ECE 541/ME 541
Microelectronic Fabrication Techniques

MW 4:00-5:15 pm

Photolithography—Part 1

Zheng Yang
Office: ERF 3017, Email: yangzhen@uic.edu
Major Fabrication Steps in MOS Process Flow

- **Silicon Substrate**
- Oxidation (Field oxide)
- Photoresist Coating
- Mask-Wafer Alignment and Exposure
- Exposed Photoresist
- Photoresist Develop

- Lithography
- **Oxide Etch**
  - $CF_2$ or $C_2F_3$ or $CHF_3$

- **Photoresist Strip**
  - $O_3$

- **Oxidation** (Gate oxide)
- Polysilicon Deposition
- Polysilicon Mask and Etch
  - $CF_2O_2$ or $Cl_2$

- Ion Implantation
- Active Regions
- Nitride Deposition
- Contact Etch
- Metal Deposition and Etch

*Used with permission from Advanced Micro Devices*
Lithography

• Basic concepts for photolithography, including process overview, critical dimension generations, light spectrum, resolution and process latitude.
• Difference between negative and positive lithography.
• Eight basic steps to photolithography.
• Wafer surface preparation for photolithography.
• Photoresist physical properties.
• Applications of conventional i-line photoresist.
• Deep UV resists
• Photoresist application techniques
• Soft bake processing
Model of Typical Wafer Flow in a Sub-Micron CMOS IC Fab
Schematic creation of MOS field effect transistor.
Step 0

The positively doped silicon wafer is first coated with an insulating layer of silicon dioxide (yellow) through chemical vapor deposition.
Step 1

An ultraviolet light-sensitive thin layer of photoresist (blue) is applied to the silicon dioxide surface and evenly spread across the wafer.
Step 2

The first mask is placed over the wafer and ultraviolet light is projected onto the mask. Areas of photoresist exposed to the light are hardened and those shielded remain soft.

(Lithography step number 1)
Step 3

The unexposed (and soft) photoresist is removed by washing with a solvent, leaving the hardened resist and underlying silicon dioxide layer intact.
Eight Steps of Photolithography

1) Vapor prime
2) Spin coat
3) Soft bake
4) Alignment and Exposure
5) Post-exposure bake
6) Develop
7) Hard bake
8) Develop inspect
Lithography: 10 Step Process

<table>
<thead>
<tr>
<th>PROCESS STEP</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surface Preparation</td>
<td>Clean and dry wafer surface</td>
</tr>
<tr>
<td>2. Photoresist apply</td>
<td>Spin coat a thin layer of photoresist on surface</td>
</tr>
<tr>
<td>3. Soft bake</td>
<td>Partial evaporation of photoresist solvent by heating</td>
</tr>
<tr>
<td>4. Alignment and exposure</td>
<td>Precise alignment of mask to wafer and exposure of photoresist. Negative resist is polymerised.</td>
</tr>
</tbody>
</table>
**Lithography: 10 Step Process**

1. **Hard bake**
   Additional evaporation of solvents

2. **Develop inspect**
   Inspect surface for alignment and defects

3. **Etch**
   Top layer of wafer is removed through opening in resist layer.

4. **Photomask removal (strip)**
   Remove photomask layer from wafer.

5. **Final inspection**
   Surface inspection for etch irregularities and other problems

Figure 8.9 Ten-step photomasking process.
Surface Preparation

Surface preparation.
Surface needs to be compatible with photoresist solvent and material. Want “wetting” of surface. Want boundary conditions for flow fixed at surface. Surface needs to be dry. Many resist material are hydrophobic and require dry surfaces for good adhesion. Traditional solution is “adhesion promoters” — chemicals that react with surface groups, especially ones that are hydrophilic, and convert to surface groups that are hydrophobic.
**Surface Drying**

Surface cleanliness is achieved by quick transfer of wafer from previous deposition (oxidation) step to this first lithographic step.

If wafer had to be stored or transferred for an excessive amount of time, previously described cleaning steps have to be applied. (Spin-Rinse-Dryer)

Wafer are stored in dry (<50% RH) air

Particulate blow-off with hot nitrogen

Three baking types possible: (low temp (150C), med. Temp (400C), high temp. (750C)). Low temp multilayer water is evaporated, Med. Temp monolayer water is evaporated, High Temp. surface OH groups are removed.

Usually only low temp heating (easy).
Surface treatment procedures.

HMDS in xylene (10-100%): common adhesion promotion agent.

\[
\begin{align*}
\text{Me}_3\text{Si} & \quad \text{NH} \\
\text{Me}_3\text{Si} & 
\end{align*}
\]

Hexamethyl disilazane \((\text{Me} = \text{CH}_3)\)

Reactivity toward surface hydroxyl groups

\[
2 \text{Surface-OH} + \text{HMDS} \rightarrow 2 \text{Surface-O-Si(Me)}_3 + \text{NH}_3
\]

Surface-OH: \emph{hydrophilic}

Surface-O-Si(Me)_3: \emph{hydrophobic and oleophilic}

Influence of HMDS treatment on surface properties of Silicon.
**Other Primers**

- Trichlorosilane
- Triethoxysilanes
**Primer Application**

**Immersion Priming**
Possible, Easy
Little control, high primer consumption, large contamination risk

**Spin-on Priming**
Possible, Easy
High Consumption

**Vapor priming:**
Very homogeneous, Low use of primer, Method of choice
Special equipment required
**HMDS Hot Plate Dehydration Bake and Vapor Prime**

**Process Summary:**
- Dehydration bake in enclosed chamber with exhaust
- Hexamethyldisilazane (HMDS)
- Clean and dry wafer surface (hydrophobic)
- Temp ~ 200 to 250°C
- Time ~ 60 sec.

**Vapor Primer**
Vapor Priming

Priming from bubbler possible. Vacuum-bake priming method of choice. First Temperature ramp to 150C, then evacuation, then primer gas.

Low consumption, no contamination
Application of HMDS through vapor phase exposure.
**HMDS Puddle Dispense and Spin**

- **Puddle formation**
- **Spin wafer to remove excess liquid**
Effect of Poor Resist Adhesion Due to Surface Contamination
Eight Steps of Photolithography

1) Vapor prime
2) Spin coat
3) Soft bake
4) Alignment and Exposure

5) Post-exposure bake
6) Develop
7) Hard bake
8) Develop inspect
Spin Coat

Process Summary:

- Wafer is held onto vacuum chuck
- Dispense ~5ml of photoresist
- Slow spin ~ 500 rpm
- Ramp up to ~ 3000 to 5000 rpm
- Quality measures:
  - time
  - speed
  - thickness
  - uniformity
  - particles and defects
Steps of Photoresist Spin Coating

1) Resist dispense

2) Spin-up

3) Spin-off

4) Solvent evaporation
**Spin-coating process.**

**Stage One:** Deposition of the coating fluid onto the substrate.

**Stage Two:** The substrate is accelerated up to its final rotation speed. The fluid becomes thin enough that the viscous shear drag exactly balances the rotational acceleration.

**Stage Three:** The substrate is spinning at a constant rate and fluid viscous forces dominate fluid thinning behavior.

**Stage Four:** The substrate is spinning at a constant rate and solvent evaporation dominates the coating thinning behavior.
Photoresist Application

Apply, Spread, Spin-Off
Photoresist Dispense Nozzle

Spinner

Nozzle position can be adjusted in four directions.
Spin-on of Resist

Cs = centistokes =
kinematic viscosity =
absolute viscosity /
density =
centipoise/(g/cm³)

Viscosity determined by solid contents
Example spin speed curve: Resist: JSR positive resist.

Spin Speed Curve for "G" Solvent Photoresists

Solution Viscosity (cP).
- □ 9cP
- ◇ 10cP
- ○ 13cP
- △ 14cP
- □ 22cP
**Spin-coating parameters.**

Theory suggests that:

\[ \text{thickness} = \frac{K}{\sqrt{\omega}} \]

Where \( \omega \) is the angular spin speed (radians per second);
And K is a constant which increases with increasing viscosity.

*See Emslie, Bonner, and Peck, J. Appl. Phys. 29 858 (1958) and Meyerhofer, J. Appl. Phys. 49 3993 (1978).*
Spin coating defects.

Photoresist coating defects can include:
   Dewetting ("fish eyes").
   Comets (from particulates).
   Striations.
   Particulates (including polymer gel, sensitizer crystals).
   Edge beads.

Striations.

Comet.
Spin coating defects: Edge bead.
Eight Steps of Photolithography

1) Vapor prime
2) Spin coat
3) Soft bake
4) Alignment and Exposure
5) Post-exposure bake
6) Develop
7) Hard bake
8) Develop inspect
**Soft bake**

Characteristics of Soft Bake:
- Improves Photoresist-to-Wafer Adhesion
- Promotes Resist Uniformity on Wafer
- Improves Linewidth Control During Etch
- Drives Off Most of Solvent in Photoresist
- Typical Bake Temperatures are 90 to 100°C
  - For About 30 Seconds
  - On a Hot Plate
  - Followed by Cooling Step on Cold Plate


**Soft Bake on Vacuum Hot Plate**

**Purpose of Soft Bake:**
- Partial evaporation of photoresist solvents
- Improves adhesion
- Improves uniformity
- Improves etch resistance
- Improves linewidth control
- Optimizes light absorbance characteristics of photoresist
Solvent Content of Resist Versus Temperature During Soft Bake

Residual Solvent (% w/w)

Bake Temperature (°C)

DNQ/Novolak resist
Heating Systems

Convection Oven, Hot Plate, Moving Belt Oven, Microwave

The cleanest: vacuum oven
## Table of Softbake Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Bake Time Min.</th>
<th>Temperature Control</th>
<th>Productivity Type</th>
<th>Rate</th>
<th>Queueing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Plate</td>
<td>5-15</td>
<td>Good</td>
<td>Single to small batch</td>
<td>60</td>
<td>Yes</td>
</tr>
<tr>
<td>Convection Oven</td>
<td>30</td>
<td>Average - Good</td>
<td>Batch</td>
<td>400</td>
<td>Yes</td>
</tr>
<tr>
<td>Vacuum Oven</td>
<td>30</td>
<td>Poor - Average</td>
<td>Batch</td>
<td>200</td>
<td>Yes</td>
</tr>
<tr>
<td>I.R. Moving Belt</td>
<td>5-7</td>
<td>Poor - Average</td>
<td>Single</td>
<td>90</td>
<td>No</td>
</tr>
<tr>
<td>Conductive Moving Belt</td>
<td>5-7</td>
<td>Average</td>
<td>Single</td>
<td>90</td>
<td>No</td>
</tr>
<tr>
<td>Microwave</td>
<td>0.25</td>
<td>Poor Average</td>
<td>Single</td>
<td>60</td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 8.41  Soft bake chart.
Eight Steps of Photolithography

1) Vapor prime
2) Spin coat
3) Soft bake
4) Alignment and Exposure
5) Post-exposure bake
6) Develop
7) Hard bake
8) Develop inspect
Section of the Electromagnetic Spectrum

Common UV wavelengths used in optical lithography.
**DUV Emission Spectrum**

**KrF laser emission spectrum**

**Emission spectrum of high-intensity mercury lamp**

* Intensity of mercury lamp is too low at 248 nm to be usable in DUV photolithography applications.

Excimer lasers, such as shown on the left, provide more energy for a given DUV wavelength.
The optical spectrum and optical light sources.

High pressure mercury arc lamp.

↑ Excimer laser lines.
## Important Wavelengths for Photolithography Exposure

<table>
<thead>
<tr>
<th>UV Wavelength (nm)</th>
<th>Wavelength Name</th>
<th>UV Emission Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>436</td>
<td>g-line</td>
<td>Mercury arc lamp</td>
</tr>
<tr>
<td>405</td>
<td>h-line</td>
<td>Mercury arc lamp</td>
</tr>
<tr>
<td>365</td>
<td>i-line</td>
<td>Mercury arc lamp</td>
</tr>
<tr>
<td>248</td>
<td>Deep UV (DUV)</td>
<td>Mercury arc lamp or Krypton Fluoride (KrF) excimer laser</td>
</tr>
<tr>
<td>193</td>
<td>Deep UV (DUV)</td>
<td>Argon Fluoride (ArF) excimer laser</td>
</tr>
<tr>
<td>157</td>
<td>Vacuum UV (VUV)</td>
<td>Fluorine (F$_2$) excimer laser</td>
</tr>
</tbody>
</table>

Table 13.1
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAM Bits/Chip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>256M</td>
<td>1G</td>
<td>4G</td>
<td>6G</td>
<td>256G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Feature Size (nm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolated Lines (MPU)</td>
<td>200</td>
<td>140</td>
<td>100</td>
<td>70</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>Dense Lines (DRAM)</td>
<td>250</td>
<td>180</td>
<td>130</td>
<td>100</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Contacts</td>
<td>280</td>
<td>200</td>
<td>140</td>
<td>110</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Gate CD Control 3σ (nm)</td>
<td>20</td>
<td>14</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Alignment (mean + 3σ) (nm)</td>
<td>85</td>
<td>65</td>
<td>45</td>
<td>35</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Depth of Focus (μm)</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Defect Density (per layer/m²)</td>
<td>100 @ 80</td>
<td>80 @ 60</td>
<td>60 @ 40</td>
<td>50 @ 30</td>
<td>40 @ 20</td>
<td>30 @ 15</td>
</tr>
<tr>
<td>@ Defect Size (nm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRAM Chip Size (mm²)</td>
<td>280</td>
<td>400</td>
<td>560</td>
<td>790</td>
<td>1120</td>
<td>1580</td>
</tr>
<tr>
<td>MPU Chip Size (mm²)</td>
<td>300</td>
<td>360</td>
<td>430</td>
<td>520</td>
<td>620</td>
<td>750</td>
</tr>
<tr>
<td>Field Size (mm)</td>
<td>22x22</td>
<td>25x32</td>
<td>25x36</td>
<td>25x40</td>
<td>25x44</td>
<td>25x52</td>
</tr>
<tr>
<td>Exposure Technology</td>
<td>248nm DUV</td>
<td>248nm DUV</td>
<td>248nm DUV or 193nm DUV</td>
<td>193nm DUV or ???</td>
<td>193nm DUV or ???</td>
<td>???</td>
</tr>
<tr>
<td>Minimum Mask Count</td>
<td>22</td>
<td>22/24</td>
<td>24</td>
<td>24/26</td>
<td>26/28</td>
<td>28</td>
</tr>
</tbody>
</table>
**Characterization of optical radiation.**

- Wavelength (or wavelength range or spectral linewidth).
- Intensity (described by Poynting vector).
  
  Energy per area per time.
  
  Typically in W/cm² or mwatt/cm² (for continuous irradiation and sometimes for pulsed irradiation averaged over many pulses).
  
  Generally averaged over spectral output or over the useful spectral output.
  
  For pulsed sources, sometimes peak power/cm², pulse length, repetition frequency, and average power/cm².

- Dose: net energy per area typically J/cm² or mJ/cm².

*For pulsed sources sometimes the pulse energy is given, for cw (continuous wave) sources always the power is stated.*
Lithography.

Basic lithographic concept:

Substrate → Resist application → Exposure

(Positive resist)

Resist removal → Etching → Development

(Negative resist)
Photolithography Processes

• Negative Resist
  • Wafer image is opposite of mask image
  • Exposed resist hardens and is insoluble
  • Developer removes unexposed resist

• Positive Resist
  • Mask image is same as wafer image
  • Exposed resist softens and is soluble
  • Developer removes exposed resist
Negative Lithography

Chrome island on glass mask

Areas exposed to light become crosslinked and resist the developer chemical.

Ultraviolet light

Exposed area of photoresist

Resulting pattern after the resist is developed.

Window

Silicon substrate
**Positive Lithography**

- Ultraviolet light
- Chrome island on glass mask
- Exposed area of photoresist
- Shadow on photoresist
- Areas exposed to light are dissolved.
- Resulting pattern after the resist is developed.
Relationship Between Mask and Resist

Desired photoresist structure to be printed on wafer

Island of photoresist

Substrate

Chrome

Window

Mask pattern required when using negative photoresist (opposite of intended structure)

Quartz

Island

Mask pattern required when using positive photoresist (same as intended structure)
**Positive or Negative?**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Negative</th>
<th>Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio (Resolution)</td>
<td>Better</td>
<td>Higher</td>
</tr>
<tr>
<td>Adhesion</td>
<td>Faster</td>
<td></td>
</tr>
<tr>
<td>Exposure Speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinhole Count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step Coverage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developers</td>
<td>Organic Solvents</td>
<td>Aqueous</td>
</tr>
<tr>
<td>Strippers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxide Steps</td>
<td>Acid</td>
<td>Acid</td>
</tr>
<tr>
<td>Metal Steps</td>
<td>Chlorinated Solvent Compounds</td>
<td>Simple Solvents</td>
</tr>
</tbody>
</table>
**Materials and processing for lithography: photoresists.**

**Desirable characteristics of photoresist materials.**

- High sensitivity (relative to applied dose).
- Excellent ambient stability (at all steps in process).
- Low shrinkage/expansion during drying.
- Robust physical characteristics.
- Image stability throughout process.
- High thermal stability for image.
- Ease of stripping (removal of resist).
- Planarized coating (usually).
- Sharp profile definition.
- Profile definition independent of feature size or shape.
- Accurate reproduction of original mask features.
- High degree of process latitude with respect to exposure, development, process etc.
- No particulate contamination or other defects.
ECE 541/ME 541
Microelectronic Fabrication Techniques

MW 4:00-5:15 pm

Photolithography—Part 2

Zheng Yang

ERF 3017, email: yangzhen@uic.edu
Major Fabrication Steps in MOS Process Flow

Used with permission from Advanced Micro Devices
Eight Steps of Photolithography

1) Vapor prime  
2) Spin coat  
3) Soft bake  
4) Alignment and Exposure

5) Post-exposure bake  
6) Develop  
7) Hard bake  
8) Develop inspect
**Lithography.**

Basic lithographic concept:
Photolithography Processes

• Negative Resist
  • Wafer image is opposite of mask image
  • Exposed resist hardens and is insoluble
  • Developer removes unexposed resist

• Positive Resist
  • Mask image is same as wafer image
  • Exposed resist softens and is soluble
  • Developer removes exposed resist
Negative Lithography

Areas exposed to light become crosslinked and resist the developer chemical.

Exposed area of photoresist

Resulting pattern after the resist is developed.
**Positive Lithography**

Chrome island on glass mask

Exposed area of photoresist

Ultraviolet light

Shadow on photoresist

Areas exposed to light are dissolved.

Resulting pattern after the resist is developed.
Contrast

- The **Contrast** of a photoresist is a well-defined property
- **Contrast** might be the most important property of any photoresist
Eight Steps of Photolithography

1) Vapor prime
2) Spin coat
3) Soft bake
4) Alignment and Exposure

5) Post-exposure bake
6) Develop
7) Hard bake
8) Develop inspect
**Post-Exposure Bake**

- Required for Deep UV Resists
- Typical Temperatures 100 to 110°C on a hot plate
- Immediately after Exposure
- Has Become a Virtual Standard for DUV and Standard Resists
Eight Steps of Photolithography

1) Vapor prime
2) Spin coat
3) Soft bake
4) Alignment and Exposure
5) Post-exposure bake
6) Develop
7) Hard bake
8) Develop inspect
**Photoresist Development**

**Process Summary:**
- Soluble areas of photoresist are dissolved by developer chemical
- Visible patterns appear on wafer
  - windows
  - islands
- Quality measures:
  - line resolution
  - uniformity
  - particles and defects
Resist Development Parameters

- Developer Temperature
- Developer Time
- Developer Volume
- Developer Concentration
- Rinse
- Exhaust Flow
Development

<table>
<thead>
<tr>
<th>Developer</th>
<th>Positive Resist</th>
<th>Negative Resist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hydroxide (NaOH)</td>
<td>Tetramethyl ammonium hydroxide (TMAH)</td>
<td>Xylene</td>
</tr>
<tr>
<td>Rinse</td>
<td>Water (H₂O)</td>
<td>n-Butylacetate</td>
</tr>
</tbody>
</table>

Figure 9.2 Resist developer and rinse chemicals.

Function of Rinse:

Stop development at specific time
Remove resist fragment
Continuous Spray Development

- Used in Wafer Track Systems
Puddle Resist Development

(a) Puddle dispense

(b) Spin-off excess developer

(c) DI H₂O rinse

(d) Spin dry
**Negative Resist Development**

(a)

Top View

[Diagram showing the process of negative resist development]

(b)

Correct Develop

Under Develop

Incomplete Develop

Severe Overdevelop
Positive Resist Development
Line width as function of development

- Resist thickness: 1µm
- Constant development time: 50 s (based on 68°F for 8-s exposure)
- Developer concentration: 50%
- Postbake: none

```
+1.50
+1.40
+1.30
+1.10
+0.90
+0.70
+0.50
+0.30
+0.10
-0.10

20-s exposure
16-s exposure
12-s exposure
8-s exposure

Developer Temperature (°F)
```
Development Process

Immersion possible but same drawbacks as primer immersion.

Spray, Rinse, Dry               Puddle, Spray, Rinse, Dry

Preferred!
Scum and Descumming

Thin layer of resist or developer might be present on surface after rinse.

Can be removed by plasma oxidation, if substrate is not damaged too severely by this
Eight Steps of Photolithography

1) Vapor prime
2) Spin coat
3) Soft bake
4) Alignment and Exposure
5) Post-exposure bake
6) Develop
7) Hard bake
8) Develop inspect
**Hard Bake**

- A Post-Development Thermal Bake
- Evaporate Remaining Solvent
- Improve Resist-to-Wafer Adhesion
- Higher Temperature (120 to 140°C) than Soft Bake
**Hard Bake**

Hardening of the resist film after development.

Makes it more durable for subsequent processes.

Typical temperatures 130-200°C and 30 min in convection oven. Other oven designs shorter duration

Don’t bake too hot! This will make the resist flow!
Photolithography Track System
Automated Wafer Track for Photolithography
Photolithography Concepts

- Patterning process
  - Photomask
  - Reticle
- Critical dimension generations
- Light spectrum and wavelengths
- Resolution
- Overlay accuracy
- Process latitude
Three Basic Exposure Methods

1:1 Exposure

Light Source
Optical System
Mask Photoresist
Si Wafer

Contact Printing

1:1 Exposure

Gap

Proximity Printing

~5:1 Exposure

Projection Printing
• **Contact printing** capable of high resolution but has unacceptable defect densities. May be used in Development but not manufacturing.
• **Proximity printing** cannot easily print features below a few μm in line width. Used in nano-technology.
• **Projection printing** provides high resolution and low defect densities and dominates today. Typical projection systems use reduction optics (2X - 5X), step and repeat or step and scan. They print » 50 wafers/hour and cost $5 - 10M.
Contact lithography – implementation.

Normally mask is aligned with substrate and then brought into contact with substrate before exposure.

Alignment

Exposure
**Contact Lithography**

- Since illumination almost perfectly follows mask, almost perfect features can be produced regardless of contrast of resist.

- Contact printing produces superb images.

- Image quality under contact printing conditions is not a reflection of quality of resist.

- Disadvantages of contact printing:
  - Contact can cause defects in resist.
  - Contact can damage mask.
  - Throughput limited.

- Contact not used in commercial production of silicon devices. However it can be used in laboratory situations as well as in special low volume production.

- Smallest feature sizes not easily attainable due to problems making the mask.
Commercial contact aligners.

Suss laboratory contact aligner.

Suss MA6a contact aligner.

Quintel contact aligner.
Commercial contact aligners....continued.

K-W MA1006 contact aligner

Suss MA8 contact aligner
Contact vs. Proximity Lithography
**Proximity lithography.**

In proximity lithography, the mask is held above the substrate by a fixed distance or gap. (better protection for mask)

| Limiting factor: Fresnel diffraction. |
| General rule: resolution $\sim (g \lambda)^{0.5}$ where g is gap. |

*Derivation: Chang and Sze, ULSI Technology (McGraw Hill, 1996), p 274.*

Take $g = 20$ micron and $\lambda = 0.4$ micron: resolution $\sim 3$ micron.

Since it is difficult to maintain $g < 20$ micron, proximity lithography is rarely used in commercial production. Some versions are widely used in research and small scale production (Suss, 250 nm wavelength).
Lithographic exposure and equipment.

Diffraction pattern from coherently illuminated mask.
Projection lithography: General considerations.
Properties of optical lenses used in lithography.

Simple lens can be characterized by diameter $D$ and focal length, $f$. Source distance $d_1$ from lens will be focused at distance $d_2$ according to the relation:

$$\frac{1}{f} = \frac{1}{d_1} + \frac{1}{d_2}$$

Thus if $d_1=\infty$ then $d_2 = f$.

Image will be magnified by factor $m=d_2/d_1$.

Could alternately define simple lens in terms of numerical aperture NA and $D$ where $NA = D/(2f)$.

Lithographic lenses are extremely complex lenses with multiple elements to minimize aberrations resulting from several phenomena. However they can to first order be described in terms of simple lens equivalent.
Projection lithography: Resolution.

Limitations are due to Fraunhofer diffraction. Consider the following geometry:

- Source
- Collection optics
- Mask
- Projection lens: NA
- Image onto surface of wafer
Projection lithography: General considerations.

Fraunhofer Diffraction:

Resolution = $k_1 \lambda / NA$

Minimum intensity at space is 0.735 X maximum intensity. Theory: $k_1 = 0.61$ for optical resolution.

$k_1$ can vary with esoteric optical systems or if response of resist is included.
ECE 541/ME 541  
Microelectronic Fabrication Techniques  

MW 4:00-5:15 pm  

Photolithography—Part 3  
(Lift-off process for metal deposition)  

Zheng Yang  

ERF 3017, email: yangzhen@uic.edu
Lift-off process for metal patterning