EE C245 – ME C218
Introduction to MEMS Design
Fall 2009

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Lecture Module 4: Lithography, Etching, & Doping

Lecture Outline

- Reading: Senturia, Chpt. 3; Jaeger, Chpt. 2, 4, 5
  - Lithography
  - Etching
    - Wet etching
    - Dry etching
  - Semiconductor Doping
    - Ion implantation
    - Diffusion

Lithography

Lithography

Lithography
- Method for massive patterning of features on a wafer → pattern billions of devices in just a few steps

Four Main Components
(that affect resolution)

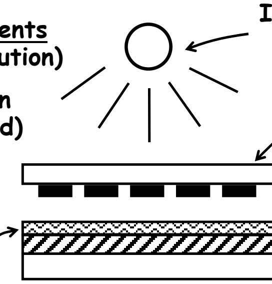
I. Radiation Source

Designated pattern
(clear or dark field)

emulsion chrome

- Generated from layout

II. Mask



III. Photoresist

IV. Exposure System ⇒ contact, step and repeat
optics ⟶ this is where the real art is!

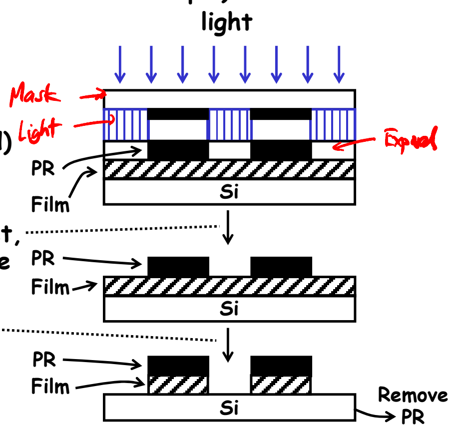
Lithography (cont.)

The basic Process – (Positive Resist Example)

Exposed PR ⟶ converts to another form after reaction with light (e.g., (+)-resist: polymer ⟶ organic acid)

Dip or spray wafer with developer ⟶ if (+) resist, developer is often a base

Etch ⟶ PR protects film; open areas of film get etched



Lithography (cont.)

With each masking step usually comes a film deposition, implantation and/or etch. Thus, the complexity of a process is often measured by # masks required.

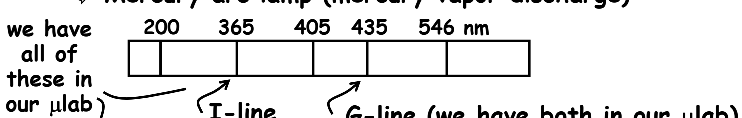
- NMOS: 4-6 masks
- Bipolar: 8-15 masks
- BICMOS: ~20 masks
- CMOS: 8-28 masks (↖ Multi-level metallization)
- Comb-Drive Resonator: 3 masks
- GHz Disk: 4 masks

Now, take a closer look at the 4 components:

I. Radiation Source

I. Radiation Source
- Several types: optical (visible, UV, deep UV light), e-beam, X-ray, ion beam
  - The shorter the wavelength → Better the resolution
  - Today's prime choice due to cost and throughput. (Can expose billions of devices at once!)

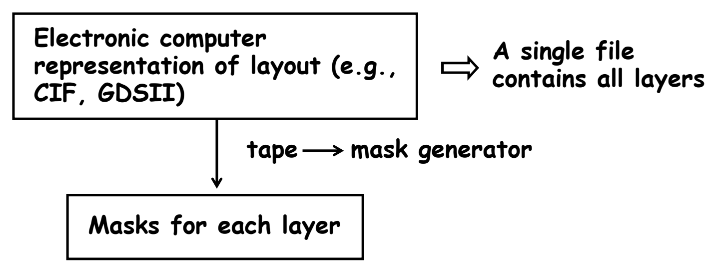
Optical Sources:
- Mercury arc lamp (mercury vapor discharge)



- For deep UV, need Excimer laser (very expensive)
  - Glass opaque, so must use quartz mask and lens

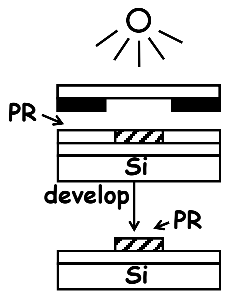
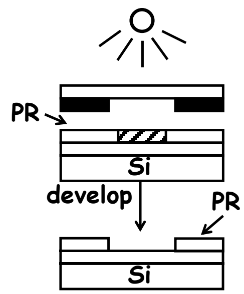
II. Mask

II. Mask → has become one of today's biggest bottlenecks!



Mask Material:
- Fused silica (glass) ⟶ inexpensive, but larger thermal expansion coeff.
- Quartz ⟶ expensive, but smaller thermal expansion coeff.

III. Photoresist (optical)

	Negative	Positive
Pictorial Description:		
Exposed Area:	remains	removed

III. Photoresist (optical)

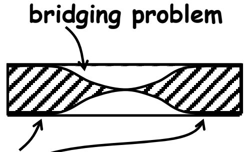
	Negative	Positive
Mechanism:	photoactivation ↓ Polymerization (long, linked Carbon chains) ↓ Developer solvent removes unexposed PR	photoactivation ↓ Converts exposed PR to organic acid ↓ Alkaline developer (e.g.,kOH) removes acid

III. Photoresist (optical)

Issues:

Negative

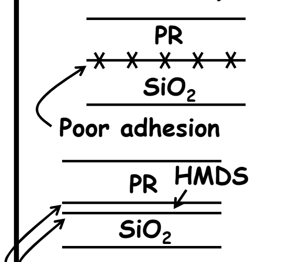
Polymerized PR swells in solvent → bridging problem



Exposed and polymerized

Positive

Doesn't adhere well to SiO_2
Need primer: HMDS (hexamethyl disilazane)

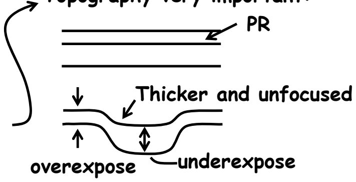


Typical Procedure for Lithography

- Clean Wafer — Very important step
- ↓ Dry Wafer — 30 min. @ 120°C pre-bake
- ↓ Deposit HMDS — (for oxide on wafer surface)
- ↓ Spin-on PR — 30-60 sec @ 1000-5000 rpm
- ↓ Soft Bake — 2 min @ 90°C. Improve adhesion and remove solvent from PR
- ↓ Align & Expose
- ↓ Develop → Descum → Post Bake

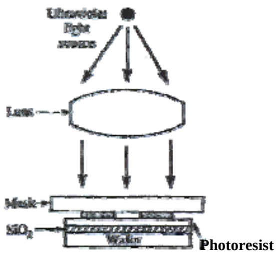
Descum: Oxygen plasma (low power ~ 50W)

Topography very important:



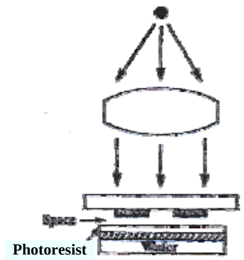
IV. Exposure System/Optics

Contact Printing



- Mask in contact with wafer
- *Problem*: mask pattern can become damaged with each exposure → must make a new mask after x number of exposures

Proximity Printing

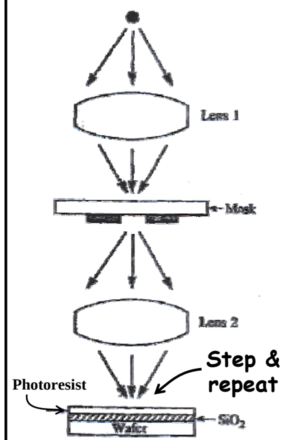


- Mask in very close proximity but not touching

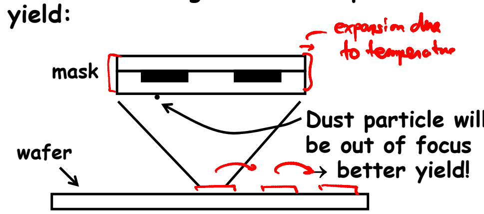
- 1X printing very useful for MEMS → can expose surfaces with large topography (where reduction printers cannot)

IV. Exposure System/Optics

Projection Printing



- Dominates in IC transistor fabrication
- 5X or 10X reduction typical
- Mask minimum features can be larger than the actual printed features by the focused reduction factor → less expensive mask costs
- Less susceptible to thermal variation (in the mask) than 1X printing
- Can use focusing tricks to improve yield:

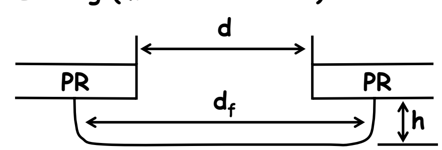


Etching

Etching Basics

- Removal of material over designated areas of the wafer
- Two important metrics:
  1. Anisotropy
  2. Selectivity

1. <u>Anisotropy</u> –
   a) Isotropic Etching (most wet etches)



If 100% isotropic: $d_f = d + 2h$

Define: $B = d_f - d$

If $B = 2h$ ⇨ isotropic

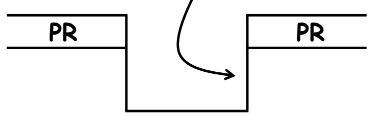
Etching Basics (cont.)

b) Partially Isotropic: B < 2h
(most dry etches, e.g., plasma etching)

Degree of Anisotropy: (definition)

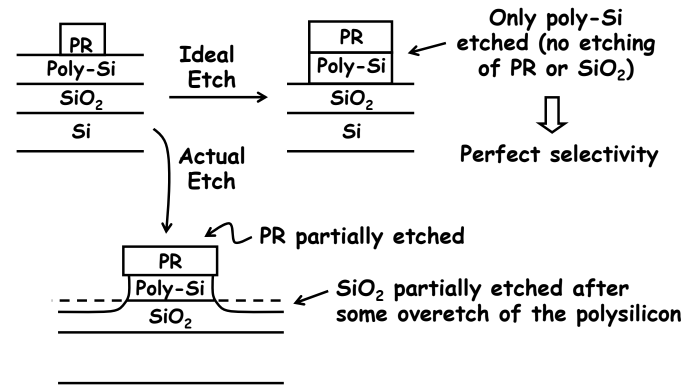
$$A_f = 1 - \frac{B}{2h} = 0 \quad \text{if 100\% isotropic}$$

$$0 < A_f \leq 1 \leftarrow \text{anisotropic}$$



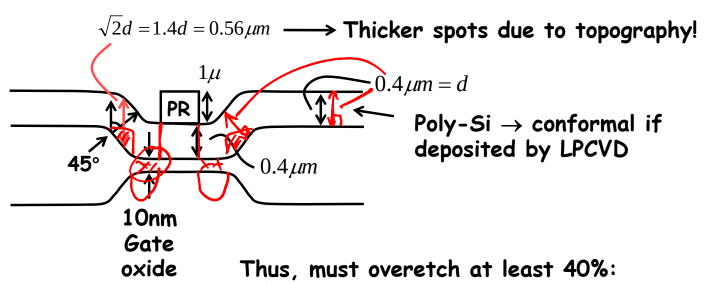
Etching Basics (cont.)

2. Selectivity -



Etching Basics (cont.)

Why overetch?



Thus, must overetch at least 40%:
40% overetch → (0.4)(0.4) = 0.16 μm poly
= ??? oxide

Depends on the selectivity of poly-Si over the oxide

Etching Basics (cont.)

Define selectivity of A over B:

$$S_{ab} = \frac{E.R._a}{E.R._b}$$

$E.R._a$ ← Etch rate of A
$E.R._b$ ← Etch rate of B
S_{ab} ← Selectivity of A over B

e.g., wet poly etch (HNO_3 + NH_4 + H_2O)

$$S_{poly/SiO_2} = \frac{15}{1} \quad \text{(very good selectivity)}$$

$S_{poly/PR}$ = Very high (but PR can still peel off after soaking for > 30 min., so beware)

e.g., polysilicon dry etch:

$$S_{poly/SiO_2} = \frac{5-7}{1}$$

← Regular RIE (but depends on type of etcher)
ECR: 30:1
Bosch: 100:1 (or better)

$$S_{poly/PR} = \frac{4}{1}$$

Etching Basics (cont.)

If $S_{poly/SiO_2} = \frac{8}{1}$ ⟹ 40% overetch removes

$\frac{0.16}{8} = 20 \text{ nm of oxide!}$ ⟹ This will etch all poly over the thin oxide, etch thru the 10nm of oxide, then start etching into the silicon substrate → needless to say, this is bad!

with better selectivity:

e.g., $S_{poly/SiO_2} = \frac{30}{1}$

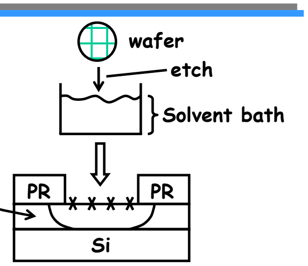
(Can attain with high density Cl plasma ECR etch!)

40% overetch removes $\frac{0.16}{30} = 5.3nm$ (better)

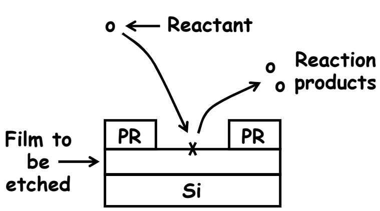
Wet Etching

Wet Etching

- Wet etching: dip wafer into liquid solution to etch the desired film
  - Generally isotropic, thus, inadequate for defining features < 3μm-wide



- General Mechanism -



1. Diffusion of the reactant to the film surface
2. Reaction: adsorption, reaction, desorption
3. Diffusion of reaction products from the surface

Wet Etching (cont.)

- There are many processes by which wet etching can occur
  - Could be as simple as dissolution of the film into the solvent solution
  - Usually, it involves one or more chemical reactions
    - Oxidation-reduction (redox) is very common:
      (a) Form layer of oxide
      (b) Dissolve/react away the oxide

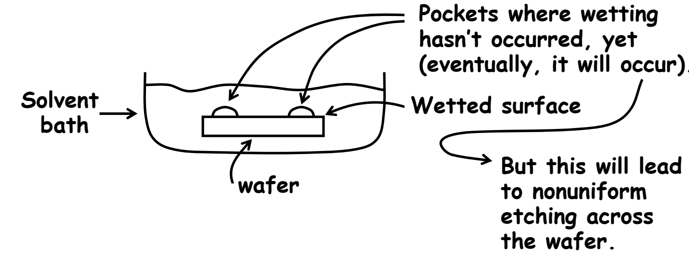
- Advantages:
  1. High throughput process → can etch many wafers in a single bath
  2. Usually fast etch rates (compared to many dry etch processes)
  3. Usually excellent selectivity to the film of interest

Wet Etching Limitations

1. Isotropic
   - Limited to <3μm features
   - But this is also an advantage of wet etching, e.g., if used for undercutting for MEMS
2. Higher cost of etchants & DI water compared w/ dry etch gas expenses (in general, but not true vs. deep etchers)
3. Safety
   - Chemical handling is a hazard
4. Exhaust fumes and potential for explosion
   - Need to perform wet etches under hood
5. Resist adhesion problems
   - Need HMDS (but this isn't so bad)

Wet Etch Limitations (cont.)

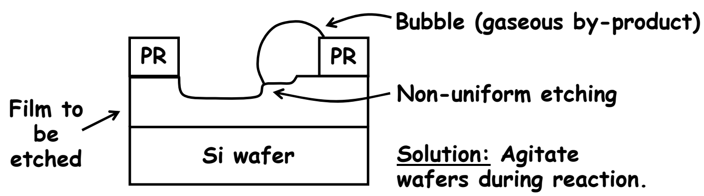
6. Incomplete wetting of the surface:



- For some etches (e.g., oxide etch using HF), the solution is to dip in DI water first, then into HF solution → the DI water wets the surface better

Wet Etch Limitations (cont.)

7. Bubble formation (as a reaction by-product)
   - If bubbles cling to the surface → get nonuniform etching



Solution: Agitate wafers during reaction.

Some Common Wet Etch Chemistries

Wet Etching Silicon:

Common: (isotropic) $Si + HNO_3 + 6HF \longrightarrow H_2SiF_6 + HNO_2 + H_2 + H_2O$

- HNO_3 (nitric acid) → (1) forms a layer of SiO_2
- HF (hydrofluoric acid) → (2) etches away the SiO_2

Different mixture combinations yield different etch rates.