Lithography in Microfabrication

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Fabrication

**Macro**
- Machine Shop
- drilling, milling, cutting, welding, screws
- 3D objects assembled from pieces
- Start with CAD drawing

**Micro**
- Cleanroom
- lithography to define areas where we deposit, remove(etch) or modify (implant).
- 3D objects built layer by layer on a flat substrate
- Start with CAD drawing
Lithography

- Structures and Devices are built layer by layer
- Add (deposit) Remove (etch) or Modify (implant, anneal) material
- Define the areas to be modified by patterning a resist (resin or polymer)
- Lithography is central to most of the fabrication steps.

Microfabrication
Microfabrication

Lithography

- Optical (photolithography)
- Electron beam
- Holographic
- Focused Ion Beam
Resist Exposure

Photolithography

Hg arc lamp
• Parabolic reflector + mirrors
• Illuminate the mask + wafer
• Calibrate intensity (feedback)
• Exposure requires a certain power density of a particular UV wavelength (eg 450 mJ/cm² at 365nm)
• Mask Aligner or Stepper
Mask Aligner

- Hg discharge lamp (UV source)
- Reflecting optics (parallel illumination)
- Detector feedback to lamp power supply to maintain constant output
- Timer & shutter to control exposure
- Substrate can be moved relative to mask in x, y, z & rotation
- Optics for viewing alignment marks (front & back)

Photolithography
Photoresist

- Sensitivity to UV exposure
- Positive or negative
- Thickness control (spinning)
- Reflections & interference
- Developing
- Example: Shipley 1800
- Example: SU-8
Spinning Resist

MICROPOSIT S1800 PHOTO RESIST UNDYED SERIES
Figure 1. Spin Speed Curves

- S1822
- S1818
- S1813
- S1811
- S1805
MICROPOSIT S1813 and S1813 J2 PHOTO RESISTS

Figure 4. Interference Curves

EXPOSURE DOSE, $E_f$ (mJ/cm$^2$)

PHOTORESIST THICKNESS (Å)

Interference
UV Exposure

• A pattern will be produced over a range of doses to find appropriate dose
• Feature size is determined by exposure & developing time
• Sensitivity
Shipley 1800 Process Flow

- Substrate Preparation
- Coat
- Soft Bake
- Expose
- Develop
- Hard Bake (optional)

SU-8 (negative resist)

50 micron thick resist
SU-8 Process Flow

- Substrate Preparation
- Coat
- Soft Bake (slow)
- Expose
- Post-Exposure Bake
- Develop
- Hard Bake (optional)

Limitations of Resist

- Polymer chains have finite size
- Mechanically soft
- Adhesion to substrate
- May be damaged by further processing
Limitations

Resist polymer chains are finite size

Limitations

Resist has limited mechanical strength and adhesion
Etch & Deposition

Subtractive Process

Additive Process

Photolithography

Etch

Deposit

Strip Resist

Pattern transfer by etching

Pattern transfer by lift off

Etching

- Etching can be wet (chemical) or dry (RIE)
- Isotropic vs anisotropic

Anisotropic

Isotropic
Anisotropic Etching (KOH)

- Silicon (111) direction etches much more slowly than (100)
- Etching ‘stops’ on 111 planes
- Depth is determined by size of opening
- Typically used for large features
- Resist would be removed by KOH -> pattern transferred to a silicon nitride layer first
- Hard Mask

Anisotropic Etching (DRIE)

- Protective layer deposited on the sidewall to protect it from etching
- Bosch Process
- SF6 / C4F8 cycling
- Selectivity to resist
Isotropic & Anisotropic Etching

- Au/Cr/Si/SiO2/Si, photoresist mask
- Au & Cr etched chemically
- Silicon etched by DRIE
- SiO2 etched by HF
- Note Undercutting
Isotropic & Anisotropic etching

- Si/SiO2/Si, resist mask
- Silicon etched by DRIE
- SiO2 etched by HF
- Critical Point Drying

Deposition

- Evaporation (metals)
- Sputtering (metals & oxides)
- PECVD (silicon oxide & nitride)
- Thermal Oxidation (Silicon Oxide)
Metal Lift-Off

• Typically evaporated (line of sight)
• Negative slope ensures disconnect between metal on substrate and on top of resist
• Resist is dissolved, washing away metal on top of resist
• Limits of size, thickness
Metal Lift-Off

Limits of Resolution
- Thickness of metal vs thickness of resist
- Thickness of resist vs lateral size
- Granularity of metal

Lift-off Resist
- Resist with negative slope (undercut)
- Bi-layer of resist
- LOR layer not UV sensitive
- Undercut by developer
- Ensures discontinuity
Multilayer Resists

- Resists with differing sensitivities to radiation or developer
- Example from PMMA datasheet
- High MW PMMA produces smaller features than low MW PMMA
- Copolymer dissolves as LOR in previous example

Alignment

- Layer by layer fabrication
- Each layer must overlay the previous
- Alignment marks on wafer & mask
Alignment

• Adjust x, y and rotation with mask near wafer
• Put in contact to expose
Electron Beam Lithography

- Beam can be focused to a few nm
- Resolution limited by resist
- “Write” patterns by moving the beam
- CAD drawing → beam movement
- Beam blanker (on/off)
- Precision stage for ‘stitching’ large patterns

Electron Beam Lithography

- ‘Serial’ process – not for large areas
- Combine with photolithography to write high resolution components
- No mask → easy to modify pattern
- High energy minimizes interaction volume in resist layer and secondary electrons
High Resolution – Small Features

• Minimum feature size is determined by resist resolution and thickness
• Example very high resolution MaN 2403 showing 20nm features

E-beam Lithography

• Ideal for small features
• Low density
• Modest areas <1mm
• Example with negative resist MaN2403
E-beam Lithography

- E-beam patterned resist can be etched or used for metal lift-off
- Smallest features require thin resist
- Limits thickness of metal or depth of (isotropic) etch that can be achieved

E-beam Lithography

- Maximum writing field for high resolution writing ~150 microns
- For larger patterns need to move the stage and ‘stitch’ fields together
- Laser Interferometer controlled stage allows ~100nm stitching precision
Holographic (Interference)

- Intensity variations provided by constructive / destructive interference
- Written with a pulsed laser
- Ideal for gratings – precise periodicity
- 3- and 4- wave mixing can make 3d patterns

Focused Ion Beam Lithography

- 30 keV Ga ions
- Focused to 10nm-500nm, depending on beam current
- Sputter Milling removes material from substrate, no resist required
- Can be used for cutting, milling, sectioning of almost any material
- Lithographic control -> CAD drawing
FIB Lithography

- Can mill features directly from a CAD drawing
- Milling is not simply dose dependent
- Requires complex patterning/repetition
- Can see the result immediately and adjust accordingly

Cleanroom