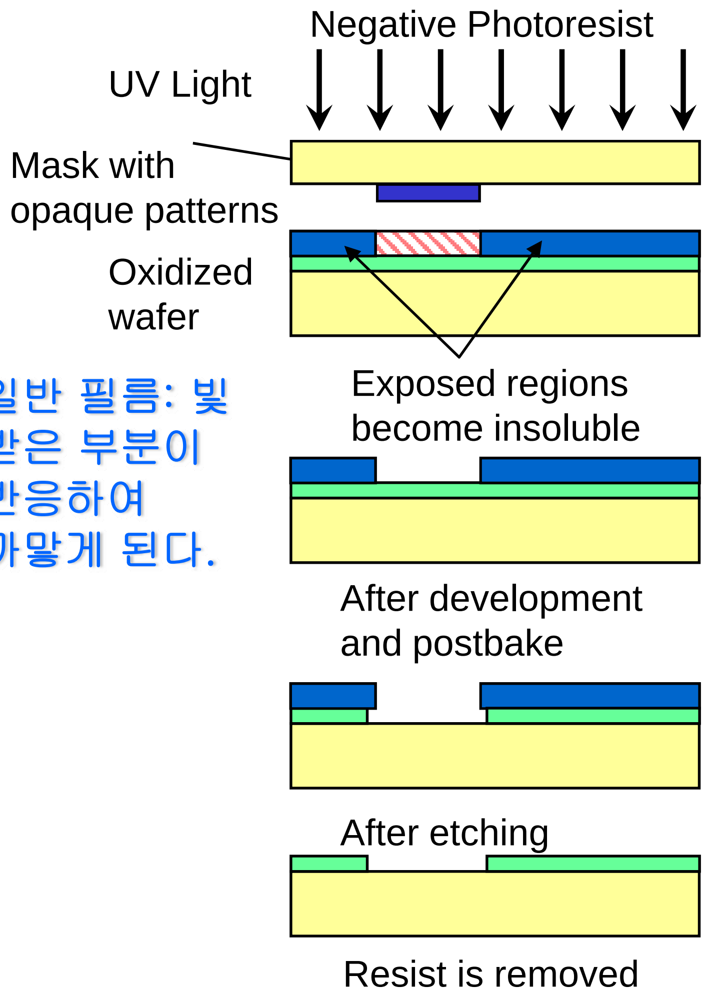
Optical Lithography

- The enabling materials of optical lithography are photoresists, polymeric optically-sensitive materials that are deposited onto the wafer surface by spin casting.
- **Prebake:** Following spinning, the resists are prebaked at low temperature to remove solvent, but are not fully hardened.
- **Postbake:** Completion of the hardening process occurs after optical expose.
- Ultraviolet light is directed through the mask onto the wafer, exposing the unprotected portions of the resist, which change their chemical properties as a result of the light exposure.
- Photochemical processes are high in contrast, and develop **sharp boundaries**.
- **Contact lithography** is one of standard processes in MEMS.



Illustrating contact or proximity photolithography

Negative and Positive Photoresists



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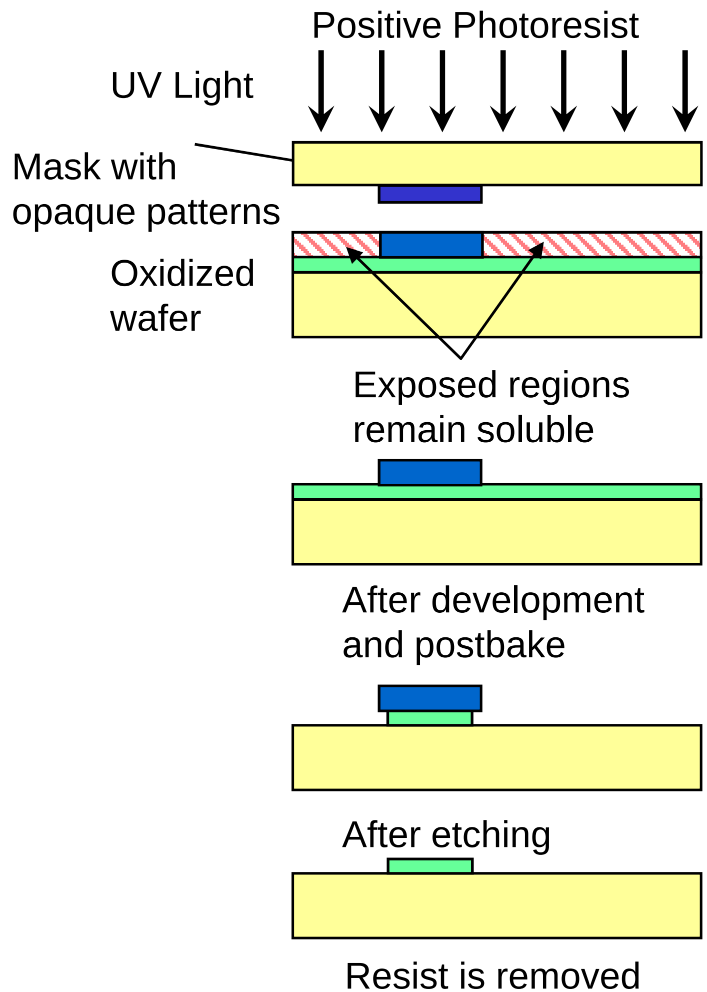

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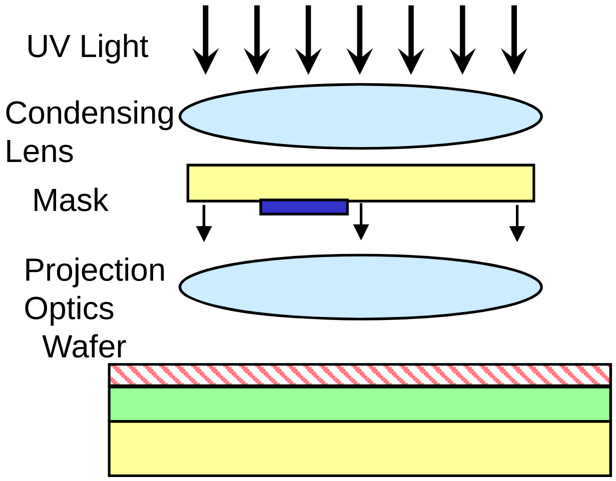
Illustrating how negative and positive photoresists result in different patterns from the same mask.

Proximity Lithography

- Because direct contact between the wafer and the mask can eventually cause damage to the mask, a variant of the contact lithography is to leave a small air gap between the mask and the photoresist-covered wafer.
- This is called ***proximity lithography.***
- The achievable resolution is somewhat less than with contact lithography, because diffraction can occur at the edges of the opaque regions.
- This process was used in the early days of integrated circuit technology, but has now been largely replaced by step-and-repeat projection lithography.
- When using contact lithography, the mask must be the same size as the wafer, and every feature to be transferred must be placed on the mask at its exact final size.

Projection Step-and-Repeat Lithography

- The projection optics operated as in a photographic enlarger, except the mask image is *reduced* by a factor of 5 or 10 when projected onto the wafer.
- Advantages:
- (1) The mask can be drawn with larger feature sizes: a 0.3 microns feature on a wafer requires a relatively easy-to-create 3 microns feature on a mask.
- (2) Because of reduction, only a portion of the wafer is exposed at one time. The exposed region is typically one "chip", a complete integrated circuit.



Illustrating projection lithography. The projection optics typically reduce the mask features by a factor 5 or 10 when projected onto the wafer.

(continued)

Projection Step-and-Repeat Lithography

- Chip sizes of 10 to15 mm can be made in this way
- In order to expose the entire wafer, the wafer is moved after each exposure to bring the next chip under the projection optics.
- While it requires rather **expensive equipment** to do the **projection and precision positioning** needed for the step-and-repeat operation, it has the distinct advantage that alignment of successive patterns is done locally, one chip at a time.
- It is not necessary to maintain rigid positional accuracy of successive layers at the 0.1 microns level across the full diameter of the wafer, a task that becomes impossibly difficult as wafer sizes increase.

Scanning 1:1 Projection Aligner

- Another alternative to contact lithography is the **scanning 1:1 projection aligner,** which illuminates an arc-shaped portion of the mask, and has an optical system that accurately projects this region onto the wafer.
- Then, both the mask and the wafer are scanned synchronously, projecting the scanned mask image onto the scanned wafer.

- Because the "stepper" has a field of view on the wafer on the order of 1 cm, many MEMS devices cannot be fabricated with stepping lithography, but must use contact or scanning projection lithography.
- A rule of thumb is that feature down to **1 – 2 microns** can be successfully patterned with **contact or scanning projection lithography** on wafers that already have some structure present, with alignment accuracies on the order of a few tenth of microns.

Systemic Errors

- There can be systemic errors in the pattern-transfer process.
- The regions of the photoresist that remain on the wafer may not match exactly the corresponding mask regions.
- The optical exposure and development step may result in pattern expansion or reduction.
- Further, the etching step can undercut the resist slightly.
- The net effect of the optical and etching steps is to introduce a systemic error between the drawn mask dimension and the final dimension of the patterned feature on the wafer.
- This systemic error is called a ***process bias***.
- First-order compensation of process bias can be achieved by determining through experiment what the bias is, and then adjusting the dimensions of the mask feature so that the final fabricated dimension is correct.

Random Errors

- There are also random errors in pattern transfer.
- These can arise from errors in registering one pattern to what is already present on the wafer, or from slight variations in resist exposure, or etching times.
- The behavior of MEMS devices can depend strongly on device dimensions.
- Therefore, both process biases and random patterning errors can result in variations in device performance that must be corrected with suitable calibration procedures.