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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

PR

film

Si

Steep vertical wall

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Problems With Ion Milling

PR etched down to here

PR

PR

PR

film

Si

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

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- 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

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

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Ex: Polysilicon Etching w/ CF₄ and O₂

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

Si Neutral radical (highly reactive!)
~~+~~ $e^- + CF_4 \rightarrow CF_3 + F + e^-$

SiCF₆, SiF₄ ← both volatile ∴ dry etching is possible.

- F⁰ is the dominant reactant → but it can't be given a direction → thus, get isotropic etch!

isotropic component → F⁰ PR F⁰ SiF₄
 polySi

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Ex: Polysilicon Etching w/ CF₄ and O₂

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isotropic component → F⁰ PR F⁰ SiF₄
 polySi

- Problems:**
 - Isotropic etching
 - Formation of polymer because of C in CF₄
 - ↪ **Solution:** add O₂ to remove the polymer (but note that this reduces the selectivity, S_{poly/PR})
- Solution:**
 - ↪ Use Reactive Ion Etching (RIE)

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Reactive Ion Etching (RIE)

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- 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
 - Surface damage mechanism
 - Surface inhibitor mechanism

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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

Enhanced reaction over

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

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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

no reaction

(+) 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 (CF_2^-)_n
- Etch mask selectivity:
 - $\text{SiO}_2 \sim 200:1$
 - Photoresist $\sim 100:1$
- Issue:** finite sidewall roughness
 - scalloping < 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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