Overview

- Immersion lithography
- EUV lithography
- Interference lithography
- Imprint lithography
- Maskless lithography (ML2)
Trends in lithography

Resolution limit = $k_1\lambda/NA$ and $NA = nsin\theta$
Immersion lithography

- Resolution limit = $\frac{\lambda}{2NA}$ and $NA = n \sin \theta$
- Conventional lithography: $n = 1$
  Immersion lithography: $n = 1.44$ (pure water)
  $\rightarrow$ Current projected limit = 35 nm half pitch.

- Issues need to be taken care of:
  - Possible bubbling of water
  - Water temperature control to keep the refractive index constant
  - Water-resist interaction $\rightarrow$ resist needs to be water resistant
  - Metrology (e.g. registration) can be a challenge if done through water
How to introduce water?

- **Swimming pool design**
  - Entire stage under water

- **Bathtub design**
  - Entire wafer under water

- **Shower design**
  - Water is injected to the part of the wafer that’s going to be exposed.
Shower design

Wafer edge exposure may be an issue.

4. A shower system for immersion lithography delivers the liquid onto the wafer from one side, then takes it away from the other. (Source: Nikon)
First generation of immersion tools

- NA < 1. But DOF is improved.

5. Keeping NA the same for immersion systems as it is for dry systems (in this case 0.75) does not improve resolution, but does increase the depth of focus, which relaxes the $k_1$ factor. (Source: ASML)
Extreme UV lithography (EUVL)

- At wavelength of 13-14 nm: no refractive optics. Need to use reflection optics. Reflectors are made of Mo/Si Bragg reflectors.
EUVL system schematic

From Nanoelectronics and Information Technology
Interference lithography

\[ p = \frac{\lambda}{2 \sin \theta/2} \]
Extension from conventional lithography

- Add intensities from exposures with different illumination angles.
- Add in zero order through a separate optical path when needed.
Why do we need the zero-th order

<table>
<thead>
<tr>
<th>Printed Resist</th>
<th>Calculated Image</th>
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<tbody>
<tr>
<td>Conventional Exposure</td>
<td>High Spatial Frequencies Only</td>
</tr>
<tr>
<td>High Spatial Frequencies Plus Zero Order</td>
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Implementation of IIL

Zero order light follows the path on the right.

The movable mirror M1 selects the diffraction orders that will add with zero order at the wafer.

The effective NA approaches \( \sin(U + \sin^{-1}NA_{obj}) \).
IIL with i-line lithography

CD = 100 nm
Pitch = 360 nm

CD = 50 nm
Pitch = 2 \mu m

CD = 150 nm
Pitch = 300 nm

CD = 90 nm
Pitch = 180 nm

All results at I-line (365 nm) with industry standard resists.
Multiple beam interference

28 nm half-pitch in PMMA
Four-beam interference

42 nm half-pitch in PMMA
Three-beam interference

six-beams
eight-beams
Imprint lithography

- Nice tutorial on the web: [link](http://www.molecularimprints.com/Technology/technology2.html)
Maskless lithography (ML2)

- SCAPAL (scattering with angular limitation in projection electron beam lithography)
Proximity effect in e-beam lithography

- Resolution limit is not determined by electron wavelength but rather by backscattered electrons (proximity effect.)
Schedule for the rest of the semester

- Etching
- Thin film deposition
- Self-assembly and hybrid nanofabrication
- Miscellaneous e.g. VLS nanowire growth, …
- Summary of the course and outlook

+ guest lecture on photonic crystals (time TBA)