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Etching

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Etching Basics

- Removal of material over designated areas of the wafer
- Two important metrics:
 - Anisotropy
 - 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?

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

$0.4\mu m = d$

10nm Gate oxide

45°

PR

Poly-Si \rightarrow conformal if deposited by LPCVD

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

Depends on the selectivity of poly-Si over the oxide

Handwritten notes:
- Thicker spots due to topography!
- Poly-Si \rightarrow conformal if deposited by LPCVD
- Thus, must overetch at least 40%:
- 40% overetch $\rightarrow (0.4)(0.4) = 0.16\mu m$ poly = ??? oxide
- Depends on the selectivity of poly-Si over the oxide
- This is a problem caused by topography!
- need to overetch to remove!
- stringer \rightarrow remaining after etching just this

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Etching Basics (cont.)

Define selectivity of A over B:

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

\leftarrow Etch rate of A
 \leftarrow Etch rate of B

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:

Regular RIE

$$S_{poly/SiO_2} = \frac{5-7}{1} \quad (\text{but depends on type of etcher})$$

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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Etching Basics (cont.)

Dry Etching

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Dry Etching

- Physical sputtering
- Plasma etching
- Reactive ion etching

All based upon plasma processes.

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

RF (also, could be μ wave)

Develop (-) bias

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

E-field

wafer

Develops (+) charge to compensate for \therefore (+) ions will be accelerated to the wafer

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Physical Sputtering (Ion Milling)

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

ions

plasma

PR

film

Si

Steep vertical wall

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Problems With Ion Milling

PR etched down to here

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

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

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

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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:

- Reactive species generated in a plasma.
- Reactive species diffuse to the surface of material to be etched.
- Species adsorbed on the surface.
- Chemical reaction.
- By-product desorbed from surface.
- Desorbed species diffuse into the bulk of the gas

1 plasma

2

3

4

5

6

PR

Film to be etched

Si

MOST IMPORTANT STEP! (determines whether plasma etching is possible or not.)

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Ex: Polysilicon Etching w/ CF_4 and O_2

$CF_4 \xrightarrow{\text{plasma}} CF_4^+ + CF_3^+ + CF_2^+ + CF^+ + F^+ + F^0 + CF_2^+ + \dots$

Si

Neutral radical (highly reactive!)

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

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

F^0 is the dominant reactant \rightarrow but it can't be given a direction \rightarrow thus, get isotropic etch!

isotropic component $\rightarrow F^0$

PR

polySi

SiF_4

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Ex: Polysilicon Etching w/ CF_4 and O_2

isotropic component $\rightarrow F^0$

PR

polySi

SiF_4

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

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Reactive Ion Etching (RIE)

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

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RIE: Surface Damage Mechanism

plasma

reactive radical $\rightarrow F^0$

PR

film

Si

Enhanced reaction over

Result: E.R. at surface \gg E.R. on sidewalls

- 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

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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

(+) ions breakup the polymer layer
get reaction

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

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Deep Reactive-Ion Etching (DRIE)

The Bosch process:

- Inductively-coupled plasma
- Etch Rate: 1.5-4 $\mu\text{m}/\text{min}$
- 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 $(\text{CF}_2)_n$
- Etch mask selectivity:
 - $\text{SiO}_2 \sim 200:1$
 - Photoresist $\sim 100:1$
- Issue:** finite sidewall roughness
 - scallop < 50 nm
- Sidewall angle: $90^\circ \pm 2^\circ$

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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

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