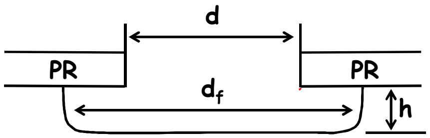
Etching

Etching Basics

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

1. Anisotropy –
   a) Isotopic Etching (most wet etches)



If 100% isotropic: $d_f = d + 2h$
Define: $B = d_f - d$
If $B = 2h$ ⇨ isotropic

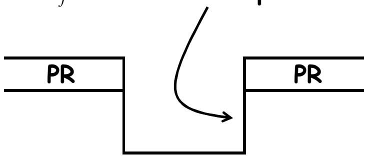
Etching Basics (cont.)

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

Degree of Anisotropy: (definition)

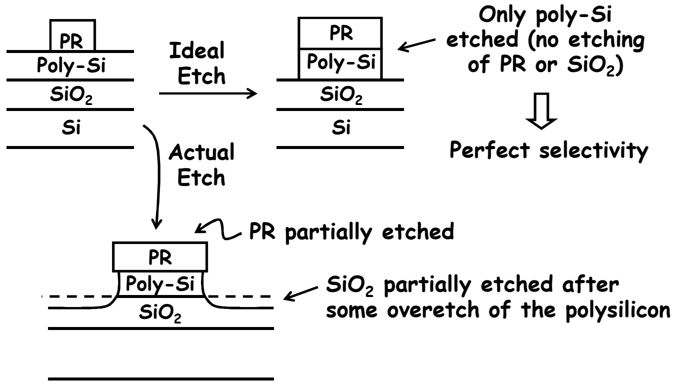
$$A_f = 1 - \frac{B}{2h} = 0 \quad \text{if 100\% isotropic}$$

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



Etching Basics (cont.)

2. Selectivity –



Only poly-Si etched (no etching of PR or SiO_2)
⇩
Perfect selectivity

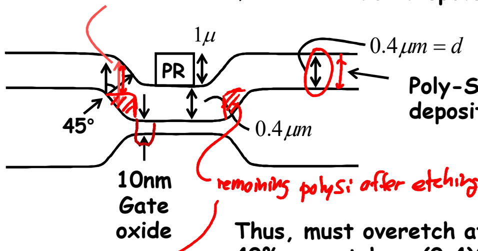
PR partially etched

SiO_2 partially etched after some overetch of the polysilicon

Etching Basics (cont.)

Why overetch?

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



Poly-Si → conformal if deposited by LPCVD

remaining polySi after etching 0.4μm → stringer

get rid of the stringer by overetching

This is caused by topography!

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)

$S_{poly/SiO_2} = \frac{15}{1}$ (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)

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

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

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!)

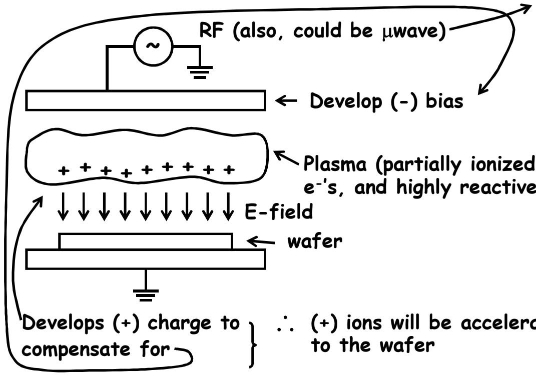
40% overetch removes $\frac{0.16}{30} = 5.3nm$ (better)

Dry Etching

Dry Etching

- Physical sputtering
- Plasma etching
- Reactive ion etching

All based upon plasma processes.



RF (also, could be µwave)

(+) ions generated by inelastic collisions with energetic e^{-1}'s
Get avalanche effect because more e^{-1}'s come out as each ion is generated.

Develop (-) bias

Plasma (partially ionized gas composed of ions, e^{-}'s, and highly reactive neutral species)

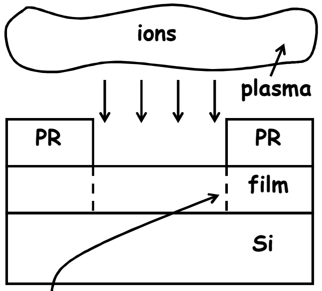
E-field

wafer

Develops (+) charge to compensate for } ∴ (+) ions will be accelerated to the wafer

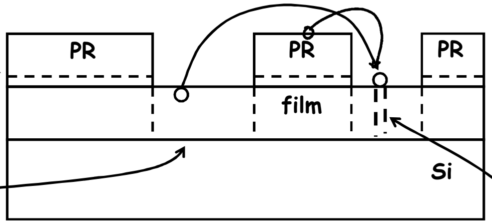
Physical Sputtering (Ion Milling)

- Bombard substrate w/ energetic ions → etching via physical momentum transfer
- Give ions energy and directionality using E-fields
- Highly directional → very anisotropic



Steep vertical wall

Problems With Ion Milling



PR etched down to here

Once through the film, the etch will start barreling through the Si

1. PR or other masking material etched at almost the same rate as the film to be etched → very poor selectivity!
2. Ejected species not inherently volatile → get redeposition → non-uniform etch → grass!

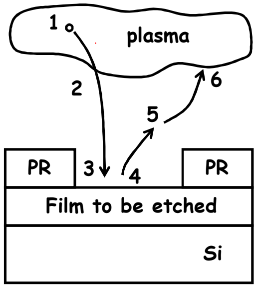
- Because of these problems, ion milling is not used often (very rare)

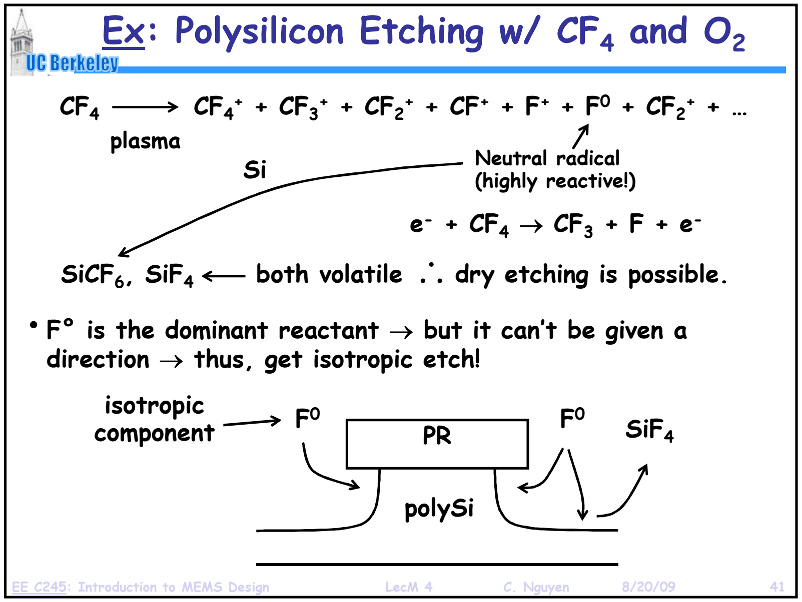
Plasma Etching

- Plasma (gas glow discharge) creates reactive species that chemically react w/ the film in question
- **Result**: much better selectivity, but get an isotropic etch

Plasma Etching Mechanism:

1. Reactive species generated in a plasma.
2. Reactive species diffuse to the surface of material to be etched.
3. Species adsorbed on the surface.
4. Chemical reaction.
5. By-product desorbed from surface. ← MOST IMPORTANT STEP! (determines whether plasma etching is possible or not.)
6. Desorbed species diffuse into the bulk of the gas





Ex: Polysilicon Etching w/ CF_4 and O_2

$CF_4 \xrightarrow[\text{plasma}]{} CF_4^+ + CF_3^+ + CF_2^+ + CF^+ + F^+ + F^0 + CF_2^+ + \ldots$

Neutral radical (highly reactive!)

Si

$e^- + CF_4 \rightarrow CF_3 + F + e^-$

$SiCF_6$, $SiF_4 \leftarrow$ both volatile ∴ dry etching is possible.

- F° is the dominant reactant → but it can't be given a direction → thus, get isotropic etch!

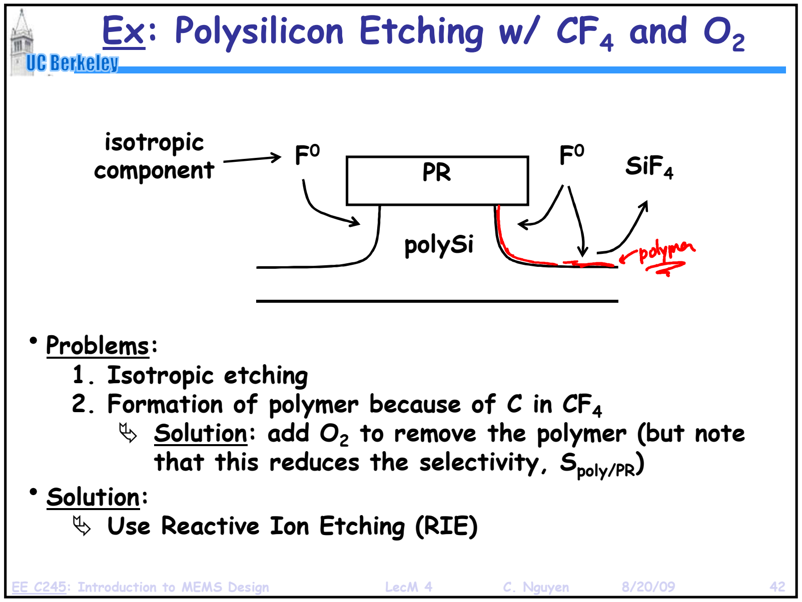
isotropic component → F^0

PR

F^0

SiF_4

polySi



Ex: Polysilicon Etching w/ CF_4 and O_2

isotropic component → F^0

PR

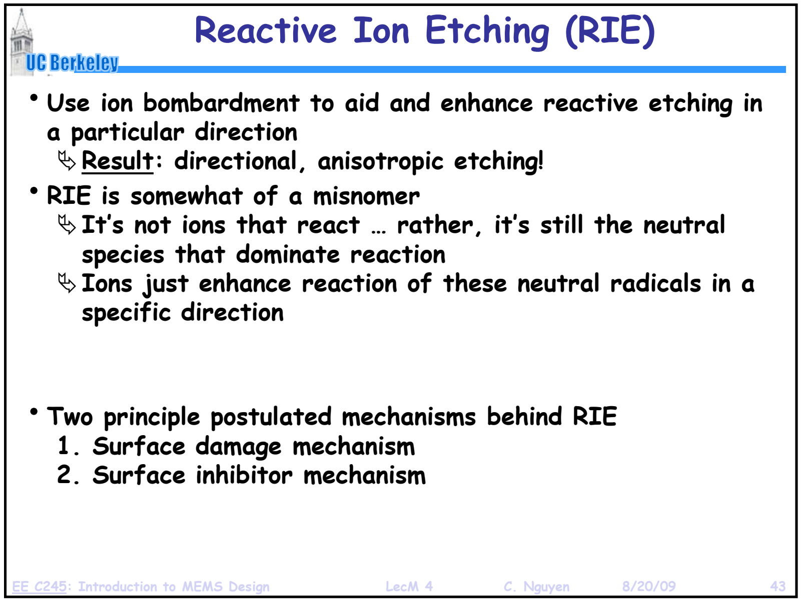
F^0

SiF_4

polySi

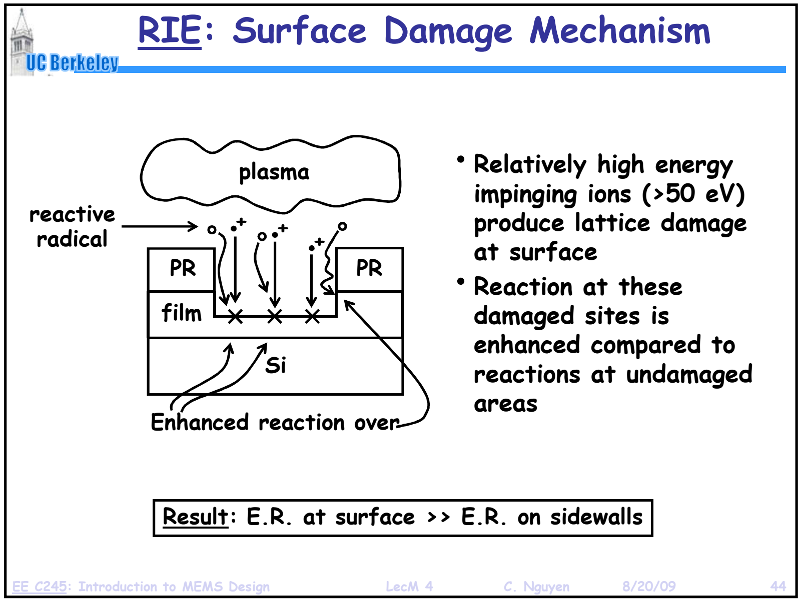
polymer

- **Problems**:
  1. Isotropic etching
  2. Formation of polymer because of C in CF_4
     - **Solution**: add O_2 to remove the polymer (but note that this reduces the selectivity, $S_{poly/PR}$)
- **Solution**:
  - Use Reactive Ion Etching (RIE)



Reactive Ion Etching (RIE)

- Use ion bombardment to aid and enhance reactive etching in a particular direction
  - **Result**: directional, anisotropic etching!
- RIE is somewhat of a misnomer
  - It's not ions that react … rather, it's still the neutral species that dominate reaction
  - Ions just enhance reaction of these neutral radicals in a specific direction
- Two principle postulated mechanisms behind RIE
  1. Surface damage mechanism
  2. Surface inhibitor mechanism



RIE: Surface Damage Mechanism

plasma

reactive radical

PR

PR

film

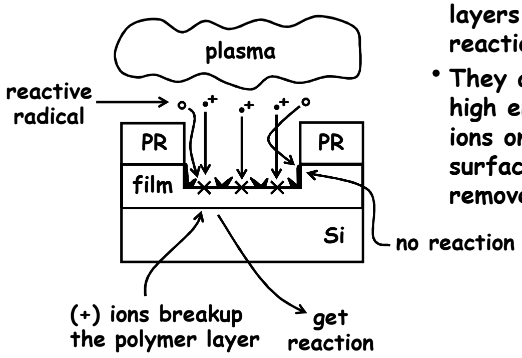
Si

Enhanced reaction over

- Relatively high energy impinging ions (>50 eV) produce lattice damage at surface
- Reaction at these damaged sites is enhanced compared to reactions at undamaged areas

Result: E.R. at surface >> E.R. on sidewalls

RIE: Surface Inhibitor Mechanism



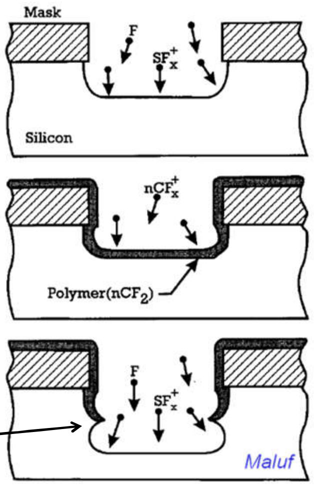
- Non-volatile polymer layers are a product of reaction
- They are removed by high energy directional ions on the horizontal surface, but not removed from sidewalls

Result: E.R. @ surface >> E.R. on sidewalls

Deep Reactive-Ion Etching (DRIE)

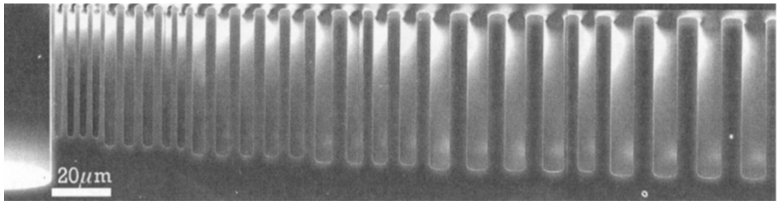
The Bosch process:

- Inductively-coupled plasma
- Etch Rate: 1.5-4 μm/min
- Two main cycles in the etch:
  - Etch cycle (5-15 s): SF_6 (SF_x^+) etches Si
  - Deposition cycle: (5-15 s): C_4F_8 deposits fluorocarbon protective polymer $(CF_2^-)_n$
- Etch mask selectivity:
  - SiO_2 ~ 200:1
  - Photoresist ~ 100:1
- Issue: finite sidewall roughness
  - scalloping < 50 nm
- Sidewall angle: 90° ± 2°

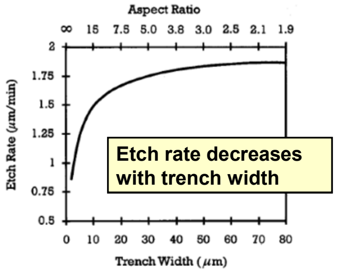


Maluf

DRIE Issues: Etch Rate Variance



- Etch rate is diffusion-limited and drops for narrow trenches
  - Adjust mask layout to eliminate large disparities
  - Adjust process parameters (slow down the etch rate to that governed by the slowest feature)



Etch rate decreases with trench width