EE143 – Fall 2016
Microfabrication Technologies

Lecture 4: Etching

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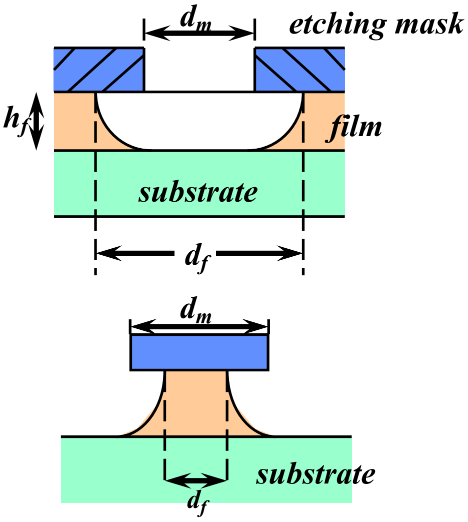
Etch Process - Figures of Merit

- Etch rate
- Etch rate uniformity
- Selectivity
- Anisotropy

Bias and Anisotropy



Bias: $B \equiv d_f - d_m$

(1) For complete isotropic etching, same lateral and vertical etching rate:

$$B = 2 \times h_f$$

(2) For complete isotropic etching:
Lateral etching rate = 0

$$B = 0$$

Degree of Anisotropy

r_{lat} **: lateral etch rate**
r_{vet} **: vertical etch rate**
A_f **: degree of isotropy**

$$A_f \equiv 1 - \frac{r_{lat}}{r_{ver}}$$

$$0 \leq A_f \leq 1$$

isotropic *anisotropic*

Etching Selectivity S

$$S_{AB} = \frac{r_A(\text{vertical etching velocity of material } A)}{r_B(\text{vertical etching velocity of material } B)}$$

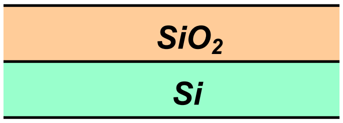
Wet Etching

S is controlled by:
chemicals, concentration, temperature

RIE

S is controlled by:
plasma parameters, plasma chemistry,
gas pressure, flow rate & temperature.

Selectivity Example



SiO_2/Si etched by HF solution

$S_{SiO2,\ Si}$ Selectivity is very large (~ infinity)

SiO_2/Si etched by RIE (e.g. CF_4 plasma)

$S_{SiO2,\ Si}$ Selectivity is finite (~ 10)

Uniformity

(a) Film thickness variation across wafer

$$h_{f(\max)} = h_f \cdot (1+\delta)$$

Thickness variation factor

Nominal thickness

- **The variation factor δ is dictated by the deposition method, deposition equipment, and manufacturing practice.**

(b) Film etching rate variation

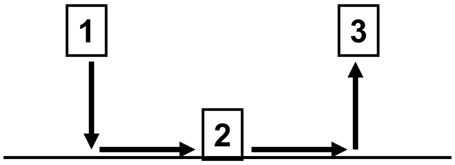
variation factor

$$r_{f(\min)} = r_f (1-\phi_f)$$

$$Worst-case\ etching\ time\ required\ to\ etch\ the\ film$$

$$= \frac{h_{f(\max)}}{r_{f(\min)}} = \frac{h_f}{r_f} \cdot \frac{(1+\delta)}{(1-\phi_f)}$$

Wet Etching



1. **Reactant transport to surface**
2. **Selective and controlled reaction of etchant with the film to be etched**
3. **Transport of by-products away from surface**

Wet Etching (cont.)

- Wet etch processes are generally isotropic
- Etch rate is governed by temperature, concentration, chemicals, etc.
- Wet etch processes can be highly selective
- Acids are commonly used for etching:

$HNO_3 <=> H^+ + NO_3^-$

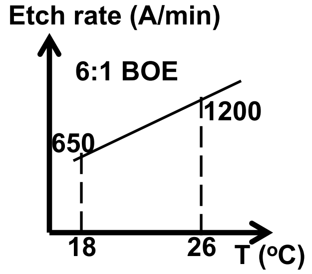
$HF <=> H^+ + F^-$

H^+ is a strong oxidizing agent

=> high reactivity of acids

Wet Etch Process for SiO_2

To etch SiO_2 film on Si, use $HF + H_2O$



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

Note: HF is usually buffered with NH_4F to maintain $[H^+]$ at a constant level (for constant etch rate). This HF buffer is called Buffered Oxide Etch (BOE)

$$NH_4F \rightarrow NH_3 + HF$$

Wet Etch Process for Si_3N_4

- To etch Si_3N_4 film on SiO_2, use H_3PO_4 (phosphoric acid)
  - (180°C: ~100 A/min etch rate)
  - Typical selectivity:
    - 10:1 for nitride over oxide
    - 30:1 for nitride over Si

Wet Etch Process for Aluminum

- To etch Al film on Si or SiO2, use
  - $H_3PO_4 + CH_3COOH + HNO_3 + H_2O$ @ 30°C
    (phosphoric acid), (acetic acid), (nitric acid)
- $6H^+ + 2Al \rightarrow 3H_2 + 2Al^{3+}$
  - Al^{3+} is water-soluble

Wet Etch Process for Silicon

- Isotropic etching
  - Use HF + HNO_3 + H_2O
  - 3 Si + 4 HNO_3 → 3 SiO_2 + 4 NO + 2 H_2O
  - SiO_2 + 6 HF → H_2SiF_6 + $2H_2O$
- Anisotropic etching

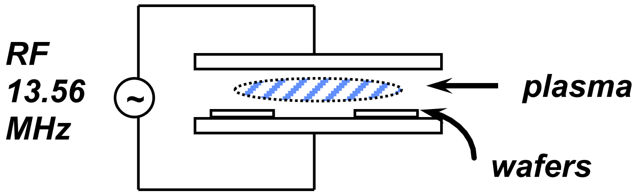
  KOH for single crystalline Si

Drawbacks of Wet Etching

- Lack of anisotropy
- Poor process control
- Poor uniformity
- Excessive particulate contamination

→ Wet etching used for noncritical feature sizes

Reactive Ion Etching (RIE)



Parallel-Plate Reactor

Plasma generates (1) Ions

(2) Activated neutrals

↑

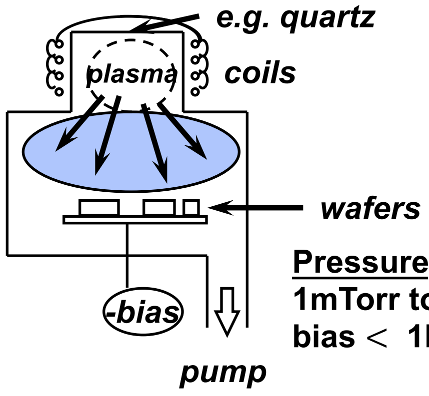
Enhance chemical reaction

Remote Plasma Reactors

<u>Plasma Sources</u>

(1) Transformer Coupled Plasma (TCP)

(2) Electron Cyclotron Resonance (ECR)

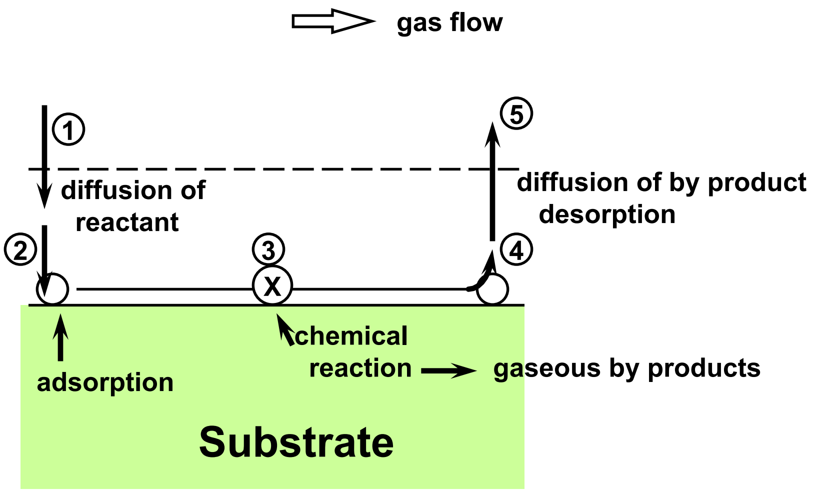


<u>Pressure</u>

1mTorr to 10mTorr

bias < 1kV

RIE Etching Sequence



gas flow

① diffusion of reactant

② adsorption

③ chemical reaction → gaseous by products

④ desorption

⑤ diffusion of by product

Substrate

Volatility of Etching Product

* Higher vapor pressure ⟹ higher volatility

$$e.g.\ Si + 4F^{*} \rightarrow SiF_4 \uparrow$$

$$e.g.\ Cu + Cl^{*} \rightarrow CuCl(low\, vapor\, pressure)$$

Example

Difficult to RIE Al-Cu alloy with high Cu content

Examples

For etching Si *Use CF_4 gas*

$$CF_4 + e \Leftrightarrow CF_3^{+} + F^{*} + 2e$$

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

F* are Fluorine radicals (highly reactive, but neutral)

Aluminum

$$CCl_4 + e \Leftrightarrow CCl_3^{+} + Cl^{*} + 2e$$

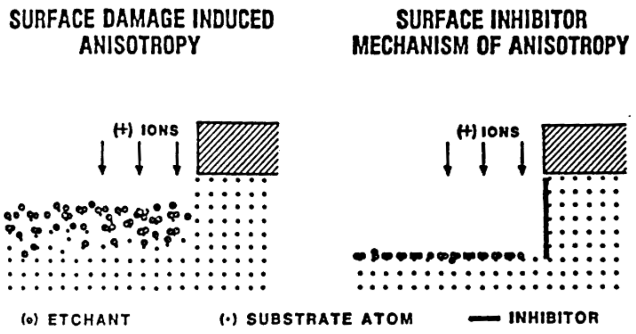
$$Al + 3Cl^{*} \rightarrow AlCl_3 \uparrow$$

Photoresist

$$C_xH_yO_z + O_2 \quad \begin{matrix} CO_x \\ HO_x \end{matrix}$$

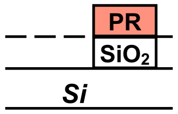
How to Control Anisotropy ?

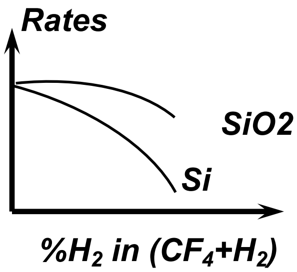
1) ionic bombardment to damage expose surface.
2) sidewall coating by inhibitor prevents sidewall etching.

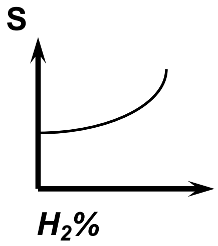


How to Control Selectivity ?

E.g. SiO_2 etching in CF_4+H_2 plasma







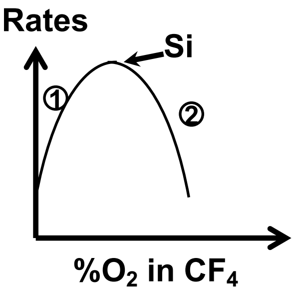
$$S = \frac{Rate\,SiO_2}{Rate\,Si}$$

Reason:

$$F^* + H \rightarrow HF \therefore F^* content\downarrow$$

$$\therefore SiF_4\downarrow$$

Example: Si etching in CF4+O2 mixture



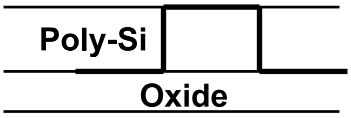
Reason:

$(1) O + CF_x \rightarrow COF_x + F^*$

F^* increases Si etching rate

$(2) Si + O_2 \rightarrow SiO_2$

$SiF_4 + O_2 \rightarrow SiO2 + 4F^* \therefore rate\downarrow$



Example: RIE of Aluminum Lines

It is a three-step sequence :

1) Remove native oxide with BCl_3

2) Etch Al with Cl-based plasma

3) Protect fresh Al surface with thin oxidation