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EE C247B - ME C218 Introduction to MEMS Design Spring 2014

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Lecture Module 4: Lithography, Etching, & Doping

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Lecture Outline

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

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Lithography

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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

II. Mask

Mask (glass/quartz)

Photoresist (~1 μm-thick)

Film to be patterned (e.g., poly-Si)

↳ Generated from layout

III. Photoresist

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

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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

Remove PR

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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:

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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)

we have all of these in our μlab	200	365	405	435	546 nm
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I-line G-line (we have both in our μlab)

For deep UV, need Excimer laser (very expensive)

Glass opaque, so must use quartz mask and lens

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II. Mask

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

Electronic computer representation of layout (e.g., CIF, GDSII) ⇒ A single file contains all layers

tape → mask generator

Masks for each layer

Mask Material:

- Fused silica (glass) → inexpensive, but larger thermal expansion coeff.
- Quartz → expensive, but smaller thermal expansion coeff.

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III. Photoresist (optical)

Pictorial Description:

Negative

Exposed Area: **remains**

Positive

Exposed Area: **removed**

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III. Photoresist (optical)

Mechanism:

Negative

photoactivation

↓

Polymerization
(long, linked Carbon chains)

↓

Developer solvent
removes
unexposed PR

Positive

photoactivation

↓

Converts exposed PR
to organic acid

↓

Alkaline developer
(e.g., KOH) removes
acid

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III. Photoresist (optical)

Issues:

Negative

Polymerized PR swells in solvent → bridging problem

Exposed and polymerized

Positive

Doesn't adhere well to SiO₂
Need primer: HMDS (hexamethyl disilazane)

Poor adhesion

Good adhesion at both HMDS interfaces

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Typical Procedure for Lithography

- Clean Wafer
- Dry Wafer
- Deposit HMDS
- Spin-on PR
- Soft Bake
- Align & Expose
- Develop
- Descum
- Post Bake

Very important step

30 min. @ 120°C pre-bake
(for oxide on wafer surface)

30-60 sec @ 1000-5000 rpm

2 min @ 90°C
Improve adhesion and remove solvent from PR

Oxygen plasma (low power ~ 50W)

Topography very important:

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

Proximity Printing

- Mask in very close proximity but not touching

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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:

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Etching

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Etching Basics

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

1. Anisotropy -

a) Isotropic Etching (most wet etches)

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

Define: $B = d_f - d$

If $B = 2h \Rightarrow$ isotropic

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Etching Basics (cont.)

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

Degree of Anisotropy: (definition)

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

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

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Etching Basics (cont.)

2. Selectivity -

Only poly-Si etched (no etching of PR or SiO₂)
↓
Perfect selectivity

PR partially etched
SiO₂ partially etched after some overetch of the polysilicon

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Etching Basics (cont.)

Why overetch?

$\sqrt{2}d = 1.4d = 0.56\mu\text{m} \rightarrow$ Thicker spots due to topography!

10nm Gate oxide

Thus, must overetch at least 40%:
40% overetch $\rightarrow (0.4)(0.4) = 0.16 \mu\text{m}$ poly = ??? oxide

Depends on the selectivity of poly-Si over the oxide

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Etching Basics (cont.)

Define selectivity of A over B:

$$S_{ab} = \frac{E.R._a}{E.R._b} \quad \leftarrow \begin{array}{l} \text{Etch rate of A} \\ \text{Etch rate of B} \end{array}$$

Selectivity of A over B

e.g., wet poly etch (HNO3 + NH4 + H2O)

$$S_{\text{poly}/\text{SiO}_2} = \frac{15}{1} \quad (\text{very good selectivity})$$

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

e.g., polysilicon dry etch:

Regular RIE

$$S_{\text{poly}/\text{SiO}_2} = \frac{5-7}{1} \quad (\text{but depends on type of etcher})$$

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

ECR: 30:1
Bosch: 100:1 (or better)

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Etching Basics (cont.)

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

$$\frac{0.16}{8} = 20 \text{ nm of oxide!} \Rightarrow$$

This will etch all poly over the thin oxide, etch thru the 10nm of oxide, then start etching into the silicon substrate \rightarrow 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 $\frac{0.16}{30} = 5.3 \text{ nm}$ (better)

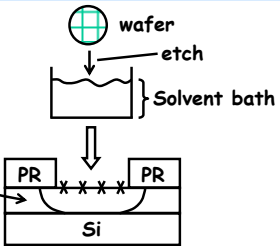
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Wet Etching

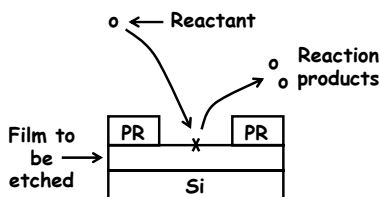
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Wet Etching

- Wet etching: dip wafer into liquid solution to etch the desired film
 - Generally isotropic, thus, inadequate for defining features $< 3\mu\text{m}$ -wide



- General Mechanism -
 - Diffusion of the reactant to the film surface
 - Reaction: adsorption, reaction, desorption
 - Diffusion of reaction products from the surface




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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:
 - Form layer of oxide
 - Dissolve/react away the oxide
- Advantages:
 - High throughput process \rightarrow can etch many wafers in a single bath
 - Usually fast etch rates (compared to many dry etch processes)
 - Usually excellent selectivity to the film of interest

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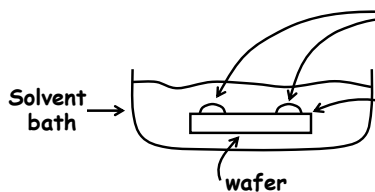
 **Wet Etching Limitations**

1. Isotropic
 - ↳ Limited to $>3\mu\text{m}$ 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)

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 **Wet Etch Limitations (cont.)**

6. Incomplete wetting of the surface:



Pockets where wetting hasn't occurred, yet (eventually, it will occur).

But this will lead to nonuniform etching across the wafer.

↳ 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

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