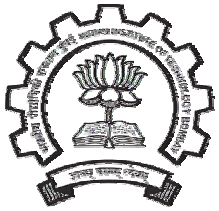
MEMS: Fabrication

Lecture 3: Lithography 1



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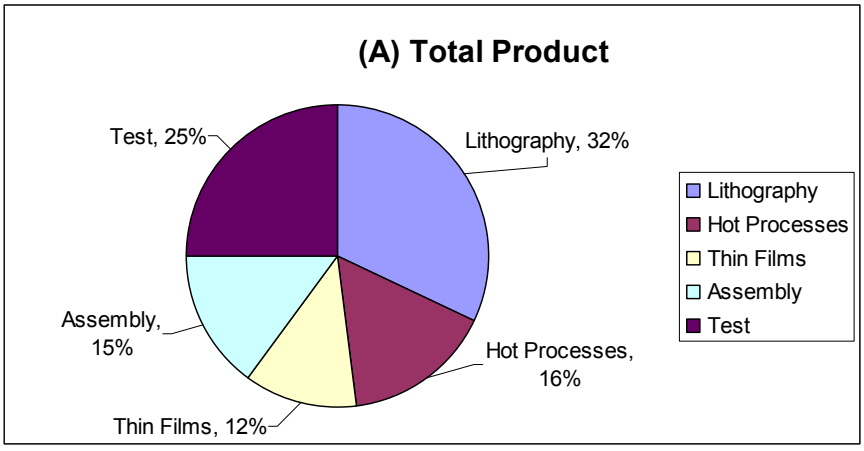
Recap: Last Class

- Applications of MEMS: commercial & research
- Fabrication processes for MEMS
  - Lithography
  - Material removal
  - Material addition

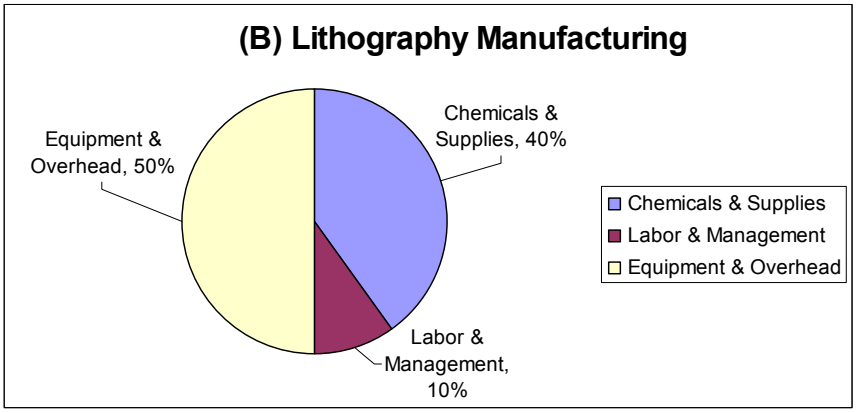
Today's Class

- Importance of lithography in VLSI based MEMS
- Fabrication processes for MEMS: Lithography
  - Various types
  - Optical Lithography
    - Process details
    - Important parameters
- Design considerations:

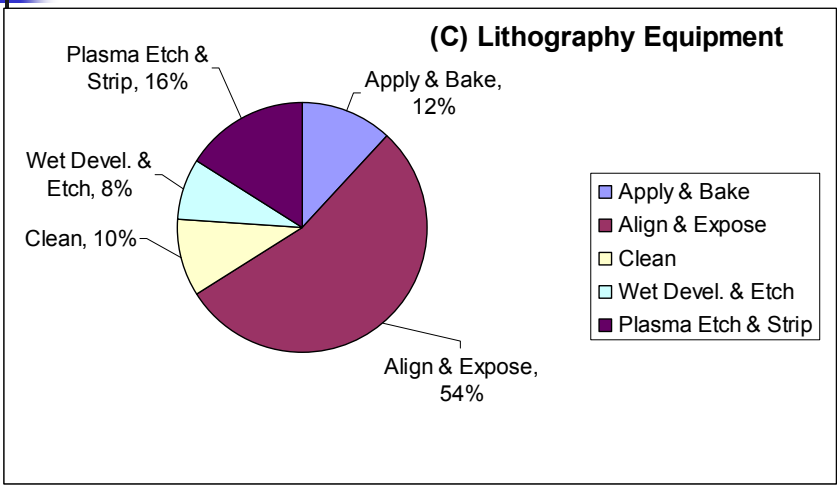
Importance of Lithography



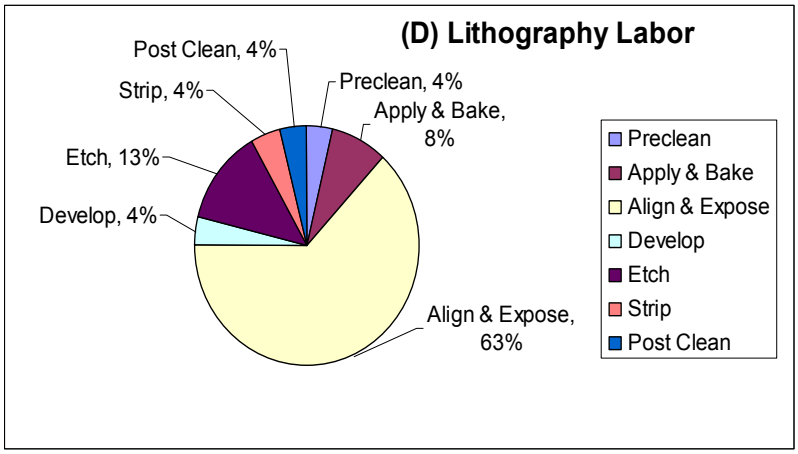
Lithography Costs



Lithography Costs



Lithography Costs



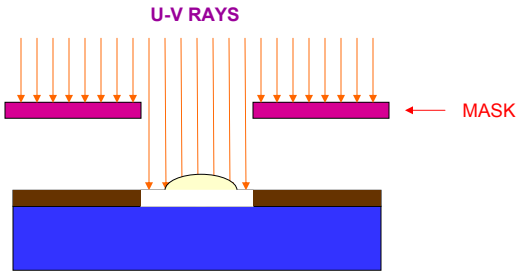
Lithography: Types

- Optical lithography
- Soft Lithography
- Electron beam lithography
- X-ray lithography
- Ion beam lithography
- Dip Pen lithography

Optical Lithography

Concept

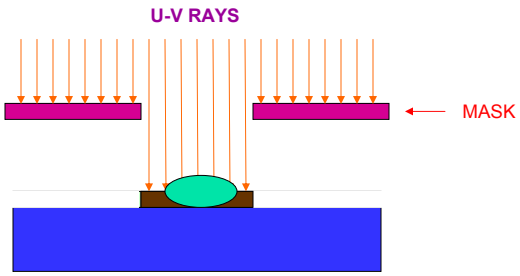
Positive Photoresist (PPR)



Optical Lithography

Concept

Negative Photoresist (NPR)



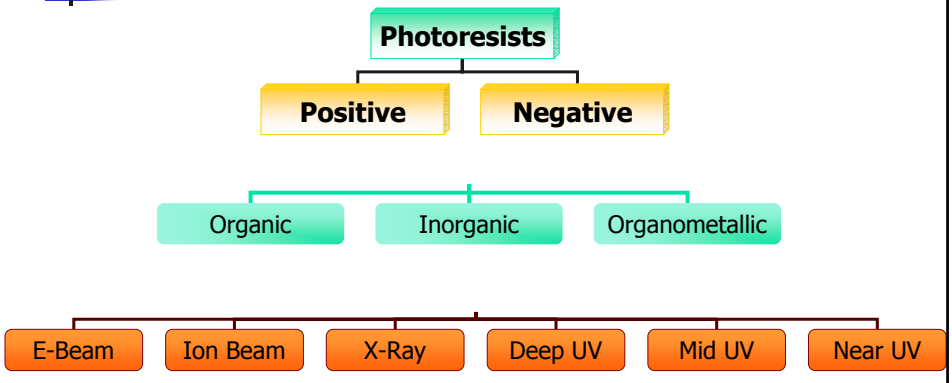
Optical Lithography

Important parameters

- Photoresist
- Ways of exposure
  - Contact printing
  - Proximity printing
  - Projection printing
- Wavelength of light
- Intensity of light
- Width w of the feature size: Diffraction effects

Photoresists

Classification



Photoresists

Properties & use

- Positive photoresist
  - Photoactive agent + Resin → inhibition destroyed
  - Better resolution than negative PR
  - Examples: MP-2400, HPR 206, Deep UV resists: PMMA (λ <250 nm), polybutene sulfone (λ <200 nm)
- Negative photoresist
  - Photoactive agent + rubber → (Inert atmosphere) less soluble
  - Swelling → Resolution 2-3 times initial film thickness
  - Examples: Su-8, Kodak microneg

www.microchem.com

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Mask Making

- EBL : commercial masks vendors $1000 perlayer
- Features greater than 50microns: use fine printing on transperancies
- Design issue: Alignment

Optical Lithography

Types

- Contact printing
- Proximity printing
- Projection printing

What is the one we saw in animation??

- Double sided

Contact Printing

Process Adv/ Disadv

- Mask pressed against resist (0.05 – 0.3atm press)
- Very high resolution (<1μm) possible
- Flexible mask
- Problems
  - Nonuniform contact, resolution decreases
  - Contact produces defects in mask and wafer (13 def/cm2 after 5 exp → 37 def/cm2 after 15) : pinholes, scratches, fractures etc.
  - Reduced mask life

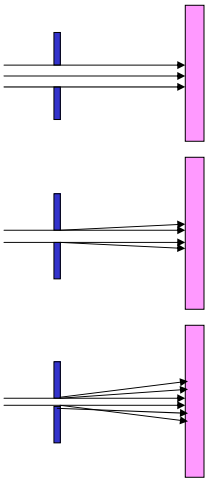
Masks for Lithography

- Usually made up of glass substrate with Cr
- For exposure at low frequencies quartz or Al2O3 as mask substrate have been used
- Process of making masks???
- E-Beam direct write lithography

Proximity Printing

- Need?? Motivation
- Contact printing problems
- Need to study some fundamentals of light to understand
  - Limitations on feature size that can be produced
  - Selection of process parameters to achieve min feature size

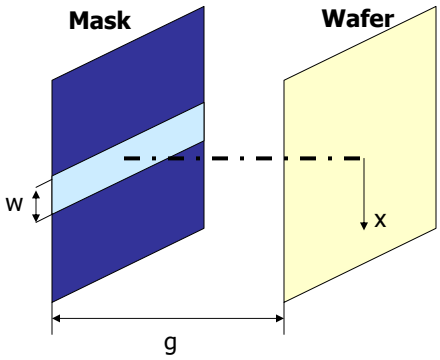
Fundamentals



Animation: practical difficulties???

- Diffraction of light

Diffraction Limits



- Assume Fresnel diffraction

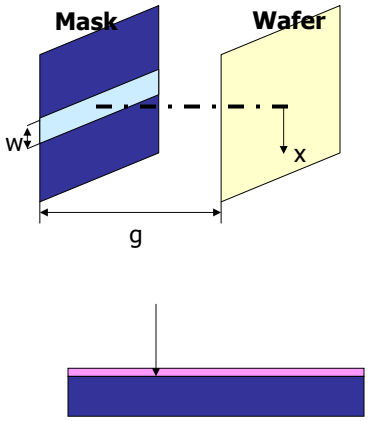
$\lambda << g < W^2/\lambda$

- Q factor

$$Q = W\sqrt{\frac{2}{\lambda g}}$$

- Larger the Q more faithful is the image
- Smaller the gaps g and shorter the wavelength λ better the resolution

Diffraction Limits



- The effects of diffraction are prominent at the corners
- Solution: make modifications in the mask to get appropriate geometrical features
- Another effect: standing waves: reflection from substrate

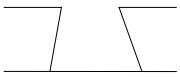
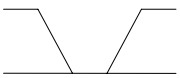
Comparison

- See the transparency

Projection Printing

- Higher resolution than proximity printing
- Larger separation between the mask and the substrate
- Reduction while projecting so better for higher resolution. Masks with lower resolution will do for getting higher resolution.
- Cost is higher on account of additional optics

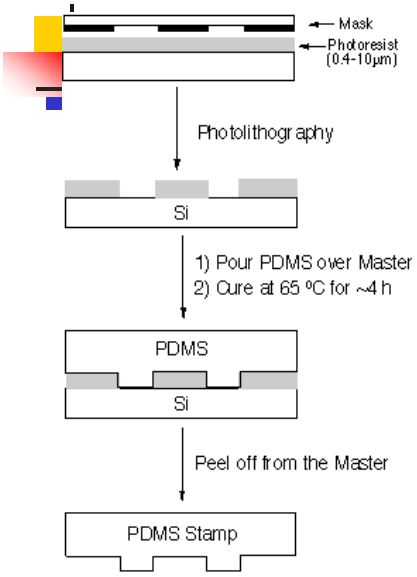
TABLE . Profiles, Expose-Develop Criteria, and Uses of Positive Resists

Profile	Dose	Developer Influence	Uses
	High	Low	Lift-off Ion implant
	Medium	Moderate	Dry etch Lift-off Wet etch
	Low	Dominant	Wet etch

Soft Lithography

- Features transferred by PDMS stamp
- Self assembled monolayers
- Next few slides: courtesy George Whitesides
  - Replica moulding
  - Micro-contact printing

Replica Molding (REM)



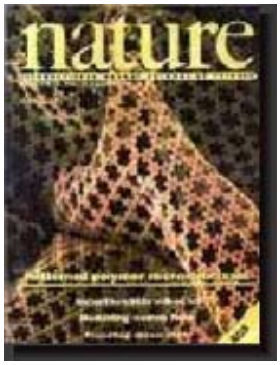
Standard photolithography is used to produce a master on Si from a mask

A monomer, oligomer, or other pre-polymer (or polymer solution) is poured over the mask to conform to features

The resulting polymer needs a Tg below processing temperature (such as PDMS) after curing by heat or UV light

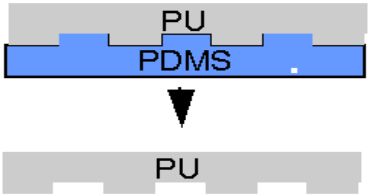
The elastomeric PDMS is removed from the original, leaving no residue and holding the negative of the surface

Replica Molding (REM)

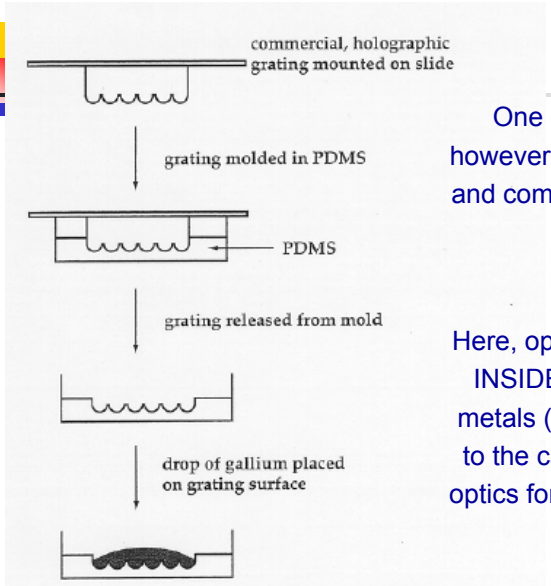


The original master can be used many times, with PDMS poured and peeled off repeatedly, with good stability

This PDMS negative can then act as mask to reproduce the original, with a high Tg polymer such as poly(methyl methacrylate) PMMA, or polyurethane



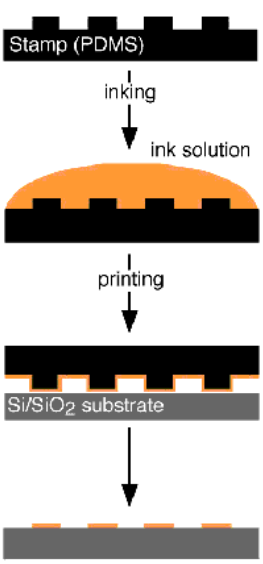
Replica Molding (REM)



One clever side application however is to use slight expansion and compression for mechanically switchable optics

Here, optical elements are formed INSIDE the PDMS using liquid metals (Hg or Ga) which conform to the cavity and act as adaptive optics for beam steering and focus

Micro Contact Printing (μCP)



The PDMS masks can also be applied as flexible stamps, inked with adsorbing or assembling molecules, and then used as small rubber contact stamps

The chemical ink covers all surfaces, but Surface relief patterns transfer only molecules in direct contact. 5nm is sufficient, with 200nm spaces.

Inks can be adsorbing polymers, reactant compounds, or self assembling monolayers based on silanes or thiols

Conclusions

- Optical lithography: widely used
  - Proximity or projection printing better methods
  - Diffraction limits the feature size in proximity printing
- Soft lithography

Next class

- E beam lithography
- Chemical etching