# All Lectures

**Book references cited :**

**S.M. Sze: Semiconductor Devices 1985**

**S.M. Sze ed: VLSI Technology 1988**

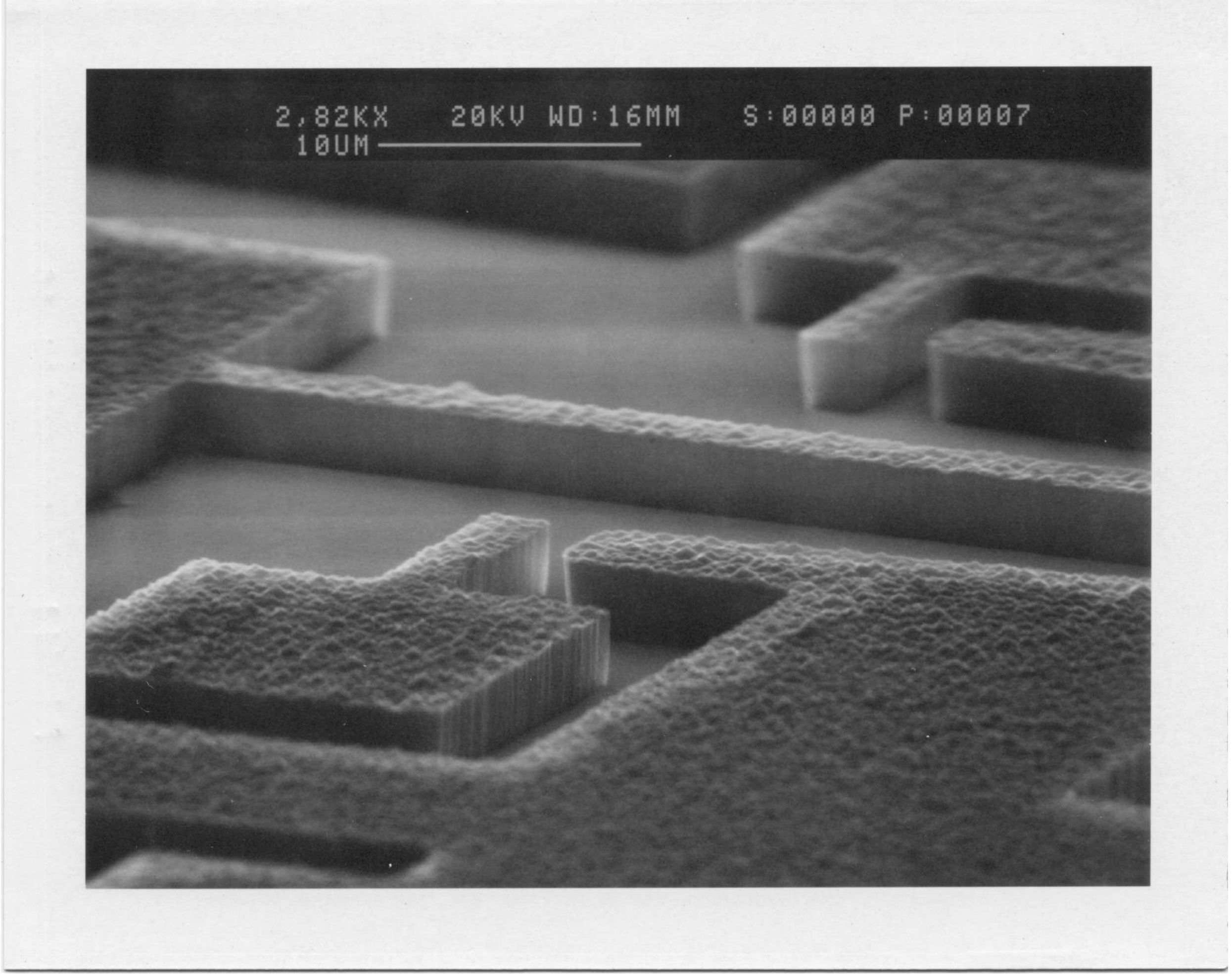
**Chang and S.M. Sze: ULSI Technology 1996**

**S. Wolf and R.N. Tauber: Silicon Processing for VLSI vol. 1 1986**

**Plummer, Deal, Griffin, Silicon VLSI Technology 2000**

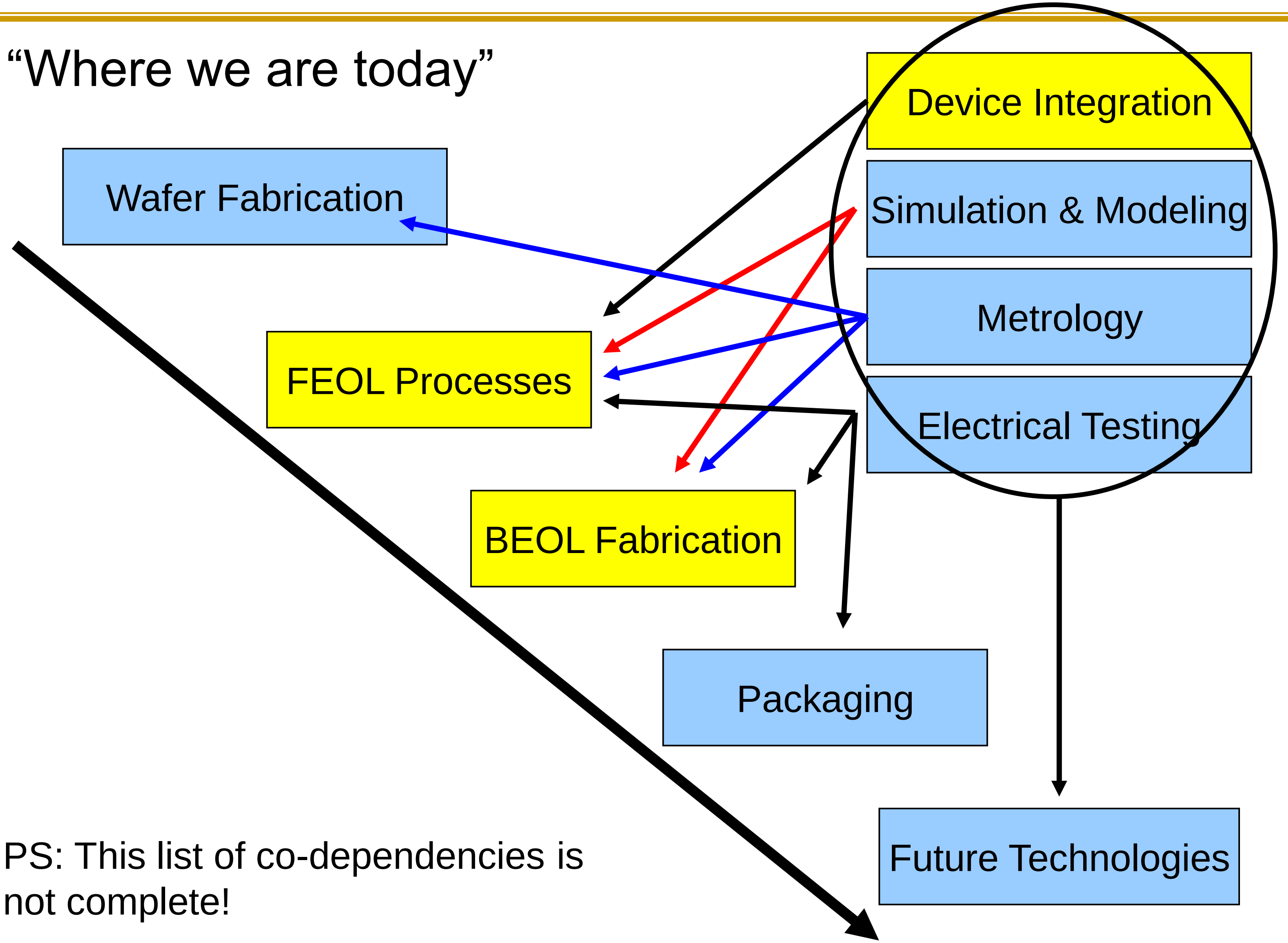
# Lecture 8

## Etching



# Lecture 7 Etching

"Where we are today"



Device Integration

Simulation & Modeling

Metrology

Electrical Testing

Wafer Fabrication

FEOL Processes

BEOL Fabrication

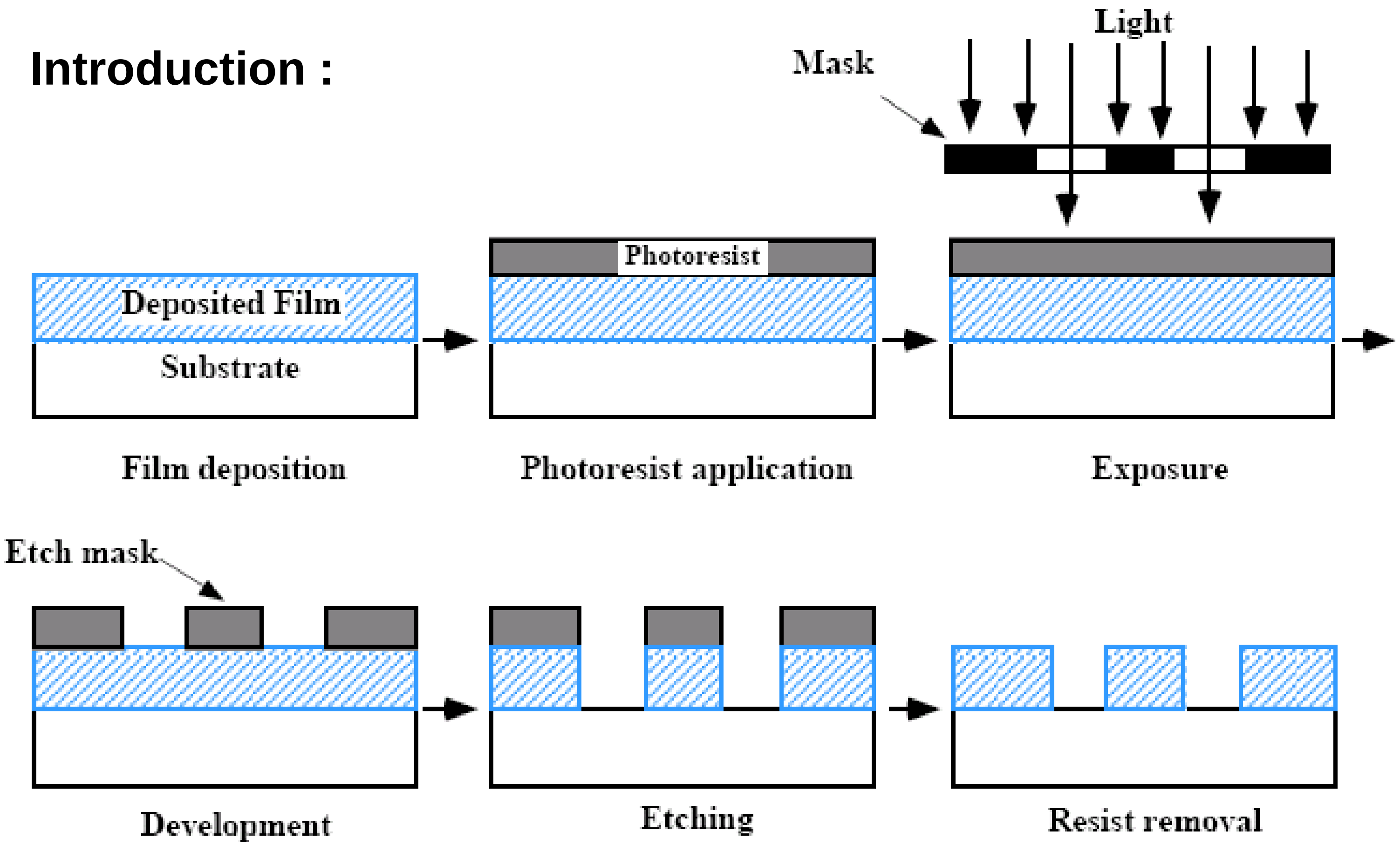
Packaging

Future Technologies

PS: This list of co-dependencies is not complete!

# Etching: Basic Terminology

**Introduction :**



- Etching of thin films and sometimes the silicon substrate are very common process steps.
- Usually selectivity, and directionality are the first order issues.

# Etching - Overview

- Basic Terminology
- Wet Etching
- Dry / Plasma Etching
  - Mechanisms
  - Example
  - Reactor Designs
- Summary and Appendix

# Etching: Basic Terminology

1. ***Etch rate***
2. ***Selectivity***
3. ***Anisotropy***
4. ***Uniformity / Homogeneity***

# Etching: Basic Terminology

## *Etch rate: r*

- Speed at which ethcing occurs
- Typical unit: r [nm/min]

## *Selectivity : S*

- Ratio of two etch rates

$$S = \frac{r_1}{r_2}$$

Example 1:

$SiO_2$ etching with hydrofluoric acid (HF): $SiO_2 + 6\,HF \rightarrow H_2SiF_6 + 2\,H_2O$

A. Determine the etch time for a 1,2 µm thick $SiO_2$ film
with $r_{SiO2} = 400$ nm/min → 3 min.

B. How thick should the resist mask be if the selectivity is $S_{SiO2/resist} = 4$?

➡ **Etch rate and selectivity are crucial for defining masks!**
**(Photo- or “Hard”masks)**

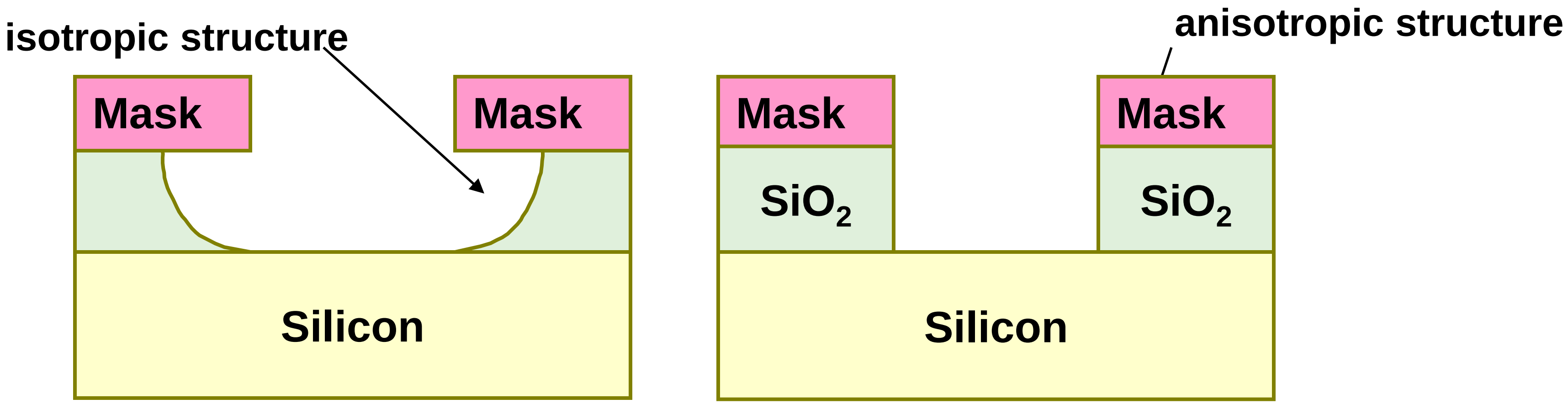
BOE : buffered oxide etching
BHF: buffered HF

→ $NH_4F$ buffer: Help to prevent depletion of F- → decrease etch rate of photoresist

# Etching: Basic Terminology

## *Anisotropy A*

- ***Isotropic*** etching removes material equally in all directions
  → Undercut of the mask



- ***Anisotropic*** etching removes material only perpendicular to the surface
  → accurate transfer of the mask pattern

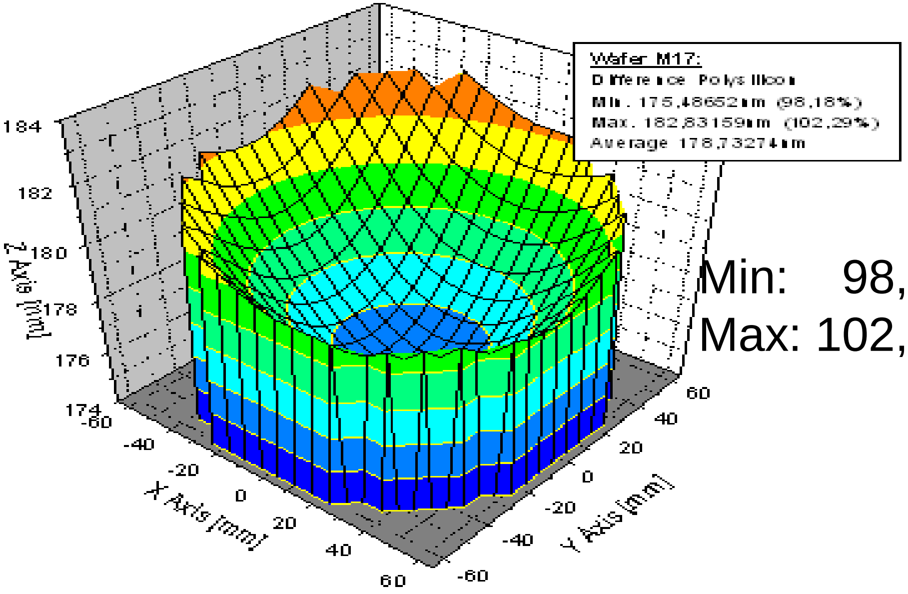
$$\text{Anisotropy}: \frac{\text{vertical etch rate - horizontal etch rate}}{\text{vertical etch rate}} \qquad A = 1 - \frac{r_{hor}}{r_{vert}}$$

# Etching: Basic Terminology
## *Uniformity / Homogeneity*

- Measures the distribution of the etch rate
  - Wafer to wafer, esp. for multi-wafer processing
  - Across one wafer (e.g. center vs. edge)
- Has to be considered when determining etching time (e.g. overetching)
- Production: Matching production tools (esp. litho and etching)

$$U = \frac{R_{high} - R_{low}}{R_{high} + R_{low}}$$

$R_{high}$: Max etch rate
$R_{low}$: Min etch rate



Min: 98,18%
Max: 102,29%

# Etching Performance Parameters

| | |
|---|---|
| **Etch Rate *R*** | **The film thickness being etched per unit time. *R* has significant effects on throughput.** |
| **Etch Uniformity** | **Variation of etch rate throughout one wafer, multiple wafers or multiple batches of wafers** |
| **Selectivity *S*** | **The ratio of the etch rates between two different materials** |
| **Anisotropy *A*** | **Etching directionality**<br>***A*=0, isotropic; *A*=1, anisotropic** |
| **Undercut** | **Unilateral overetching** |

# Etching - Overview

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## Example 1: Etch $SiO_2$ using HF

$$SiO_2 + 6HF \rightarrow H_2SiF_6 + 2H_2O$$

In practice,
BOE：buffered oxide etching → $NH_4F$ buffer: Help to prevent depletion of $F^-$ and decrease etch rate of photoresist
or BHF: buffered HF

## Example 2: Ecth Si using $HNO_3$ and HF (HNA)

$$Si + HNO_3 + 6HF \rightarrow H_2SiF_6 + HNO_2 + H_2O + H_2$$

**Isotropic**

## Example 3: Ecth $Si_3N_4$ using hot phosphoric acid

$$Si_3N_4 + H_3PO_4 + H_2O \rightarrow NO\uparrow + NO_3^- + H_2PO_4^- + H_2SiO_3$$

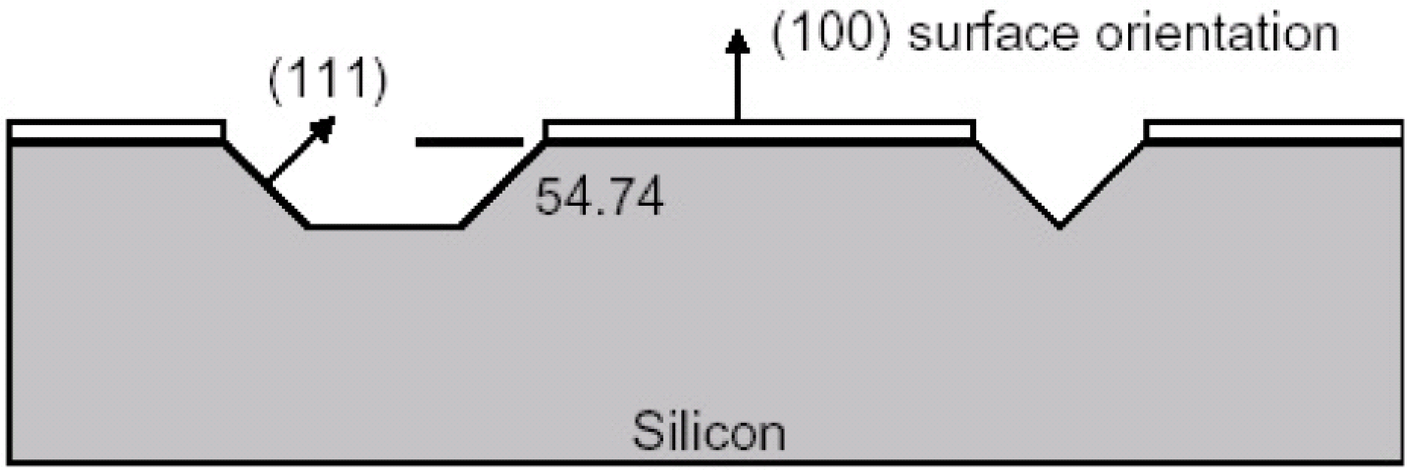
# Wet Etching: Examples

Example 4: Etch Si using KOH

**Anisotropic**

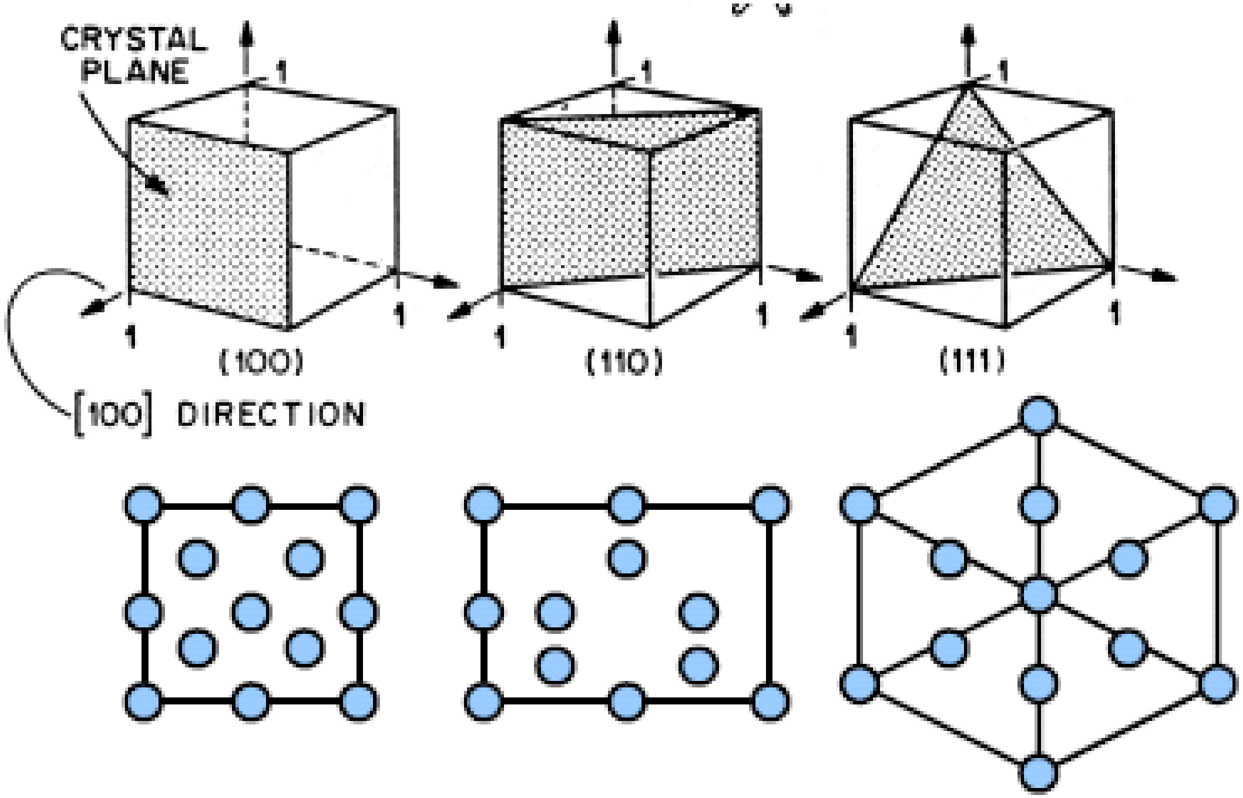
$$\mathrm{Si + 2OH^- + 4H_2O \Rightarrow Si(OH)_2^{++} + 2H_2 + 4OH^-}$$

**Anisotropic wet etching results from surface orientation**



# Wet Etching: Examples

Example 3: Etch Si using KOH

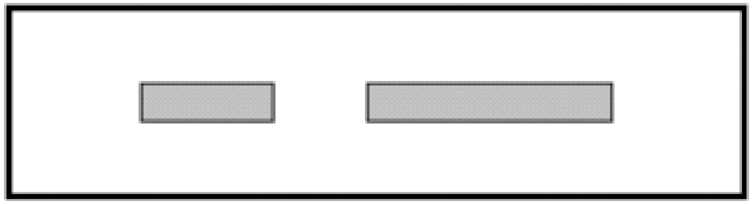


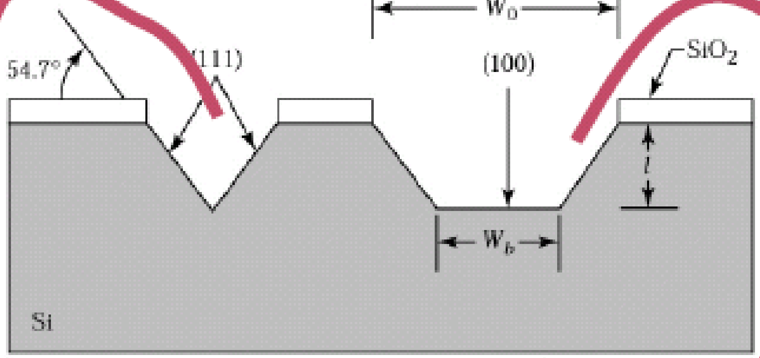
**Atomic density: <111> > <110> > <100>**

**Etch rate:** $R_{(100)} \cong 100\ R_{(111)}$

# Wet Etching: Examples

Example 3: Etch Si using KOH



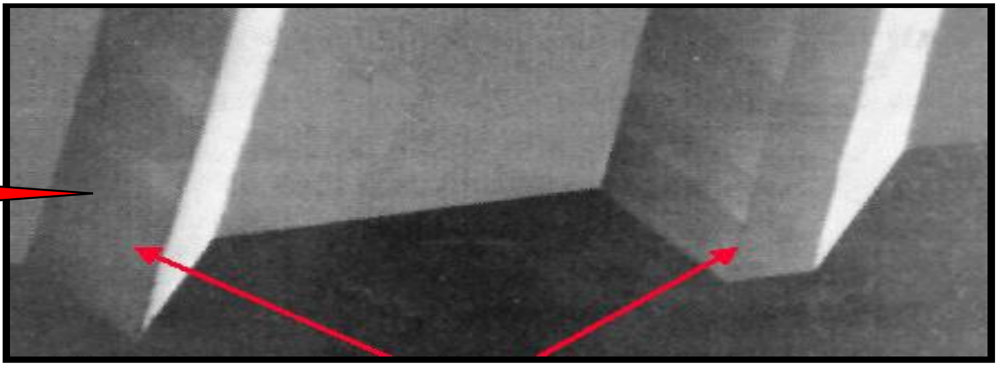


(a)

$$W_b = W_0 - 2 \cdot l \cdot \cot 54.7^0$$

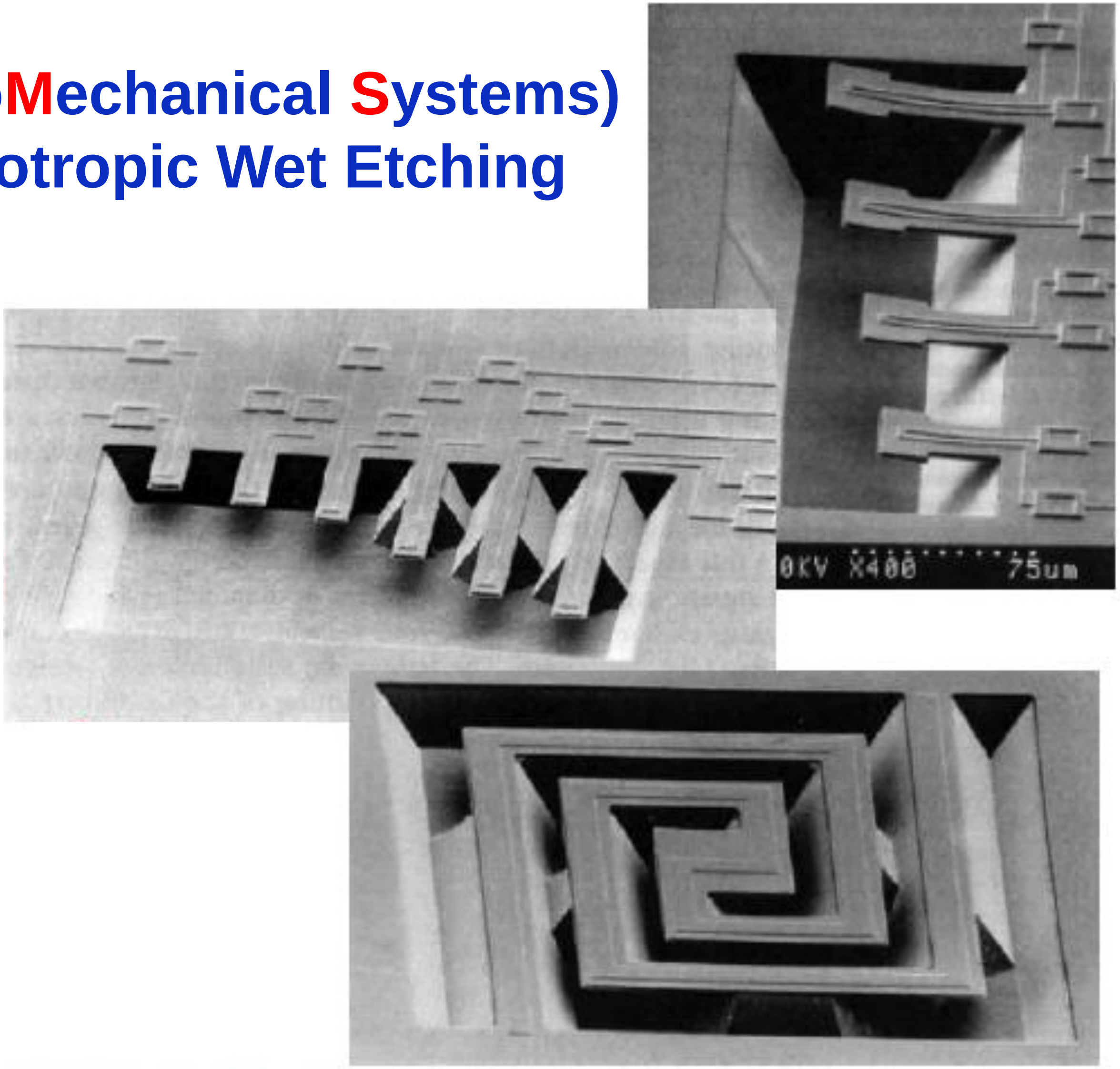
$$W_b = W_0 - \sqrt{2} \cdot l$$

**Self-Limited**



# Wet Etching: Applications

## MEMS (MicroElectroMechanical Systems) Made from Si Anisotropic Wet Etching



# Wet Etching: Drawbacks

In the manufacture of large-scale electronic ICs, wet etching is being replaced by dry etching.

(1) Wet etching is mostly isotropic.

(2) Wet etching has poor resolution.

(3) Wet etching depends on a lot of corrosive chemicals, which are harmful to human bodies and environments.

(4) Wet etching needs a large number of chemical reagents to wash away the residues. Non-economical!!

# Etching - Overview

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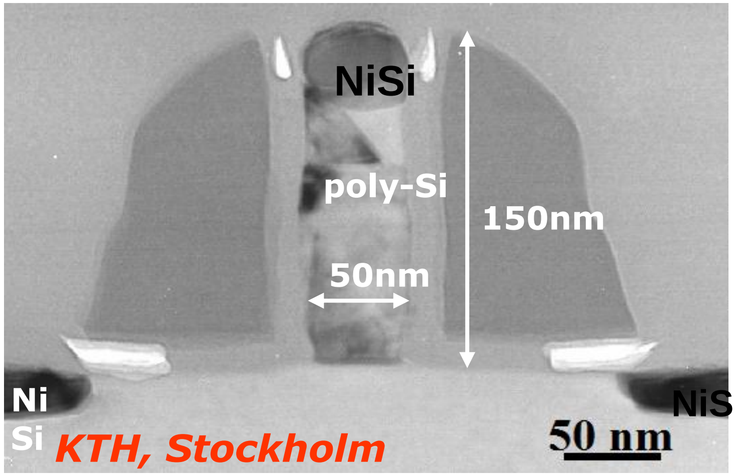
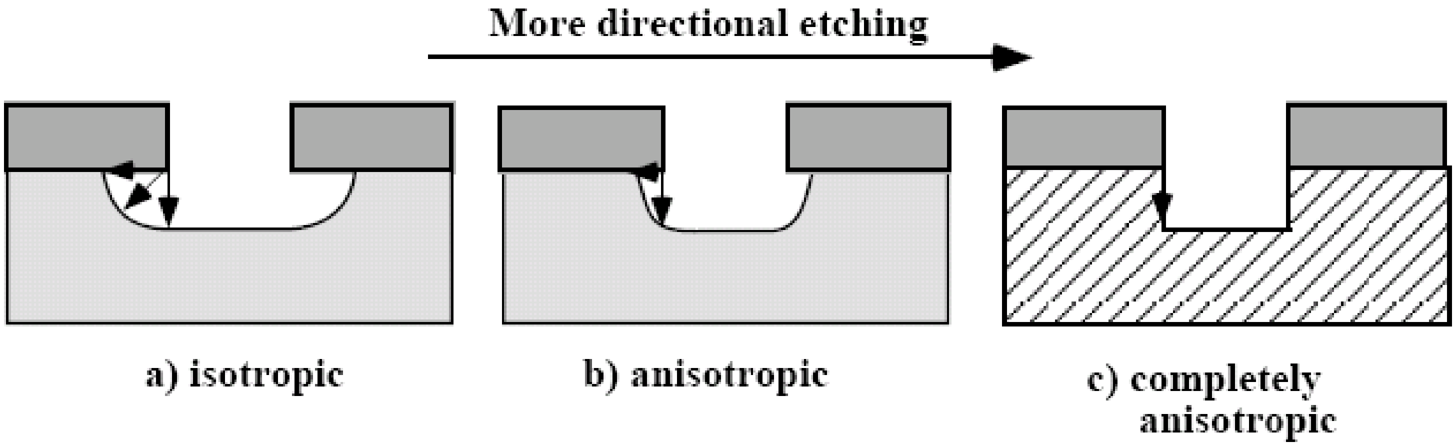
# Etching: Requirements at the Nanoscale

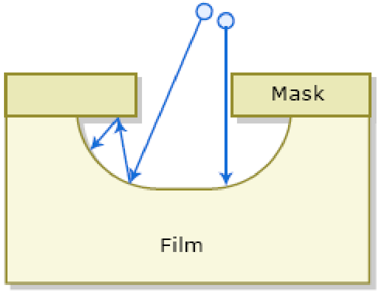
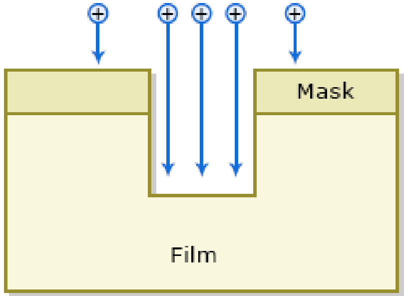


## Etch Requirements at the Nanoscale:

1. ***Obtain desired profile*** (sloped or vertical)
2. ***Minimal undercutting*** or bias
3. ***Selectivity*** to other exposed films and resist
4. Uniform and reproducible
5. Minimal damage to surface and circuit
6. Clean, economical, and safe



# Etching: Requirements at the Nanoscale

| | Reactive neutral molecules<br><br> | Ions (z.B. $Ar^+$)<br><br> |
|---|---|---|
| | **chemical** | **physical** |
| **Selectivity** | ++ | -- |
| **Anisotropy** | -- (<<1) | ++ (~1) |
| **Examples** | liquid, steam or plasma | Ion bombardment (“sputter”) |

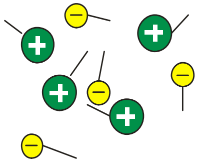
How can we combine chemical and physical components?

Plasma contains neutral radicals AND positive Ions!

# Plasma

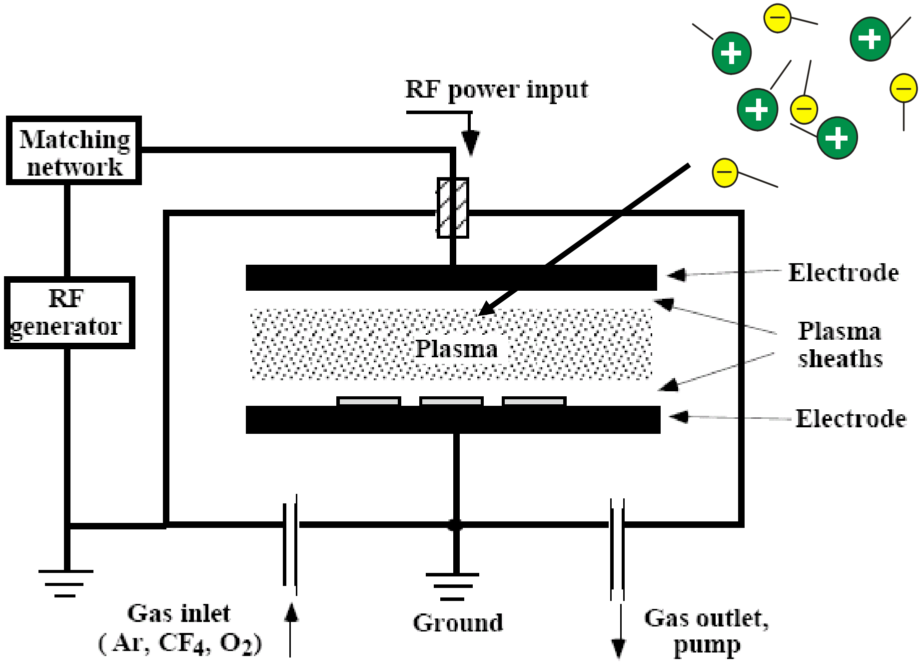
## *Plasma*

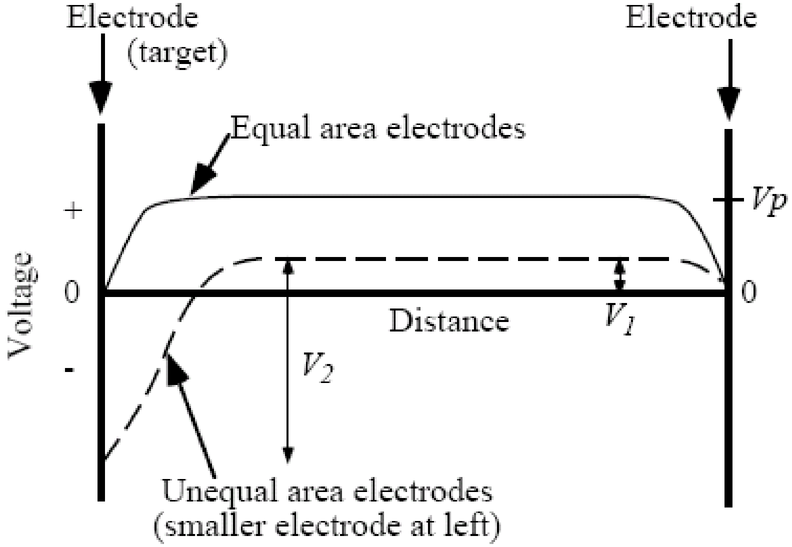
The ***4$^{th}$ aggregate state*** (in increasing excitation)

| solid | liquid | gaseous | PLASMA |
|---|---|---|---|
| **Ice**<br>**$H_2O$** | **Water**<br>**$H_2O$** | **Steam**<br>**$H_2O$** | **Ionized Gas**<br>**$H_2 \rightarrow 2H^+ + 2e^-$** |
| **T < 0°C** | **0°C < T < 100°C** | **T > 100°C** | **T > 100000°C** |
|  |  |  |  |
| atoms / molecules are fixed in the crystal lattice | atoms / molecules can move freely as a network | atoms / molecules can move freely, large distances | Ions and electrons noy bound, very large distances |

# Plasma Generation

## Application relevant generation of plasma in a parallel plate reactor





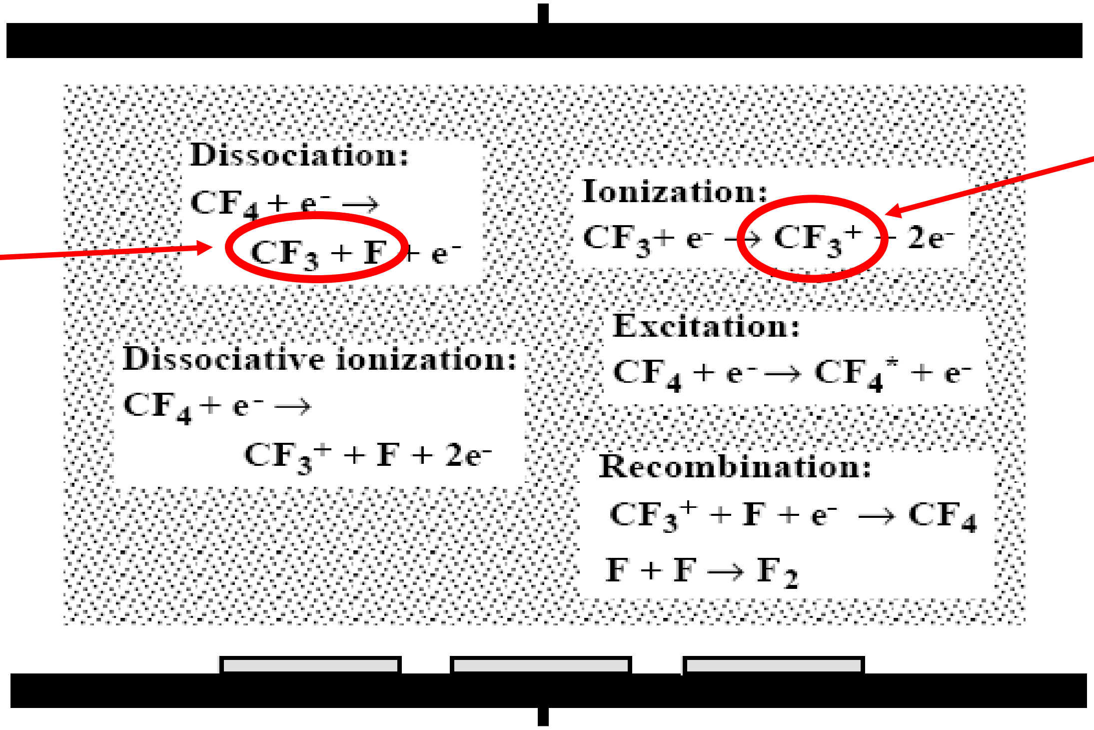
- Anode grounded
- Cathode connected to RF generator via impedance matching network
- High electric field ionizes gas molecules → Plasma!
- „Fast“ electrons follow RF field → positive ions determin plasma potential
- A smaller electrode leads to a higher voltage difference compared to plasma

# Plasma Generation

**High energy electrons in a plasma lead to further reactions**

Free radicals,
Highly reactive

chemical etching!



**Dissociation:**

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

**Ionization:**

$CF_3 + e^- \rightarrow CF_3^+ + 2e^-$

**Dissociative ionization:**

$CF_4 + e^- \rightarrow CF_3^+ + F + 2e^-$

**Excitation:**

$CF_4 + e^- \rightarrow CF_4^* + e^-$

**Recombination:**

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

$F + F \rightarrow F_2$

Ionized molecules,
positivly charged

physical etching!

- Dissociation: Partitioning a molecule into components, e.g. free radicals
- Ionization: Further generation of free electrons and charged molecules
- Excitation: excited molecules relax and emit Photons (“glow”)
- Recombination: Radicals and molecules recombine

# Plasma Etching Mechanisms

- Typically there are about $10^{15}$ $cm^{-3}$ neutral species (1 to 10% of which may be free radicals) and $10^{8}$-$10^{12}$ $cm^{-3}$ ions and electrons
- In standard plasma systems, the plasma density is closely coupled to the ion energy. Increasing the power increases both

- There are three principal mechanisms
  - chemical etching (isotropic, selective)
  - physical etching (anisotropic, less selective)
  - ion-enhanced etching (anisotropic, selective)
- Most applications today try to use the ion-enhanced mechanism (which provides in fact more than the sum of its components).

# Plasma Etching Mechanisms

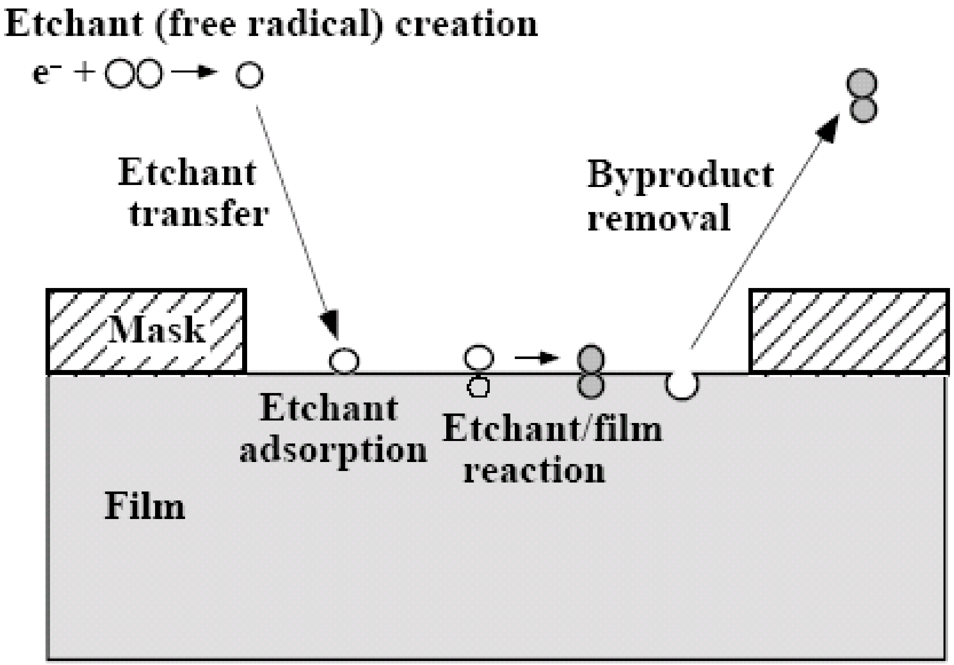
## 1. Chemical Etching

- Etching by reactive neutral species, such as “free radicals” (e.g. F, $CF_3$)
- Additives like $O_2$ can be used which react with $CF_3$ and reduce $CF_3$ + F recombination → higher etch rate

Example Chemical Etching:

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

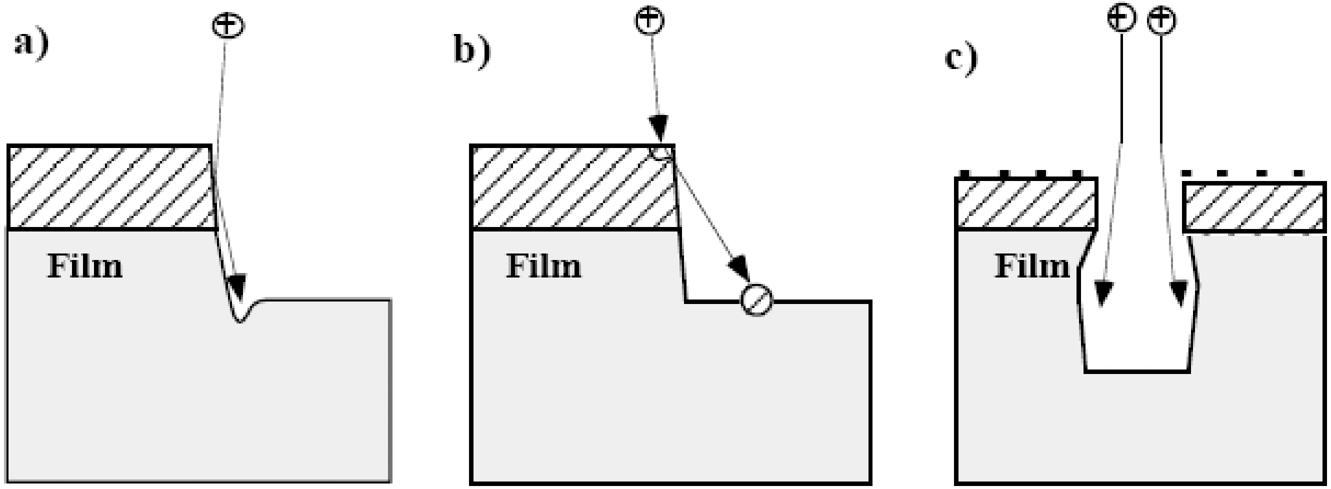
$$4F + Si \rightarrow SiF_4$$



# Plasma Etching Mechanisms

## 2. Physical Etching or ”Sputter Etching”

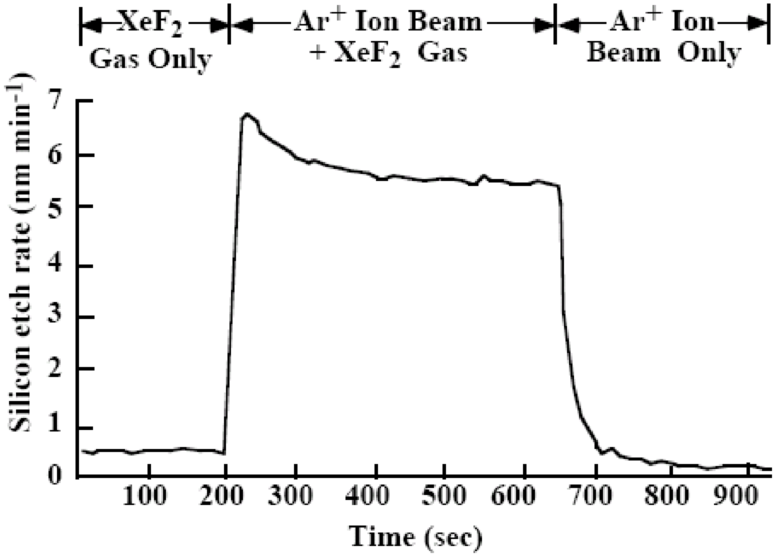
- Purely physical etching
- Highly directional (ε field across plasma sheath)
- Etches almost anything
- Poor selectivity: all materials sputter at about the same rate
- Pure sputter etching uses Ar+ →Damage to wafer surface and devices can occur:
    - (a) trenching ion
    - (b) bombardment damage, radiation damage, redeposition of photoresist
    - (c) charging
- These damages can occur in any etch system with a dominant physical etching component



# Plasma Etching Mechanisms

## 3. Ion Enhanced Etching or Reactive Ion Etching (RIE)

- It has been observed that chemical and physical components of plasma etching do not always act independently - both in terms of net etch rate and in resulting etch profile.

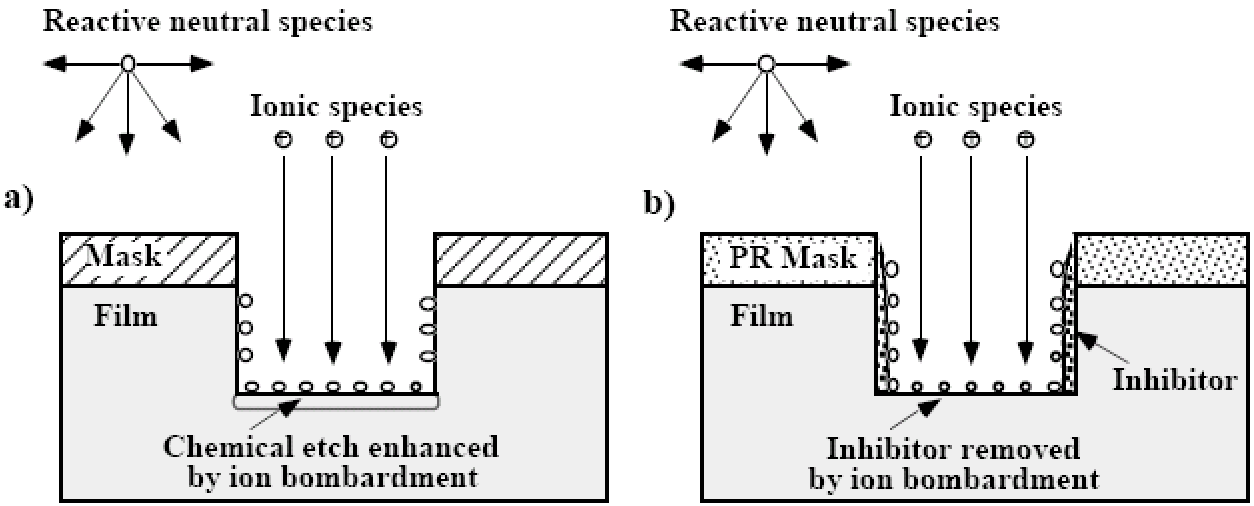


Example:

- Etch rate of silicon as $XeF_2$ gas (not plasma) and $Ar^+$ ions are introduced to silicon surface. Only when both are present does appreciable etching occur
- Etch profiles can be very anisotopic, and selectivity can be good
- Many different mechanisms proposed for this synergistic etching between physical and chemical components. Two mechanisms are shown below:

# Plasma Etching Mechanisms

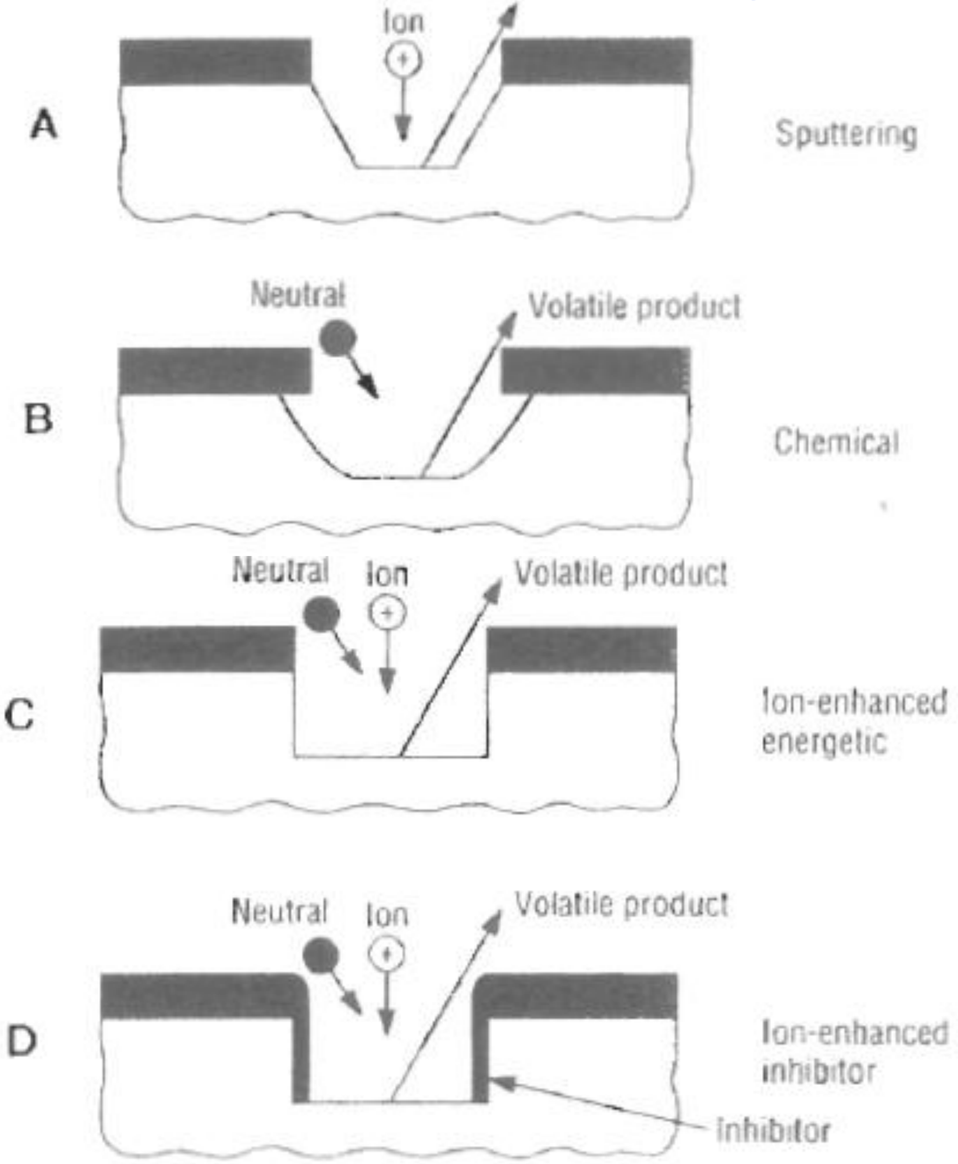
Ion Enhanced Etching



- Ion bombardment can enhance etch process (such as by damaging the surface to increase reaction, or by removing etch byproducts)
- Ion bombardment can remove inhibitor that is an indirect byproduct of etch process (such as polymer formation from carbon in gas or from photoresist)
- Whatever the exact mechanism (multiple mechanisms may occur at same time):
  - need both components for etching to occur.
  - get anisotropic etching and little undercutting because of directed ion flux.
  - get selectivity due to chemical component and chemical reactions.

→ many applications in etching today

# Summary: Plasma Etching Mechanisms



SE (sputter etching)

PE (plasma etching)

RIE (reactive ion etching)

DRIE (deep reactive ion etching)

# Si, $Si_3N_4$ and $SiO_2$ Etching

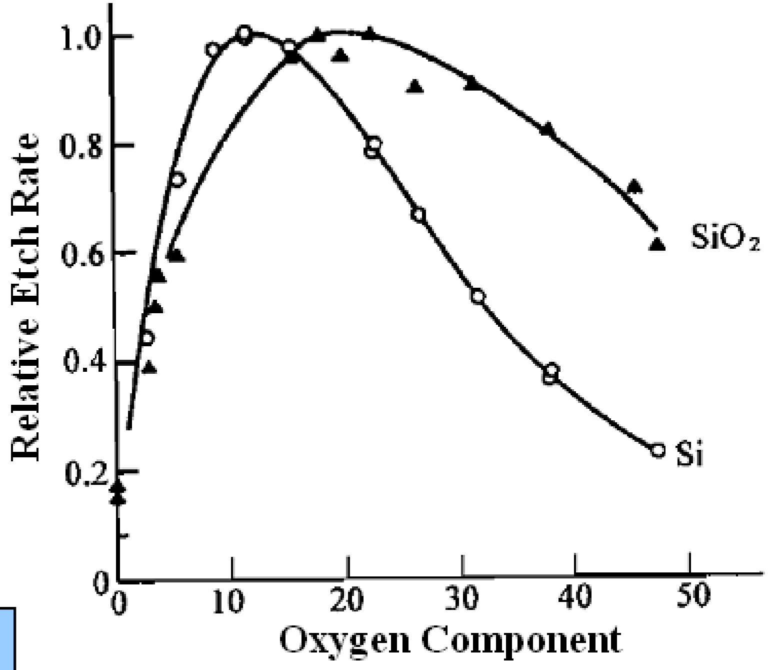
$Si+4F^* \rightarrow SiF_4\uparrow$

$SiO_2+4F^* \rightarrow SiF_4\uparrow +O_2\uparrow$

$Si_3N_4+12F^* \rightarrow 3SiF_4\uparrow +2N_2\uparrow$

**Additive gases can improve selectivity**

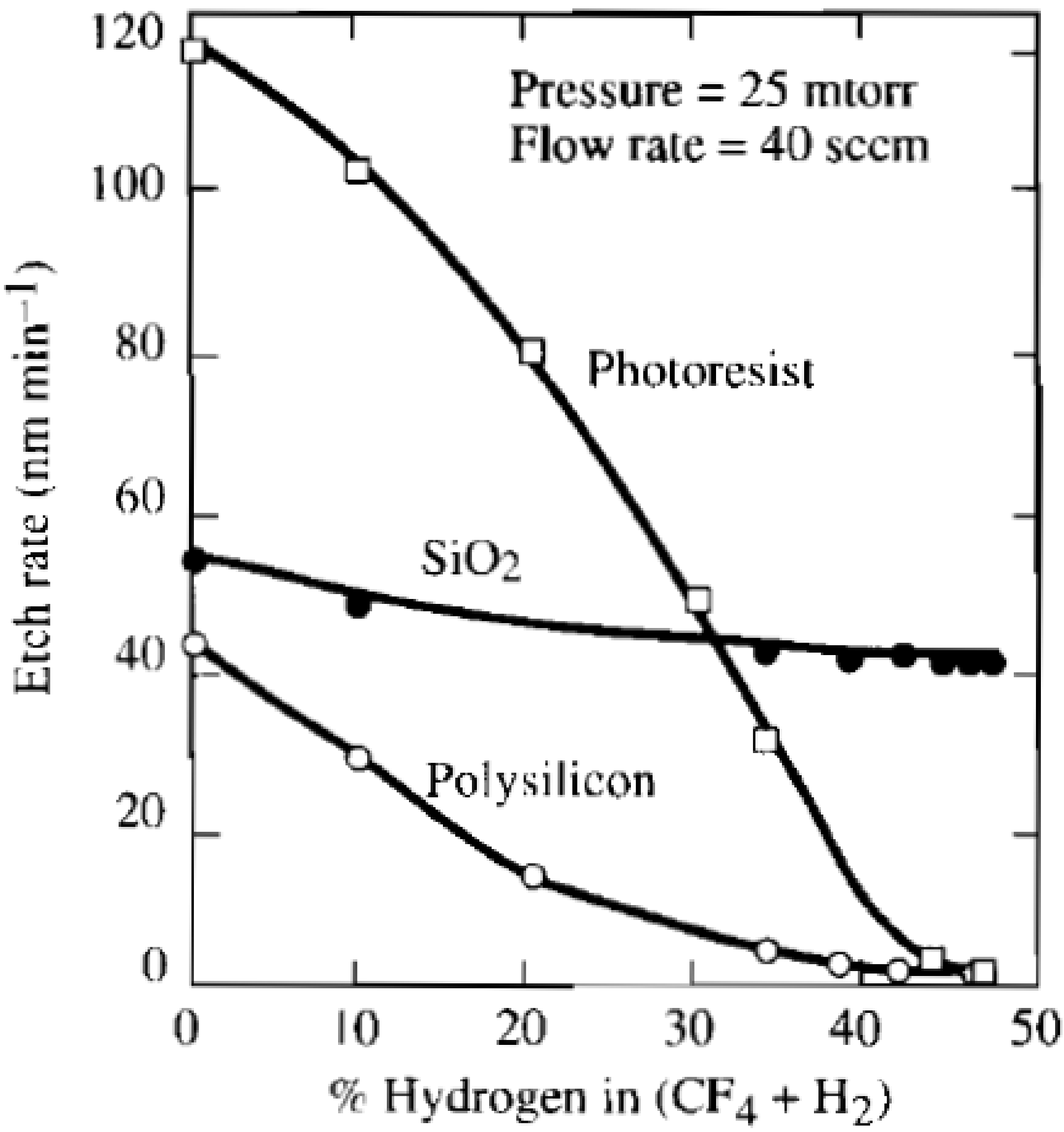
- ✓ $CF_x$ ($x \leq 3$) etches $SiO_2$ or $Si_3N_4$ faster than Si.
- ✓ Adding a little $O_2$ into $CF_4$ may increase its etch rates for Si, $SiO_2$ and $Si_3N_4$

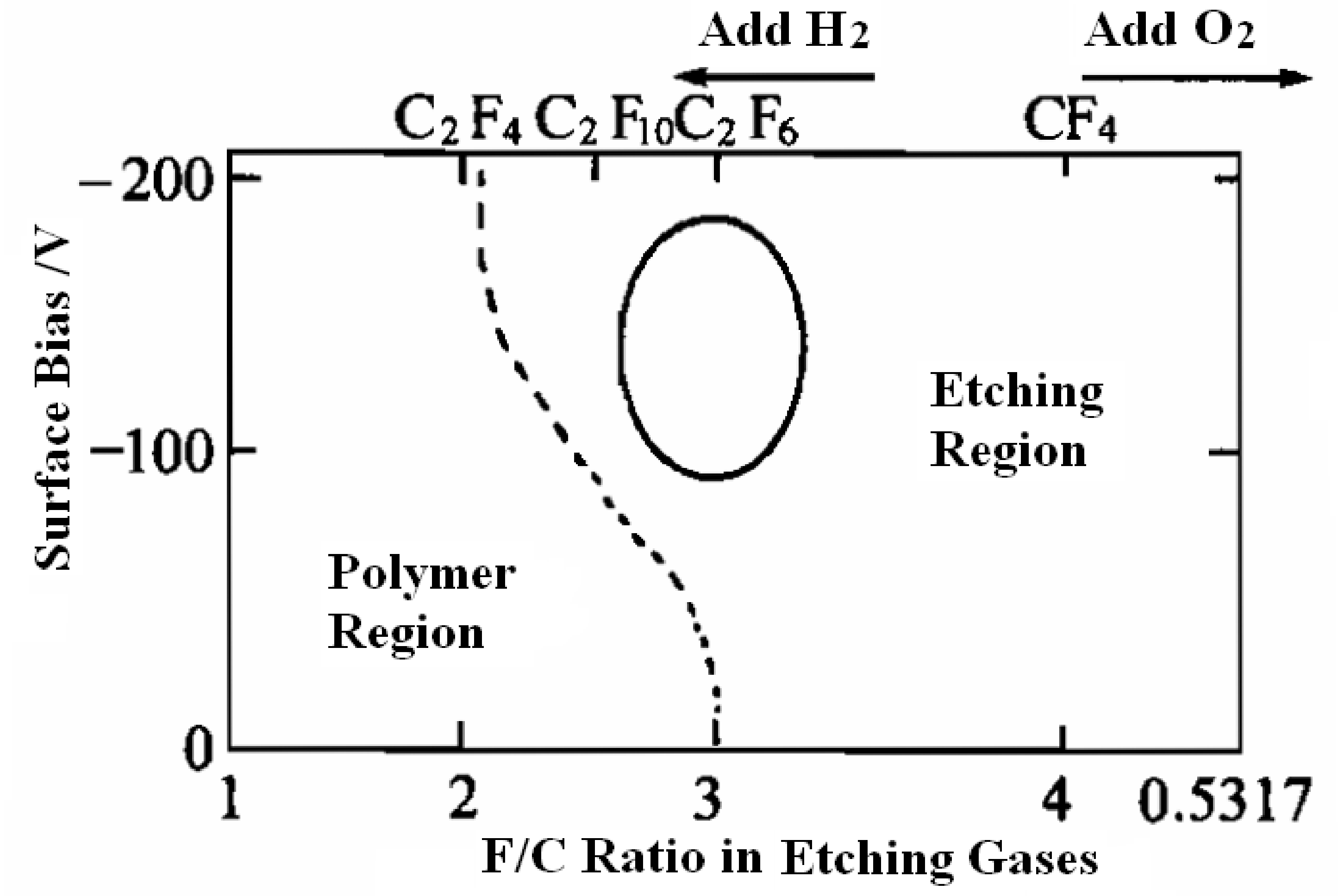


**10% $O_2$ achieves the maximum $Si/SiO_2$ etch rate ratio**

- ✓ **$CF_x$ ($x \leq 3$) etches $SiO_2$ or $Si_3N_4$ faster than Si.**

- ✓ **Adding a little $H_2$ in $CF_4$ can increase the concentration ratio of $CF_x$ : F* and hence increase the etch rate ratios of $SiO_2$ : Si and $Si_3N_4$:Si.**





**Increasing F/C by adding $O_2$ can increase etch rate**
**Decreasing F/C by adding $H_2$, etching tends to form polymer film**

# Concept Test 8

7.1: A plasma etch process can be described with the following terms:

***Etch Rate – Selectivity - Anisotropy – Uniformity***

A plasma etch tool has the following process parameters: **Pressure, Temperature, Gas composition, Gas flow, Substrate bias, RF power.**

Which of the following statements are true:

**A. Pressure affects anisotropy and rate.**

**B. Temperature affects mainly the ion driven component.**

**C. The gas composition affects mainly the etch rate.**

**D. Gas flow affects mainly the chemical component.**

**E. Substrate bias affects mainly the chemical component.**

**F. RF power affects mainly the etch rate.**

# Concept Test 8

## *Etch Rate – Selectivity - Anisotropy - Uniformity*

- **Pressure (Anisotropy and Rate: collisions, mean free path)**

- **Temperature (All: chemical component)**

- **Gas mixture (All: chemical component)**

- **Gas flow (Rate and Selectivity: more gas → more chemistry; Uniformity: in connection with chamber geometry)**

- **Substrate bias (physical component in HDP tools)**

- **RF power (rate: plasma density, anisotropy: substrate bias)**

- **Chamber geometry (usually not a parameter)**

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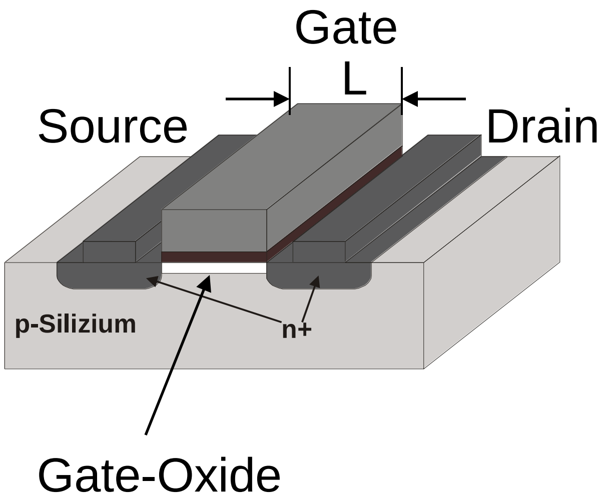
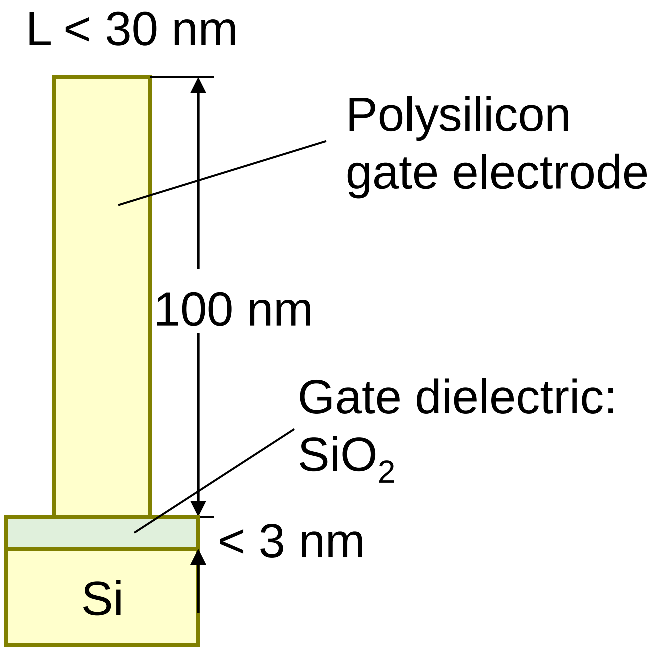
# RIE Example: Highly Selective Silicon Etch Process

**Goal**:

Gate electrode etch process for silicon MOSFET



**Requirements**:



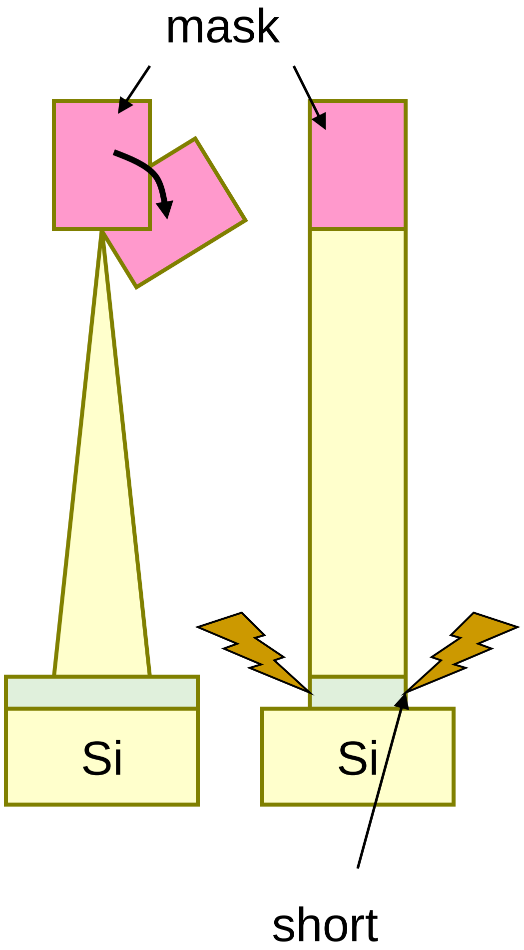
→ high anisotropy A

→ high selectivity S

→ 1 minute overetch:

$r_{SiO2} << 3$ nm/min

**Issues**:



# RIE Example: Highly Selective Silicon Etch Process

**Solution:** Gate electrode etch process for silicon MOSFET

**HBr + $O_2$ based plasma process in Oxford RIE Etcher**

+ Etch product: Si + Br = SiBr (volatile)
+ $O_2$- addition to increase selectivity
+ Sidewall passivation with SiOBr (anistropy!)
- HBr is corrosive and highly poisonous

**Process development: Optimizing process parameters**

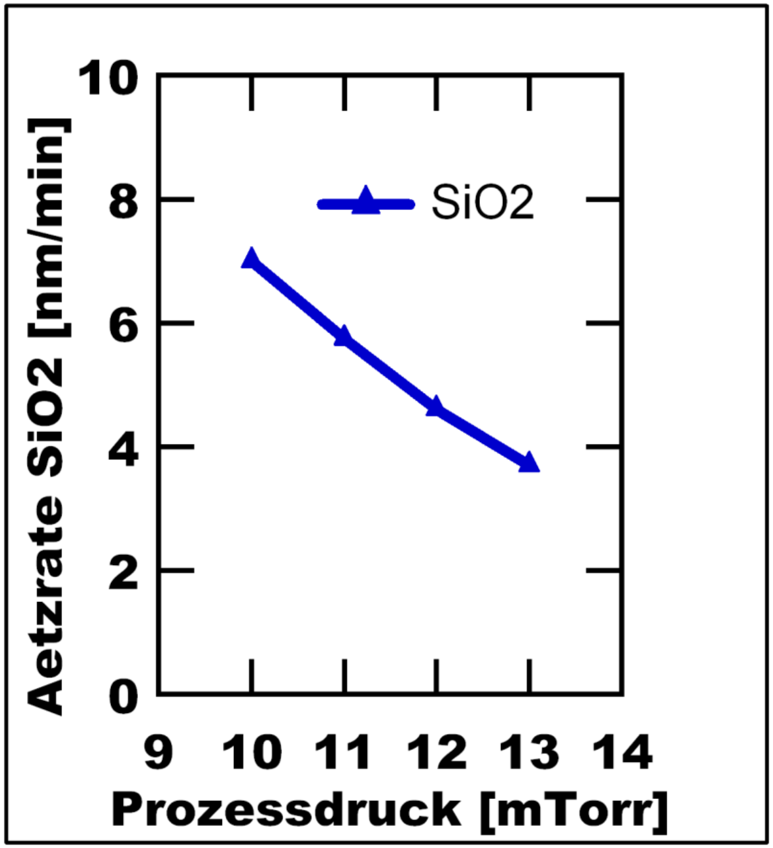
e.g. Pressure [mTorr]
 $O_2$-Admixture
 RF power
 Plasma power
 Gas flow

# RIE Example: Highly Selective Silicon Etch Process

**Process development: Optimizing process parameters**

e.g. Variation of chamber pressure [mTorr]

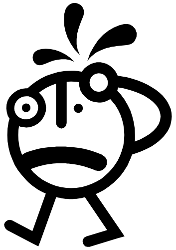
Fixed parameter: gas mixture: 2% $O_2$ in HBr



Preliminary result:

Rate too high ($r_{SiO2min}$ = 3.7 nm/min)

Further increase of pressure not feasible → loss of anisotropy



New optimization approach:

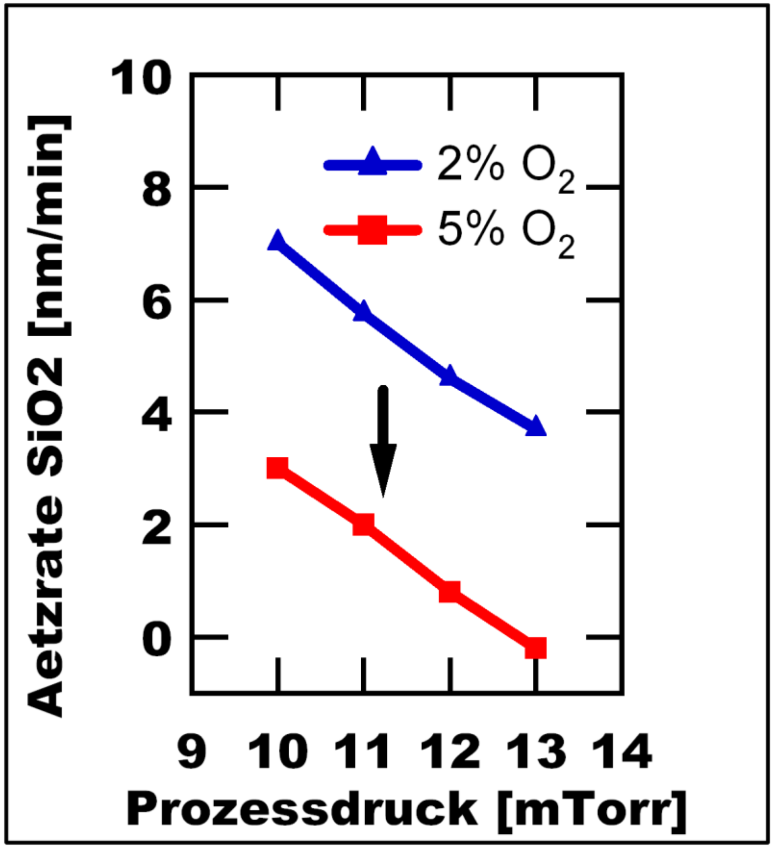
Increase of $O_2$ admixture

# RIE Example: Highly Selective Silicon Etch Process

**Process development: Optimizing process parameters**

e.g. Variation of chamber pressur [mTorr]

**NEW** parameter: gas mixture: increase from 2% $O_2$ in HBr to **5%**



Result:

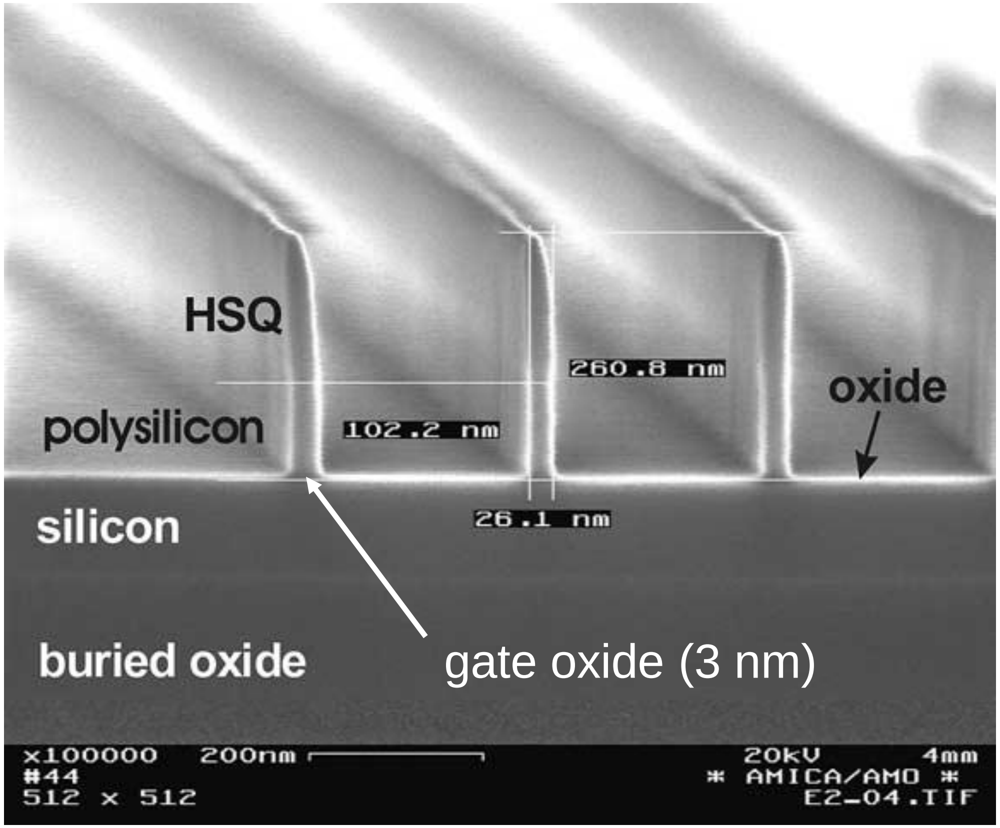
Rate optimized ($r_{SiO2min}$ ~ 0 nm/min)

Next steps:
- Check polysilicon etch rate $r_{Si}$
- Check anisotropy

- If needed: further optimization:
  - RF power
  - Plasma power
  - Gas flow…

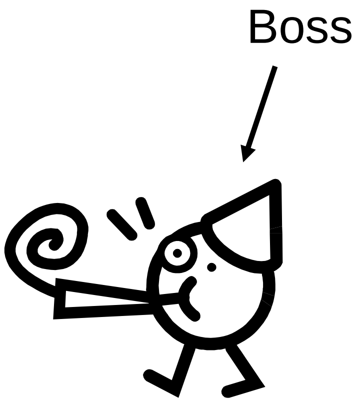
# RIE Example: Highly Selective Silicon Etch Process

**Result: highly selective, anisotropic HBr/$O_2$ RIE process**



Scanning Electron Microscope (SEM) Image:

- 26 nm Poly-Si Gates
- Etch stop on 3 nm $SiO_2$



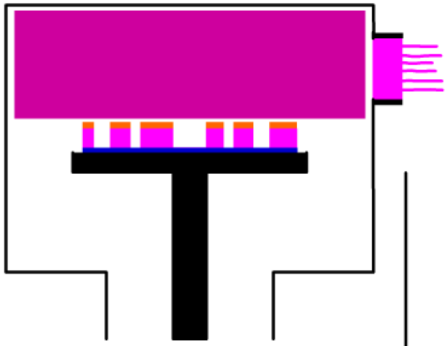
**Optimized HBr/$O_2$ Process fulfils all requirements**

# Optical Endpoint Detection

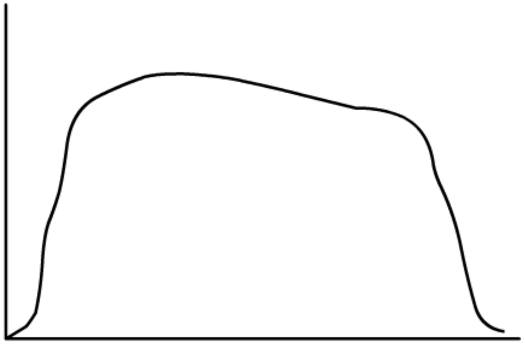
- Determining the Etch Time

**Recommended Wavelengths for Monitoring Endpoint**

| **Etch Application** | **Film Type** | **Species** | **Wavelength** |
|---|---|---|---|
| Contact & Spacer | Oxide over Si, poly, or silicide | CO<br>CF2 | 483.5nm<br>270 nm |
| Via | Oxide over metal | CO<br>CF2 | 438.5nm<br>270 nm |
| Stack | Oxide over nitride | CO<br>CN | 438.5nm<br>386.5nm |
| Isolation | Nitride over oxide | CN | 386.5nm |
| Patterned Poly | Poly over oxide | Cl, Br<br>Br | 470.5nm<br>312.5nm |
| Patterned Wsi2 | Wsi2 over poly or oxide | F | 441.5nm |
| Patterned TiSi2 | TiSi2 over poly or oxide | Cl, Br | 470.5nm |
| Patterned MoSi2 | MoSi2 over poly or oxide | Cl, Br | 470.5nm |
| Patterned Al | Al-Si-Cu over barrier metal or oxide | Al | 396 nm |



Optical Emission



www.oxfordplasma.de

OXFORD INSTRUMENTS

www.oxford.com

# Deep RIE Example: Bosch Process (Si etching)

Source: http://www.findmems.com/bosch/mems-bosch-automotive-applications-and-beyond

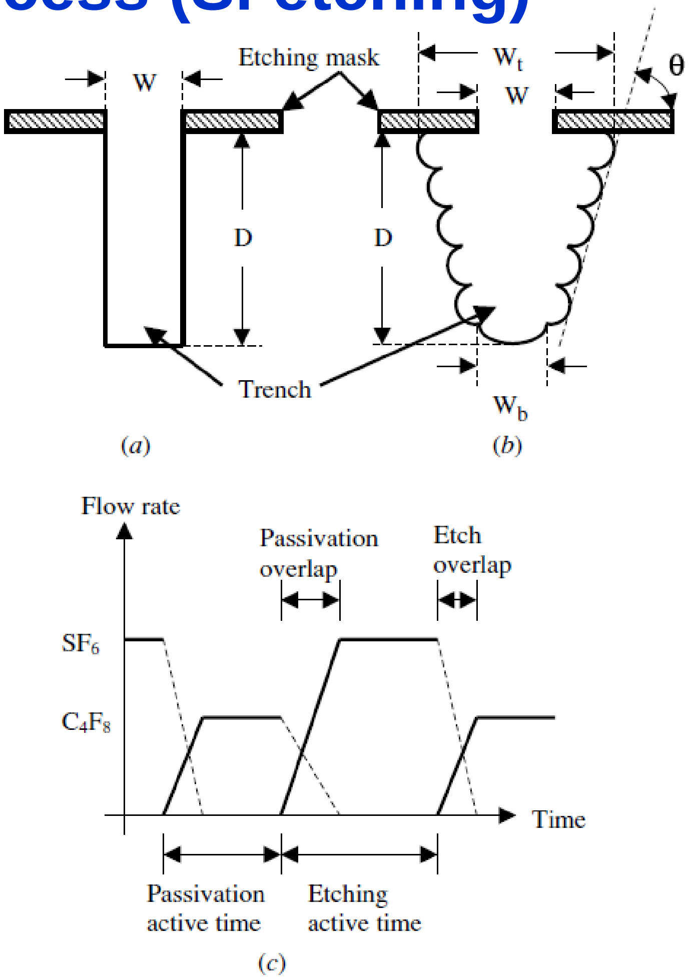


**Figure 1.** (*a*) Ideal (or targeted) profile of the etched trench by employing the Bosch process. (b) Real profile of the etched trench by employing the Bosch process. (c) The periodic cycles in the Bosch process.

C. Chang et al., J. Micromech. Microeng. 15 580 (2005)

Active Etch Step: $SF_6$ isotropic etch

Passivation Step: $C_4F_8$ inhibitor layer
→ Thin layer at Si sidewalls

# Etching - Overview

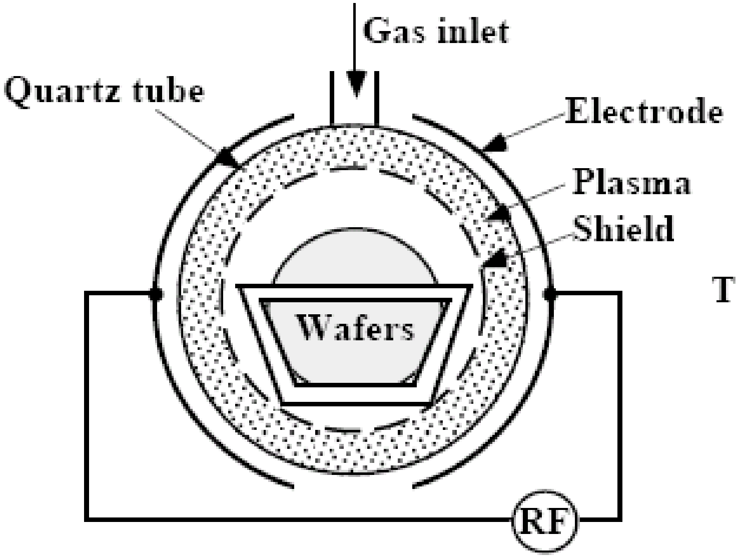
- Basic Terminology
- Wet Etching
- Dry / Plasma Etching
  - Mechanisms
  - Example
  - Reactor Designs
- Summary and Appendix

# Plasma Etching: Reactor Designs

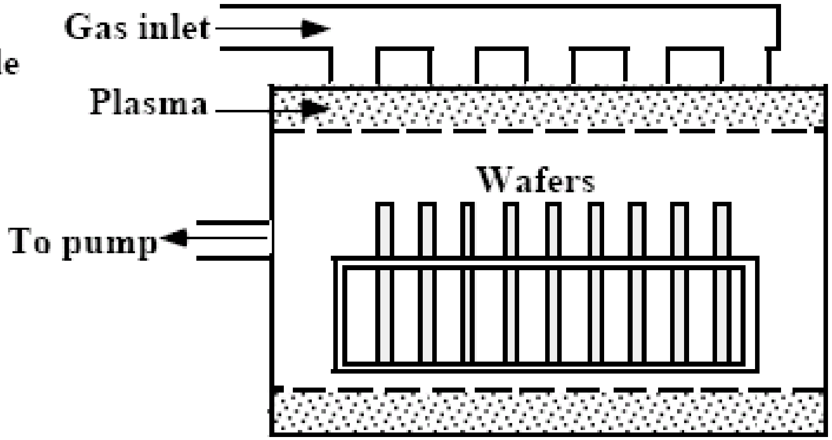
Different configurations have been developed to make use of chemical, physical or ion assisted etching mechanisms.

**Barrel Etchers**

- Purely chemical etching
- Used for non-critical steps, such as photoresist removal (”ashing”)



End view

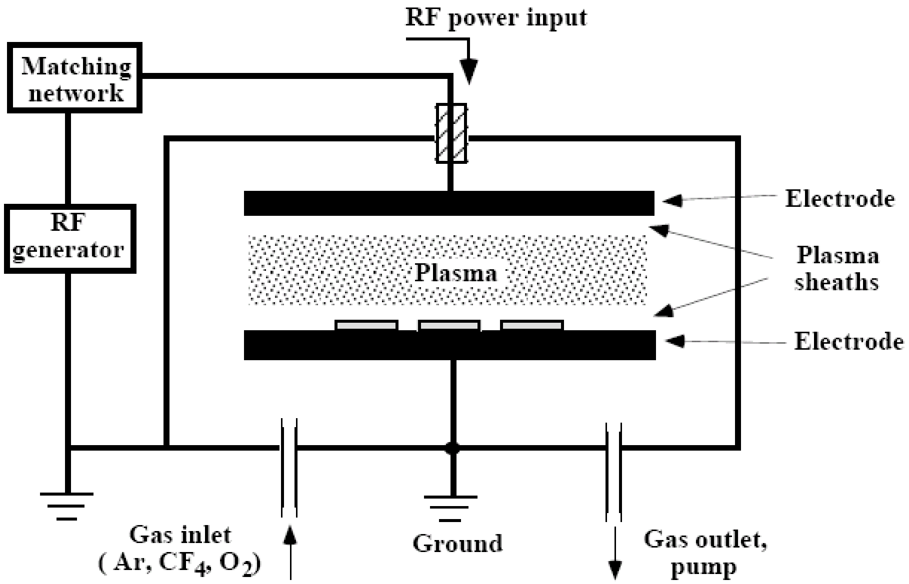


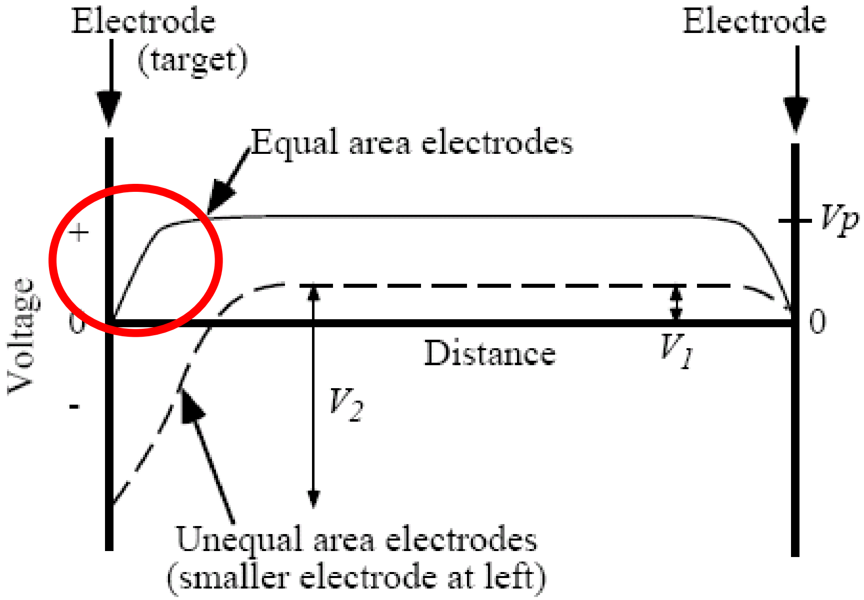
Side view

# Plasma Etching: Reactor Designs

## Parallel Plate Systems - Plasma Mode

- Electrodes have equal areas (or wafer electrode is grounded with chamber and larger)
- Only moderate sheath voltage (10-100 eV), so only moderate ionic component
- Strong chemical component
- Etching can be fairly isotropic and selective

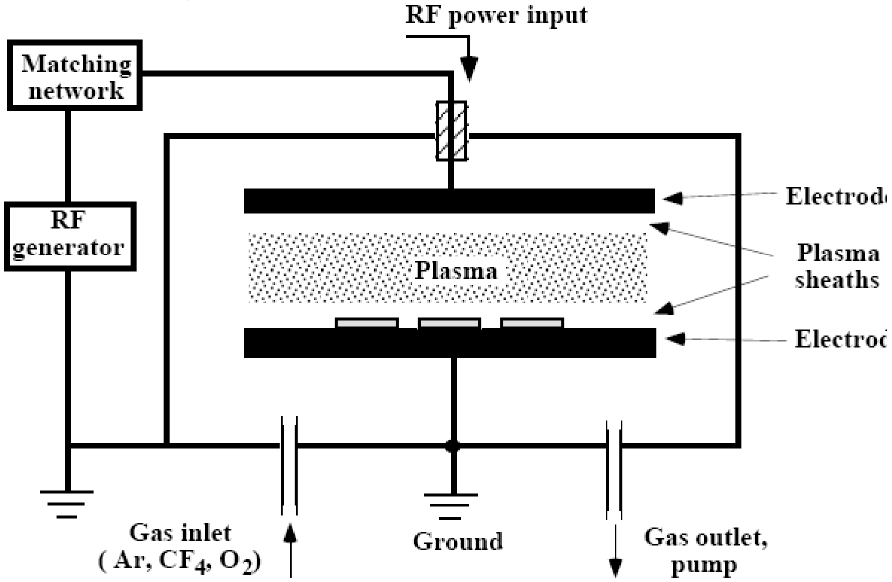


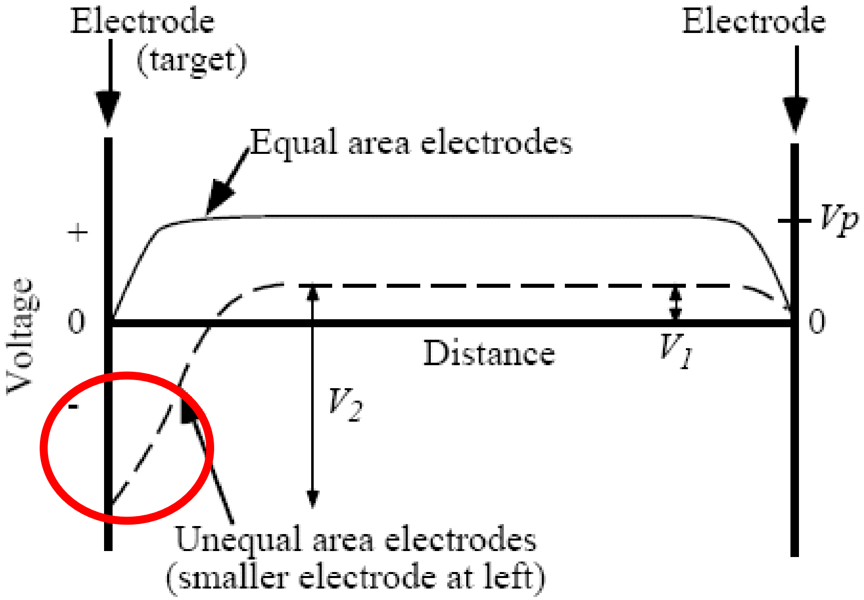


# Plasma Etching: Reactor Designs

## Parallel Plate Systems - Reactive Ion Etching ( RIE) Mode

- For more directed etching, need stronger ion bombardment
- Wafers sit on smaller electrode (RF power there)
- Higher voltage drop across sheath at wafers.(100-700 eV)
- Lower pressures are used to attain even more directional etching (10-100 mtorr)
- More physical component than plasma mode for more directionality but less selectivity



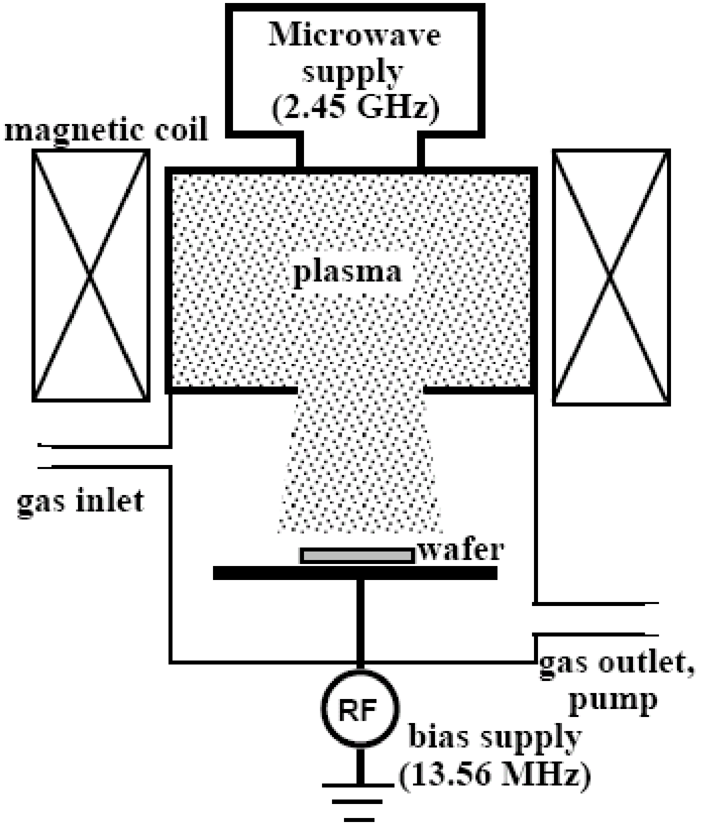


# Plasma Etching: Reactor Designs

## High Density Plasma ( HDP) Etch Systems

- Uses remote, non-capacitively coupled plasma source (Electron cyclotron resonance - ECR, or inductively coupled plasma source - ICP)
- Uses separate RF source as wafer bias. ***This separates the plasma power (density) from the wafer bias (ion accelerating field)***

- Very high density plasmas ($10^{11}$-$10^{12}$ ion $cm^{-3}$) can be achieved (faster etching)
- Lower pressures (1-10 mtorr range) can be utilized due to higher ionization efficiency (→ longer mean free path and → more anisotropic etching)
- These systems produce high etch rates, decent selectivity, and good directionality, while keeping ion energy and damage low

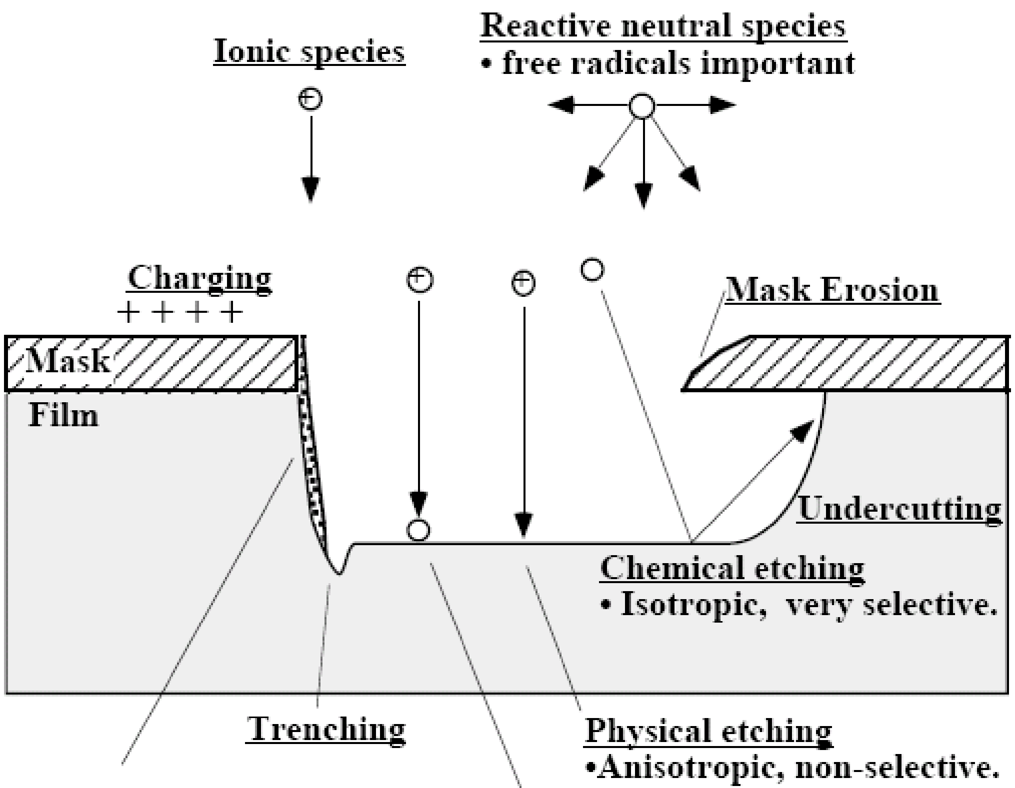


Widely used today!

# Etching - Overview

- Basic Terminology
- Wet Etching
- Dry / Plasma Etching
  - Mechanisms
  - Example
  - Reactor Designs
- Summary and Appendix

# Summary: Plasma Etching

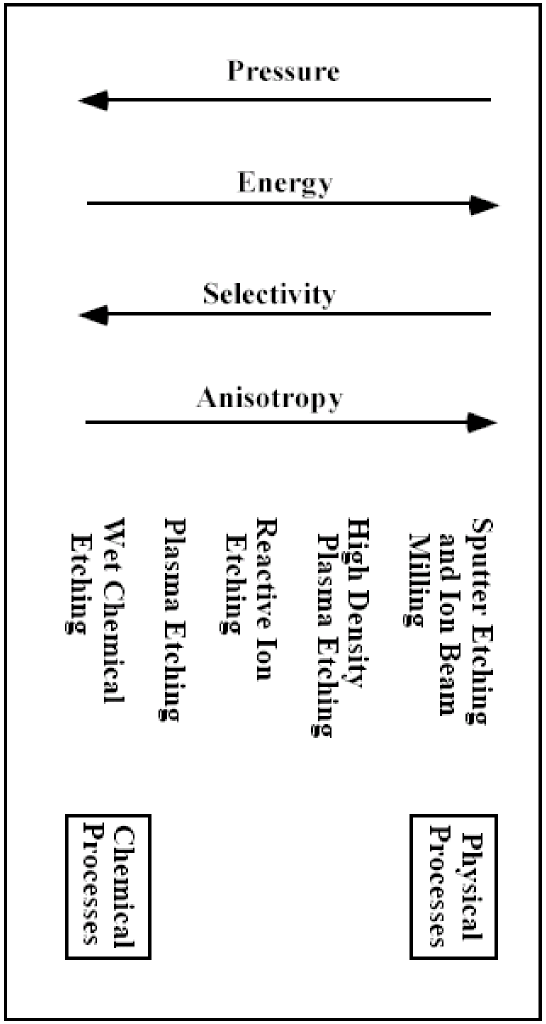


**Sidewall-inhibitor Deposition**

- Sources: etch byproducts, mask erosion, inlet gases.
- Removed on horizontal surfaces by ion bombardment.
- A possible mechanism in ion enhanced etching.

**Ion Enhanced Etching**

- Needs both ions and reactive neutrals.
- May be due to enhanced etch reaction or removal of etch byproduct or inhibitor.
- Anisotropic, selective.



# Summary: Etching

**What's pattern transfer?**

**Lithography + Etching**

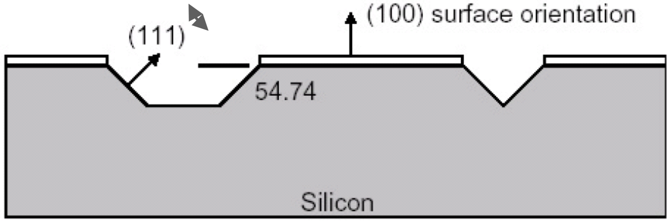
**Tow critical issues?**

**Selectivity** $S = \frac{r_1}{r_2}$ **Directionality** $A = 1 - \frac{r_{lat}}{r_{vert}}$

## Wet Etching

**Si——HNA, isotropic**

**——KOH, anisotropic**



**$SiO_2$——HF**

MEMS

## Dry Etching

**Only Physical Etching (Sputter)**

**Reaction Ion Etching (RIE)**

**Directionality and Selectivity Improvement $CF_4/O_2$**

**Only Chemical Etching PE**

# Summary of Key Ideas

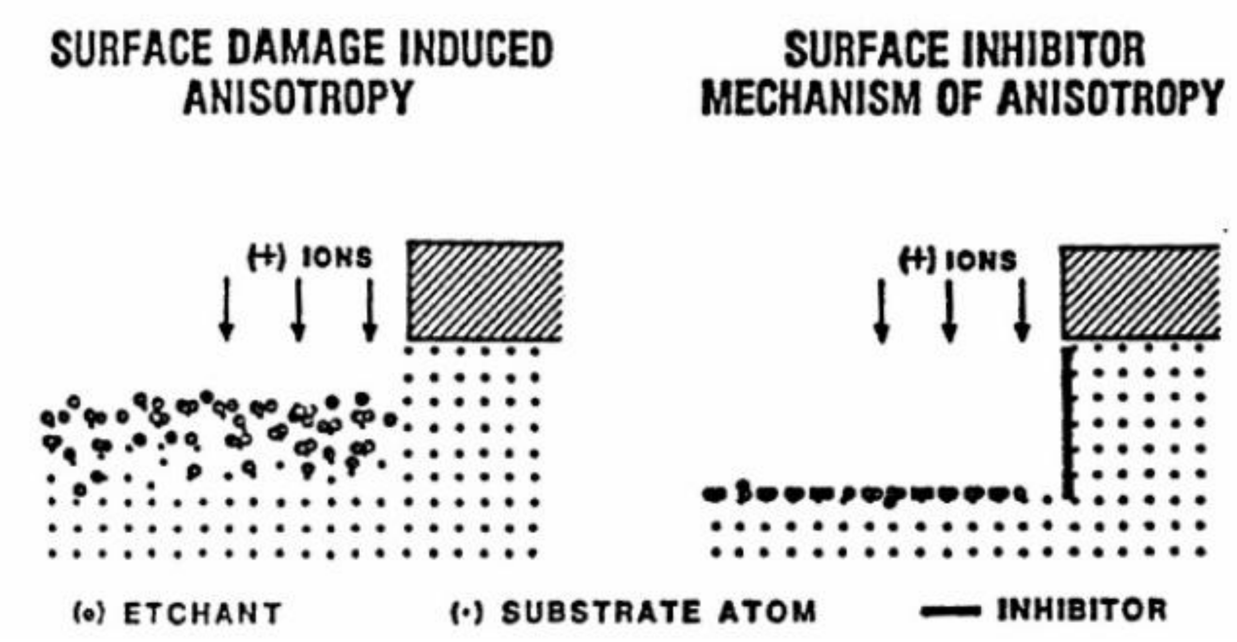
- Etching of thin films is a key technology in modern IC manufacturing.
- Photoresist is generally used as a mask, but sometimes other thin films also act as masks.
- Selectivity and directionality (anisotropy) are the two most important issues. Usually good selectivity and vertical profiles (highly anisotropic) are desirable.
- Other related issues include mask erosion, etch bias (undercutting), etch uniformity, residue removal and damage to underlying structures.
- Dry etching is used almost exclusively today because of the control, flexibility, reproducibility and anisotropy that it provides.
- Reactive neutral species (e.g. free radicals) and ionic species play roles in etching.
- Generally neutral species produce isotropic etching and ionic species produce anisotropic etching.

- Physical mechanisms:
    - Chemical etching involving the neutral species.
    - Physical etching involving the ionic species.
    - Ion-enhanced etching involving both species acting synergistically.

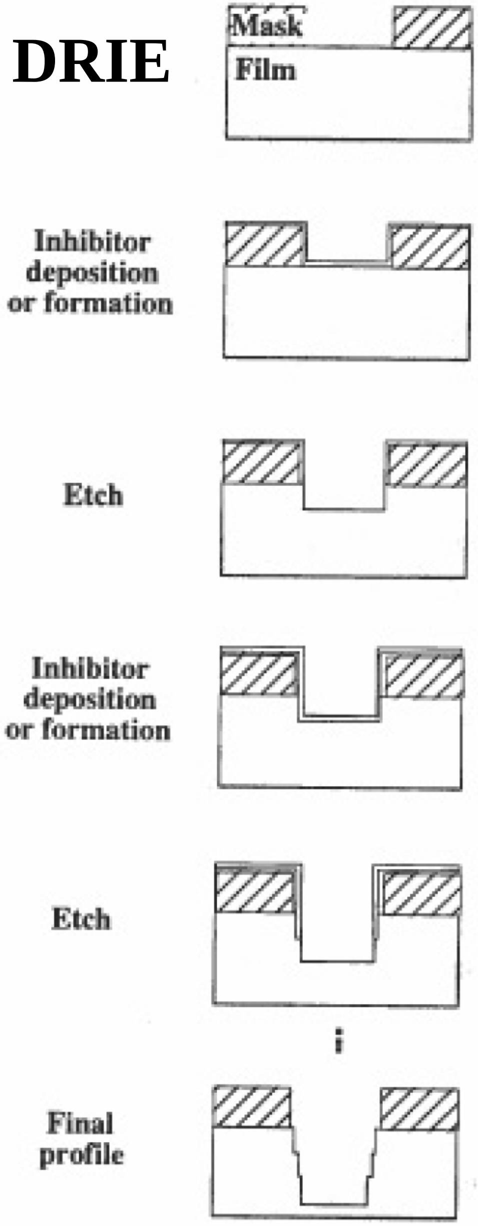
# Appendix: Improving Etching Directionality

✓Increase ion bombardment (physical component)

✓Increase sidewall inhibitor

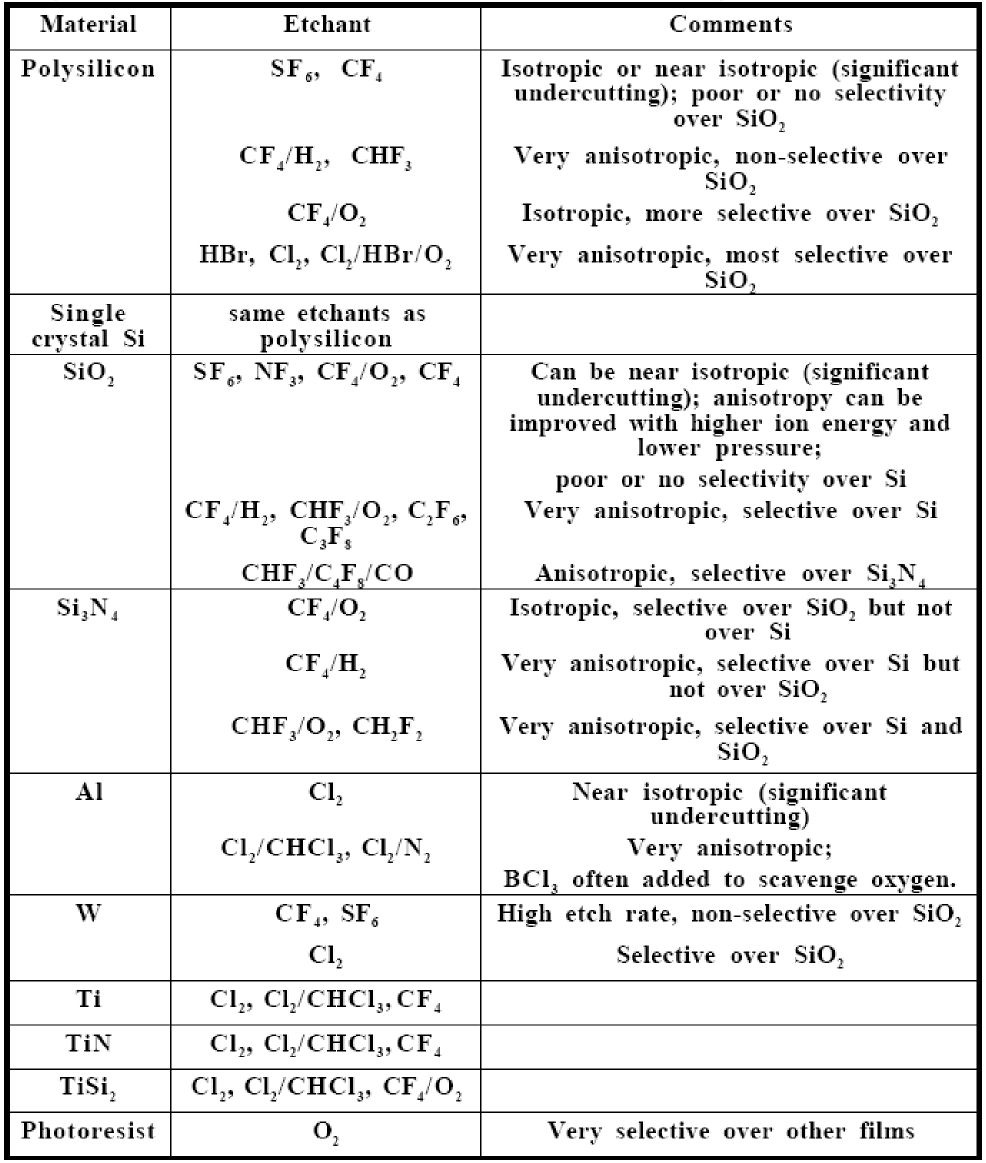


## DRIE



# Appendix: Plasma Etching in Silicon Technology

Common etchants used for various films in silicon technology.



| Material | Etchant | Comments |
|---|---|---|
| Polysilicon | $SF_6$, $CF_4$<br>$CF_4/H_2$, $CHF_3$<br>$CF_4/O_2$<br>HBr, $Cl_2$, $Cl_2/HBr/O_2$ | Isotropic or near isotropic (significant undercutting); poor or no selectivity over $SiO_2$<br>Very anisotropic, non-selective over $SiO_2$<br>Isotropic, more selective over $SiO_2$<br>Very anisotropic, most selective over $SiO_2$ |
| Single crystal Si | same etchants as polysilicon | |
| $SiO_2$ | $SF_6$, $NF_3$, $CF_4/O_2$, $CF_4$<br>$CF_4/H_2$, $CHF_3/O_2$, $C_2F_6$, $C_3F_8$<br>$CHF_3/C_4F_8/CO$ | Can be near isotropic (significant undercutting); anisotropy can be improved with higher ion energy and lower pressure;<br>poor or no selectivity over Si<br>Very anisotropic, selective over Si<br>Anisotropic, selective over $Si_3N_4$ |
| $Si_3N_4$ | $CF_4/O_2$<br>$CF_4/H_2$<br>$CHF_3/O_2$, $CH_2F_2$ | Isotropic, selective over $SiO_2$ but not over Si<br>Very anisotropic, selective over Si but not over $SiO_2$<br>Very anisotropic, selective over Si and $SiO_2$ |
| Al | $Cl_2$<br>$Cl_2/CHCl_3$, $Cl_2/N_2$ | Near isotropic (significant undercutting)<br>Very anisotropic;<br>$BCl_3$ often added to scavenge oxygen. |
| W | $CF_4$, $SF_6$<br>$Cl_2$ | High etch rate, non-selective over $SiO_2$<br>Selective over $SiO_2$ |
| Ti | $Cl_2$, $Cl_2/CHCl_3$, $CF_4$ | |
| TiN | $Cl_2$, $Cl_2/CHCl_3$, $CF_4$ | |
| $TiSi_2$ | $Cl_2$, $Cl_2/CHCl_3$, $CF_4/O_2$ | |
| Photoresist | $O_2$ | Very selective over other films |