Lithography I

- Clean Room Technology
- Optical Lithography
• If the automobile had followed the same development cycle as the computer, a Rolls Royce would today cost $100, get a million miles per gallon, and explode once a year.
  – Computerworld / Applied Materials

• Build your own transistor online:
IC’s

Figure 6-1  Schematic cross-sectional view of an MOS transistor structure with multilevel metallization scheme. Film materials deposited by CVD are indicated in the text. Note: LTO = low temperature oxide, BPSG = boron phospho-silicate glass, STI = silicon trench insulator. After K. P. Rodbell, IBM, T. J. Watson Research Division.
Optical Lithography

http://www.iue.tuwien.ac.at/phd/kirchauer/img168.gif
Depending on the coating method, conformal or direct coatings are possible.

- Flaws are difficult to avoid for large 3-d structures.
Keeping Clean

Working in a cleanroom:

- Suit made of ultra clean material
- Battery pack for air filter system
- 2 pairs of gloves (nylon & latex)
- 2 pieces of foot gear (disposable shoe covers & outer booties)
- Helmet includes air filter unit
- Will also wear hairnet & safety glasses
- Belt
Tools
Processing
Clean Rooms
Ch 1: Methods for Nanolithography

- Optical
- Nanoimprint
- Microcontact
- Direct write (FIB, SPM)
Nanolithography problems

• Throughput: features/second
• Field: size of surface area patterned in a single setup (ie before mechanical stepping, as it is difficult to realign reliably)
• Alignment/registration: ability to align adjacent patterned regions, and/or vertically stacked patterned regions
• Source: optical, ion beam, electron beam
• Source Stability, monochromacy, intensity
• Resist sensitivity (low dose for exposure -> high throughput, but little tolerance for error)
• Resist contrast (abrupt transition between sub and super critical exposures -> high resolution pattern transfer)
• Cost: Lithography cost roughly ½ new fab facility cost (Billions!)
Optical Lithography

- Primarily UV projection through a mask
  - UV for small wavelength (high resolution)
  - Reduction Projection for additional decrease in size
  - *Mask prepared using resist exposure and development (chicken and egg problem)*
  - Modifications to present methods allow nano-fab (<100 nm)

- Central to the process is the resist.
Resist

- Polymeric film
- Exposure to photons (or electrons or ions) causes structural/chemical modification to polymer
  - Greatly adjusts solubility for exposed or unexposed parts.

\[ \gamma = \log_{10} \left( \frac{D_0}{D_C} \right) \]
Resist types

• Positive resist: enhances solubility (exposed gets eaten away)
  – Exposure cuts polymer backbone (scission)
    • Lowers molecular weight, inherently more soluble.

• Negative resist: reduces solubility (exposed remains, rest of film is eaten away)
  – Exposure cross links polymer chains
    • Resulting molecule is huge and insoluble.
Resist Selection

Resists must have:

• Highly nonlinear chemical response to radiation (providing high spatial resolution)
  – Resist contrast is slope of remaining thickness vs resist exposure, normally \( \gamma = -2 \) to \(-15\)

• Structural Integrity
  – Withstand handling
  – Maintain feature widths, thicknesses without shape change

• Specific chemical properties
  – Cannot interact with other materials on surface
  – Able to be partially removed after exposure/development
  – Able to completely remove the rest in final cleaning steps
Resist Chemistry

• Conventional: excitation energy converted directly to chemical reactions
  – Initially insoluble combination of:
    • DNQ (diazo-naptho-quinones)
    • Photoactive compound (‘PAC’)
  – Post-exposure bake promotes moderate diffusion and drives out/off water.
  – Positive resist: once exposed, PAC converted to soluble acid.
    • Development in KOH, NaOH, etc. results in localized dissolution.
  – 350 nm resolution for 365 nm light (‘I-line’)
  – **100 mJ/cm^2** required
• Chemically amplified: excitation energy enables intermediate catalytic reaction
  – Insoluble combination of:
    • Polymeric backbone
    • Dissolution inhibitor
    • Photo-acid-generator (‘PAG’)
  – Once exposed, PAG creates acid group that attacks numerous polymer backbones (100:1, instead of 1:1 for conventional PAC resists).
  – **5 mJ/cm^2**
  – Higher contrast (gamma is 12 instead of 6)
Exposure

• Serial
  – Pattern created by focused beam
    • Usually electrons or ions
  – Relatively slow
  – Resolution depends on focal radius of beam

• Parallel
  – Image of a pattern is transferred to resist surface
    • Projection through a noncontact mask
    • Contact alignment of mask directly to resist surface
      – Maybe just proximity alignment (ie really close but not touching where it counts)
        » Very difficult to achieve over large areas
      – More likely pressure applied to maintain contact
        » Mask more likely to get dirty
  – Resolution defined by pattern mask and/or radiation wavelength
Paper for Thursday

• No summary due, but full discussion including 2 summary leaders
• Dip-Pen Nanolithography: Controlling Surface Architecture on the Sub-100 Nanometer Length Scale
• Chad A. Mirkin, Seunghun Hong, and Linette Demers
• CHEMPhysCHEM 2001, 2, 37-39
• Available online through library (search for journal of Chem Phys Chem)
Mask technology

• Procedure:
  – A glass or fused silica substrate is coated with up to 100 nm Cr (a good light absorber).
  – This is then coated with resist, and exposed by a ‘primary pattern generator’ following a pattern
    • Usually a stepper or ebeam or laser writer.
  – The resist is then developed causing the patterned regions to dissolve.
  – Any now-exposed Cr is etched chemically
    • Undercutting can be a problem, though
  – Leaves a Cr mask where you don’t want light, and open glass substrate where you do.

• The ‘mother mask’ is replicated for further fabrication (daughter masks)
  – Contact masks- 1:1 pattern to final structure ratio
  – Projection masks- 4:1 pattern:final structure ratio (‘reduction printing’)
    • Bonus: errors or defects in mask are reduced in size/impact
Mask Manufacturing Process (First Level)

1. Design
2. Reticle Layout
3. Pattern Generator
4. Registration
5. Pellicle
6. Defects?
7. Defects?
8. Repair
9. CD Measurement
10. Masks Chrom Blank
11. Shipment to Waferfab
Mask defect inspection/repair

• Inspect optically by comparing images of like regions or compare images to databases
  – Flag differences
    • <10 allowed for 150x150 mm mask
  – Repair using laser, FIB, AFM, or e-beam methods
    • Easy for opening up new regions in the mask
    • Harder for re-deposition (filling in holes dug into Cr film)
  – Clean
  – Store in pellicle
    • Transparent membranes on each side of mask that don’t quite touch it
    • Any particle which lands here is not in the image plane, and thus only marginally influences projected resolution
Contact Printing

• Photomask in direct mechanical contact with resist coated sample
• Illuminate uniformly (usually with UV)
• But photoresist may stick to mask
• Dust particles / last run’s photoresist chunks can prevent ideal mask contact
• Common in research/education, but not practical for industry
• All defects in mask transfer to sample at the same size.
Proximity Printing

• Similar to contact, but a small gap is maintained between sample and mask.
• Reduces defect problems from stuff sticking/stuck to mask.
  – Practically, most contact printing is actually proximity printing due to these bits of stuff.
• Challenge to control the sample/mask gap.
• All defects in mask still transfer to sample at the same size.
Projection Printing

• Shine UV light through the mask.
• Use optics to reduce the size of the projected image by $\frac{1}{4}$.
• Defects in mask transfer to sample at $\frac{1}{4}$ size too.
• Rayleigh Criteria: Limits for Optical Resolution ($R$) depend on the numerical aperture of the optics themselves, the wavelength, and a constant ($k_1$)
  \[ R = \frac{k_1 \lambda}{NA} \]
• Generally, $k_1/NA$ is about 1, so wavelength limits resolution.
• Improvements only obviously possible with:
  – smaller wavelengths
    • But harder to focus
  – Bigger NA
    • But smaller depth of focus (300 nm over 25mmx25mm)
    • To maintain focus across the field of view, the sample must be mounted with a maximum slope of $1/100,000$. 
Wavelengths

• Typically Mercury arc lamp, with strong emission at:
  – 435 nm (‘G-line’)
  – 365 nm (‘I-line’)

• KRF lasers (248, 193, or 157 nm wavelengths)
  – But lenses and masks have problems at these wavelengths
    • Mask substrate (quartz) absorbs below 248 nm.
      – Switch to CaF2 or MgF for 157 nm especially.
    • 157 nm: hydrocarbon resists are too strongly absorbing
      – Switch to fluorocarbons instead
    • Below 157 nm, mirrors instead of lenses necessary, otherwise too much absorption. Masks and photoresists have similar absorption problems.
      – No simple solution.

• Each time the wavelength is changed is a major undertaking:
  – New resists/developers.
  – New tools (very, very expensive)
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Source: Nanoink
Summary

• Clean rooms

• Optical Lithography
  – Resist
    • Positive or negative
  – Masks
    • Contact, proximity, or projection

• Next class: Resolution Enhancement Technologies
  • Resist, pattern preshaping, masks (esp. phase shifting)

• Paper discussion: Dip Pen Nanolithography (‘DPN’)
  – Chad A. Mirkin, Seunghun Hong, and Linette Demers
  – CHEMPHYSOCHEM 2001, 2, 37-39