Etching Basics

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

   ![](image1)

   If 100% isotropic: \( d_f = d + 2h \)

   Define: \( B = d_f - d \)

   If \( B = 2h \) \( \Rightarrow \) isotropic

   Degree of Anisotropy: (definition)
   \[
   A_f = 1 - \frac{B}{2h} = 0 \quad \text{if 100\% isotropic}
   \]

   \( 0 < A_f \leq 1 \) \( \iff \) anisotropic

2. Selectivity -

   ![](image2)

   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?**

\[ \sqrt{d} = 1.4a = 0.56\mu m \rightarrow \text{Thicker spots due to topography!} \]

Poly-Si → conformal if deposited by LPCVD

removing poly: after etching 0.4μm = stringy

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

Depends on the selectivity of poly-Si over the oxide

This is caused by topography!

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**Etching Basics (cont.)**

**Define selectivity of A over B:**

\[ S_{poly/PR} = \frac{E.R._{poly}}{E.R._{PR}} \]

Selectivity of A over B

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

\[ S_{poly/PR} = \text{Regular RIE} \]

\[ S_{poly/PR} = \text{ECR: 30:1} \]

\[ S_{poly/PR} = \text{Bosch: 100:1 (or better)} \]

**Dry Etching**

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If \[ S_{poly/SiO_2} = \frac{8}{1} \rightarrow \text{40% overetch removes} \]

\[ 0.16 \times \frac{1}{8} = 20\text{nm of oxide!} \]

with better selectivity:

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

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

40% overetch removes \[ 0.16 \times \frac{1}{30} = 5.3\text{nm} \] (better)
Dry Etching

- Physical sputtering
- Plasma etching
- Reactive ion etching

\[ (+) \text{ ions generated by inelastic collisions with energetic e}^{-}\text{'s}
\]

Get avalanche effect because more e\text{-'s} come out as each ion is generated.

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

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

Problems With Ion Milling

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)
Ex: Polysilicon Etching w/ CF$_4$ and O$_2$

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

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

- Solutions:
  - Use Reactive Ion Etching (RIE)

RIE: Surface Damage Mechanism

- 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.

\[
\text{PR} \rightarrow \text{PR} \rightarrow \text{Si} \\
\text{plasma} \rightarrow \text{reactive radical} \
\text{(+)} \text{ ions breakup the polymer layer} \rightarrow \text{get reaction} \\
\text{no reaction}
\]

**Result:**

\[
\text{E.R. @ surface >> E.R. on sidewalls}
\]

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**Deep Reactive-Ion Etching (DRIE)**

**The Bosch process:**

- Inductively-coupled plasma
- Etch Rate: 1.5-4 μm/min
- Two main cycles in the etch:
  - Etch cycle (5-15 s): \( \text{SF}_6 (\text{SF}_x^+) \) etches Si
  - Deposition cycle: (5-15 s): \( \text{C}_4\text{F}_8 \) deposits fluorocarbon protective polymer (\( \text{CF}_2 \)) \(_n\)

**Etch mask selectivity:**

- \( \text{SiO}_2 \approx 200:1 \)
- Photoresist \( \approx 100:1 \)

**Issue:** finite sidewall roughness

- Scallopng < 50 nm
- Sidewall angle: \( 90^\circ \pm 2^\circ \)

**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).

\[
\text{Etch rate decreases with trench width}
\]