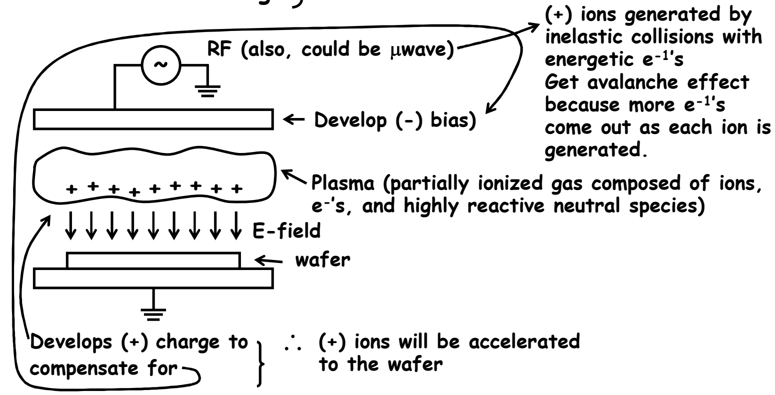
Dry Etching

Dry Etching

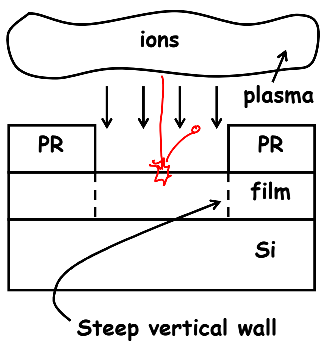
- Physical sputtering
- Plasma etching
- Reactive ion etching

All based upon plasma processes.

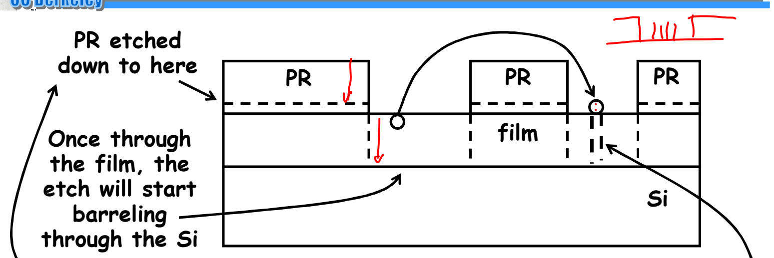


Physical Sputtering (Ion Milling)

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



Problems With Ion Milling

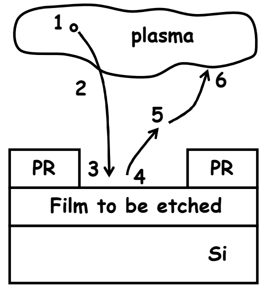


1. PR or other masking material etched at almost the same rate as the film to be etched → very poor selectivity!
2. Ejected species not inherently volatile → get redeposition → non-uniform etch → grass!

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

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

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

Neutral radical (highly reactive!)

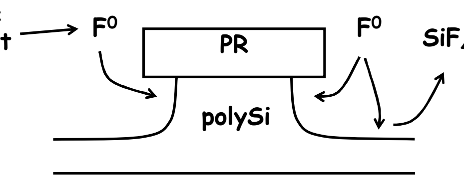
Si

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

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

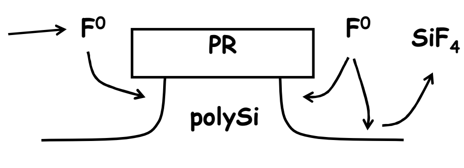
- F° is the dominant reactant → but it can't be given a direction → thus, get isotropic etch!

isotropic component →



Ex: Polysilicon Etching w/ CF_4 and O_2

isotropic component →



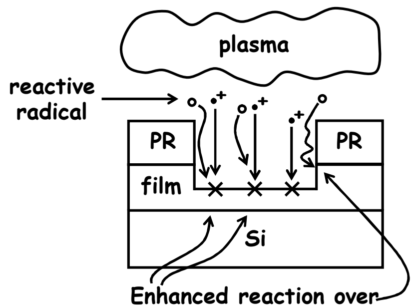
- Problems:
  1. Isotropic etching
  2. Formation of polymer because of C in CF_4
     - Solution: add O_2 to remove the polymer (but note that this reduces the selectivity, $S_{poly/PR}$)
- Solution:
  - Use Reactive Ion Etching (RIE)

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

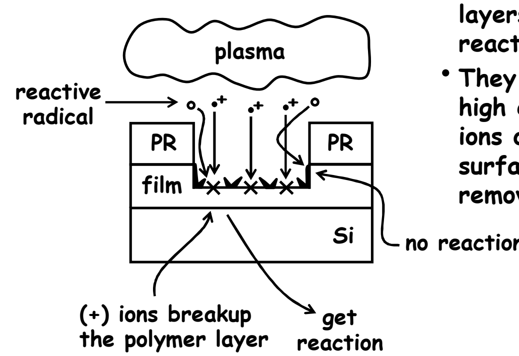
RIE: Surface Damage Mechanism



- 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



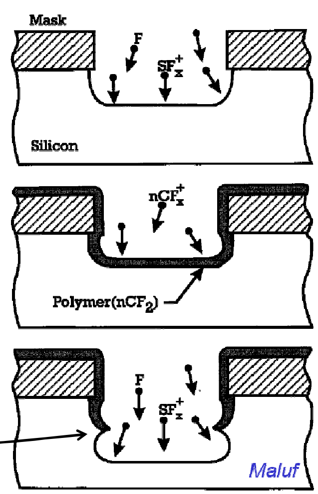
- Non-volatile polymer layers are a product of reaction
- They are removed by high energy directional ions on the horizontal surface, but not removed from sidewalls

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

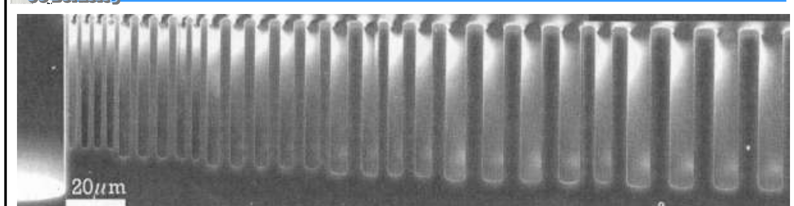
Deep Reactive-Ion Etching (DRIE)

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°



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)