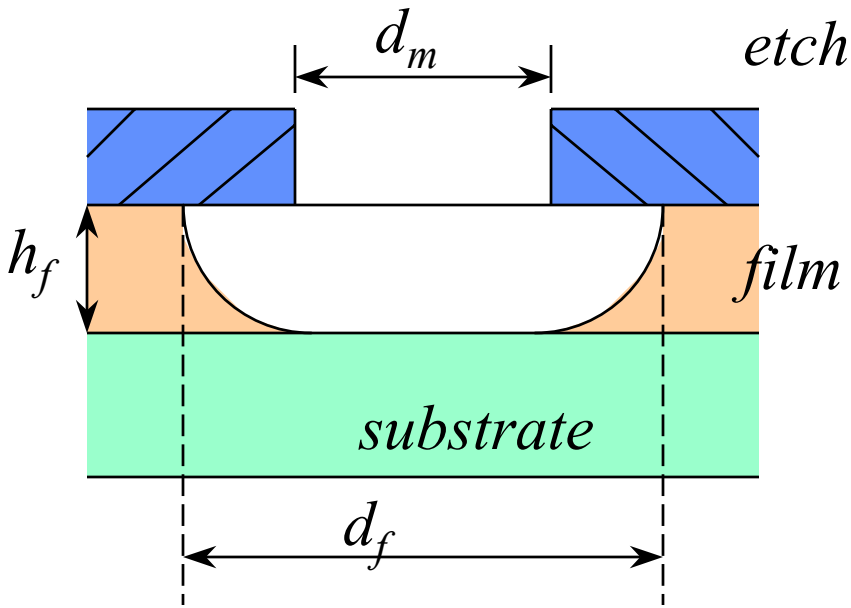
Etching

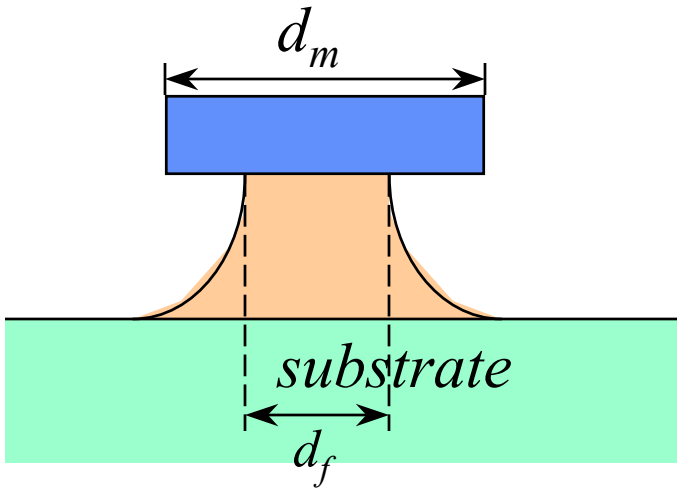
- Etching Terminology
- Etching Considerations for ICs
- Wet Etching
- Reactive Ion Etching (plasma etching)

Etch Process - Figures of Merit

- Etch rate
- Etch rate uniformity
- Selectivity
- Anisotropy

(1) Bias





$$Bias\ B \equiv d_f - d_m$$

B *can be* > 0 *or* < 0.

Complete Isotropic Etching

Vertical Etching = Lateral Etching Rate

$B = 2 \times h_f$

Complete Anisotropic Etching

Lateral Etching rate = 0

$B = 0$

(2) Degree of Anisotropy

$$A_f \equiv 1 - \frac{|B|}{2h_f}$$

$$0 \leq A_f \leq 1$$

isotropic *anisotropic*

$$\therefore \; |B| = 2h_f \qquad |B| = 0$$

(3) Etching Selectivity S

$$S_{AB} = \frac{v_A(\text{vertical etching velocity of materal A})}{v_B(\text{vertical etching velocity of materal B})}$$

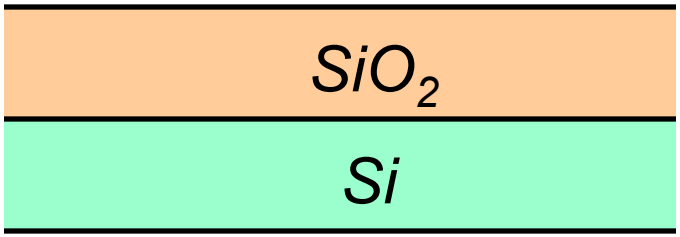
Wet Etching

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)

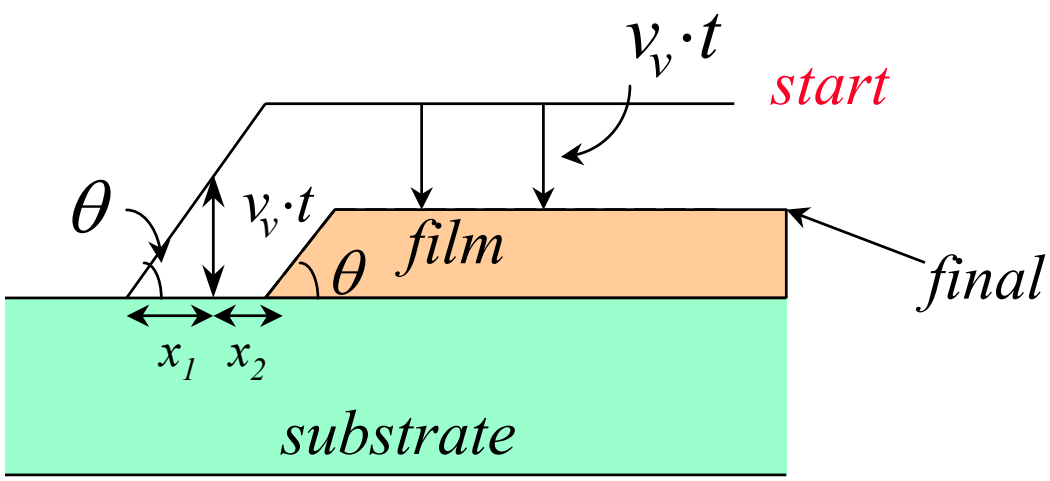
$S_{SiO2,\ Si}$ Selectivity is finite (~ 10)

Etching of Steps with a Slope

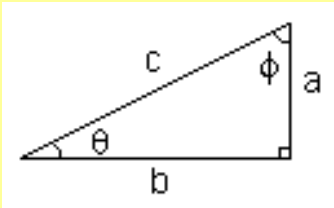
* Etching velocity has vertical component v_v and lateral component v_l

$$Let \quad etching\ time = t$$
$$v_v = vertical\ \ etch\ rate$$
$$v_l = lateral\ \ etch\ rate$$

$$x_1 = v_v \cdot t \cot\theta$$
$$x_2 = v_l \cdot t$$



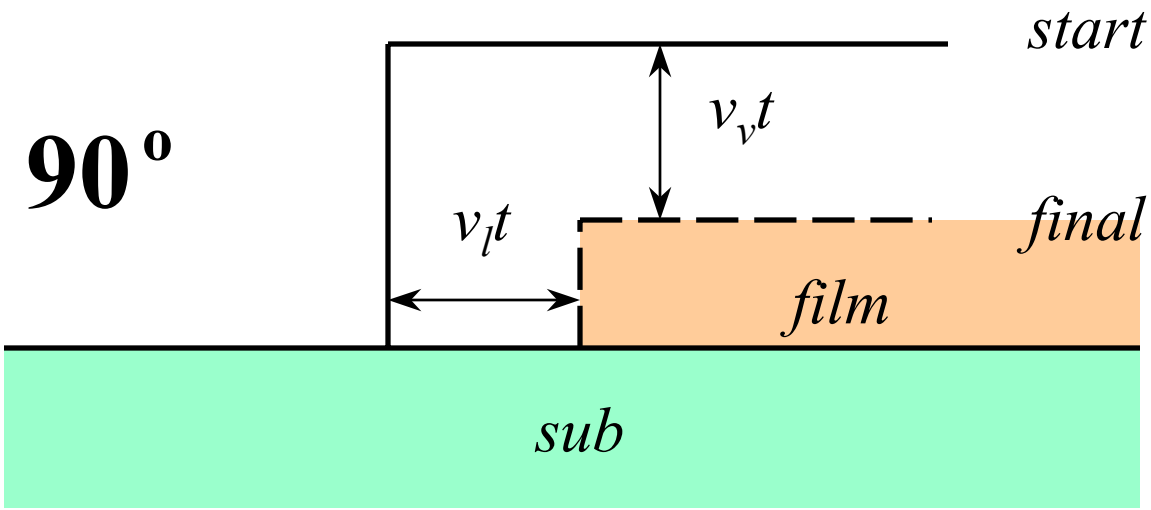
$$x = x_1 + x_2$$
$$= \left(v_v \cot\theta + v_l\right) \cdot t$$



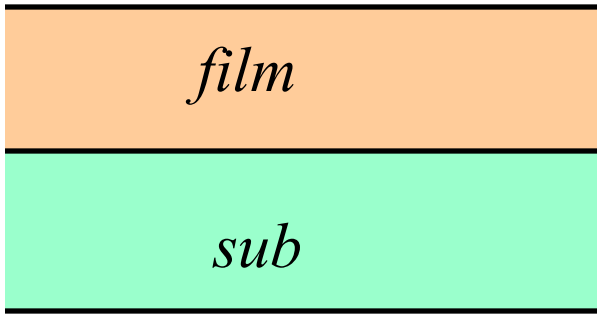
cot θ = 1/ tan θ = b / a

Slope etching examples

$\theta = 90^o$

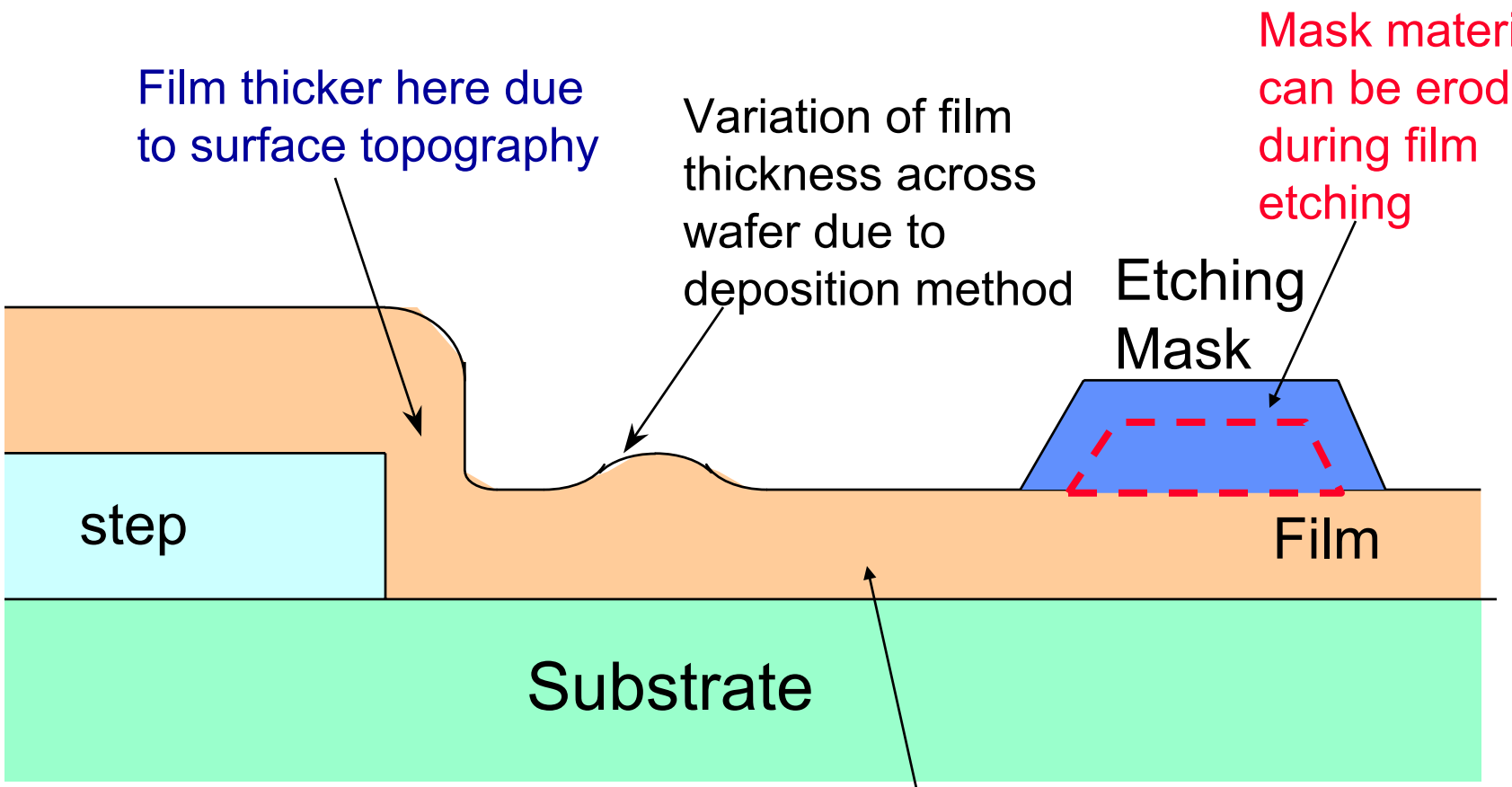


$\theta = 0^o$



Film etched uniformly laterally. Movement of "step" is "infinity".

Worst-Case Design Considerations for Etching



(a) Film thickness variation across wafer

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

Nominal thickness

Thickness variation factor

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

•Run-to-run variation of thickness data are recorded. Once the deposition process is under control, the maximum/minimum values will be used to define δ.

(b) Film etching rate variation

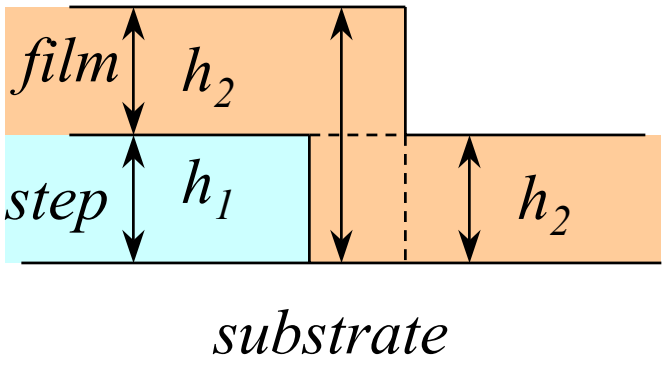
$$v_{f(min)} = v_f\left(1 - \phi_f\right)$$

variation factor

Worst – case etching time required to etch the film

$$= \frac{h_{f(max)}}{v_{f(min)}} = \frac{h_f}{v_f} \cdot \frac{\left(1+\delta\right)}{\left(1-\phi_f\right)}$$

(c) Over-etch around step

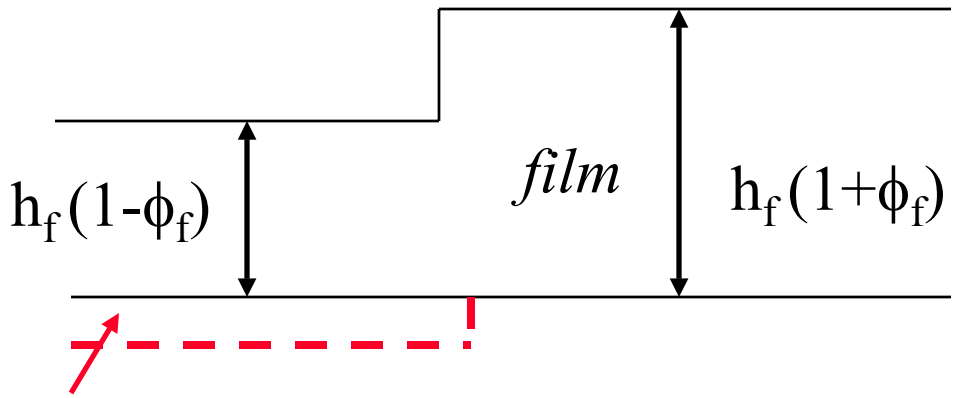


Fractional over-etch time to completely remove film
$= h_1 / h_2$

Total worst-case etching time

$$\therefore t_T = \frac{h_f(1+\delta)}{v_f(1-\phi_f)} \cdot (1+\Delta) \qquad \left(\Delta = \frac{h_1}{h_2}\right)$$

Example 1: Worst-case Consideration for substrate erosion



Film thickness has variation factor = δ

Film etching rate has variation factor = ϕ_f

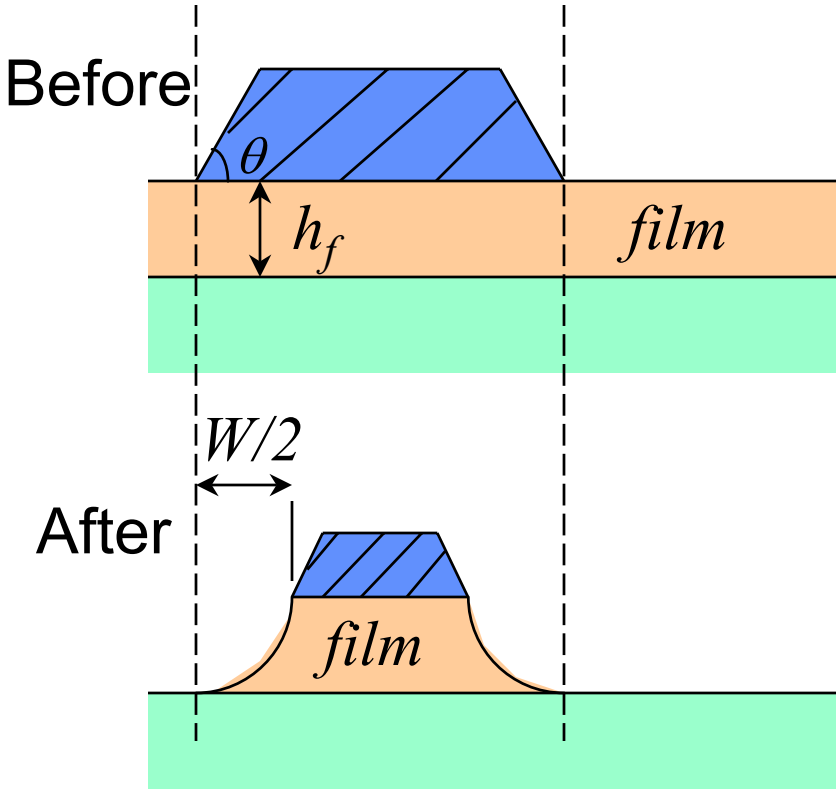
Thinnest part of film with be completely removed in $t_1 = \dfrac{h_f(1-\delta)}{v_f(1+\phi_f)}$

Thickest part of film with be completely removed in $t_2 = \dfrac{h_f(1+\delta)}{v_f(1-\phi_f)}$

Worst-case substrate erosion = $v_{substrate} \bullet (t_2 - t_1)$

Example 2: Worst-case Design With Mask Erosion

State-of-problem:
Mask material can be eroded during film etching.
Top of film will be smaller than original mask size by an amount W/2.



Let $v_{m\perp}$, $v_{m//}$ be the vertical and lateral etching rates of the mask.

Let v_f be the vertical etching rate of the film.

(lateral film etch rate is ignored In this example for simplicity)

$$\frac{W}{2} = \left(v_{m\perp}\cot\theta + v_{m//}\right)\cdot t_T$$

$$= \left(\frac{v_{m\perp}}{v_f}\right)\cdot h_f \cdot \frac{(1+\delta)(1+\Delta)}{\left(1-\phi_f\right)}\left[\cot\theta + \frac{v_{m//}}{v_{m\perp}}\right]$$

To minimize W

$$\theta \rightarrow 90^o$$

$$v_f >> v_{m\perp}$$

$$h_f \ small$$

Question: For a ***given*** allowable W/2 , what is the **minimum** etching selectivity between film and mask required?

$$S_{fm(\min)} = \frac{h_f}{\left(W/2\right)} \frac{(1+\delta)(1+\Delta)}{(1-\phi_f)} \left[\cot\theta + \frac{v_{m//}}{v_{m\perp}}\right]$$

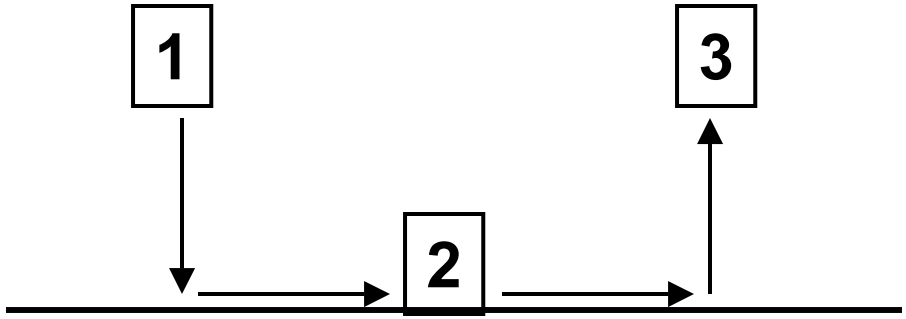
[Note] If $v_{m\perp}$ varies from run-to-run,

$$v_{m\perp(\max)} = v_{m\perp}(1+\phi_m)$$

$$\therefore S_{fm(\min)} = \frac{h_f}{W/2} \frac{(1+\delta)(1+\Delta)(1+\phi_m)}{1-\phi_f} \left[\cot\theta + \frac{v_{m//}}{v_{m\perp}}\right]$$

U_{fm} = *uniformity factor*

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
- 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

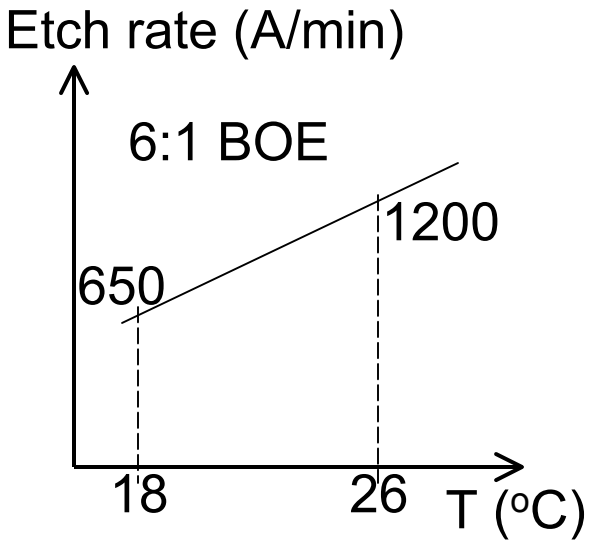
=> high reactivity of acids

Wet Etch Processes

(1) Silicon Dioxide

To etch SiO_2 film on Si, use

$HF + H_2O$



$$SiO_2 + 6HF \rightarrow H_2 + SiF_6 + 2H_2O$$

Note: HF is usually buffered with NH_4F to maintain $[H^+]$ at a constant level (for constant etch rate)

$$NH_4F \rightarrow NH_3 + HF$$

Wet Etch Processes (cont.)

(2) Silicon Nitride

To etch Si_3N_4 film on SiO_2, use

H_3PO_4

(phosphoric acid)

(180^oC: ~100 A/min etch rate)

Typical selectivities:

- 10:1 for nitride over oxide
- 30:1 for nitride over Si

Wet Etch Processes (cont.)

(3) Aluminum

To etch Al film on Si or SiO_2, use

$$H_3PO_4 + CH_3COOH + HNO_3 + H_2O$$

(phosphoric acid) (acetic acid) (nitric acid)

(~30^oC)

$$6H^+ + 2Al \rightarrow 3H_2 + 2Al^{3+}$$

(Al^{3+} is water-soluble)

Wet Etch Processes (cont.)

(4) Silicon

(i) Isotropic etching

Use $HF + HNO_3 + H_2O$

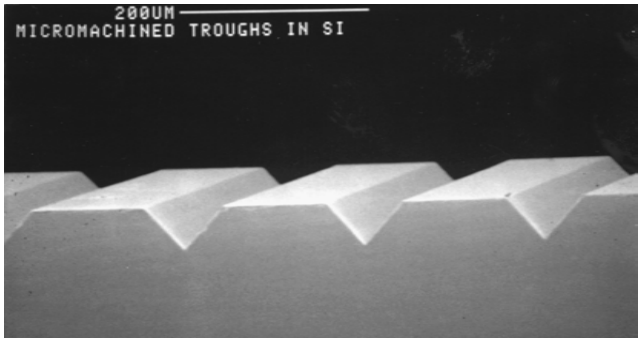
$$3Si + 4HNO_3 \rightarrow 3SiO_2 + 4NO + 2H_2O$$

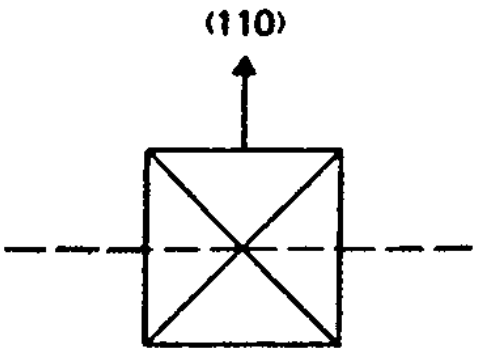
$$3SiO_2 + 18HF \rightarrow 3H_2SiF_6 + 6H_2O$$

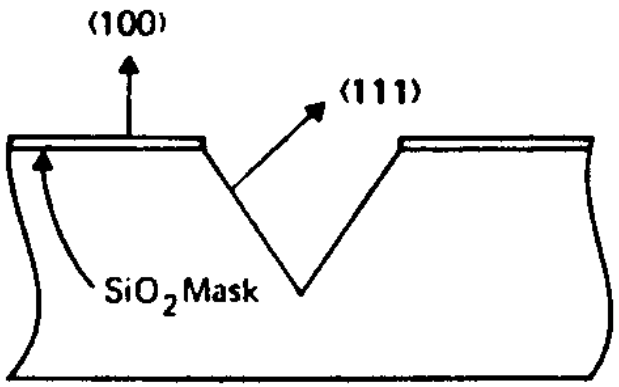
(ii) **Anisotropic etching (e.g. KOH, EDP)**

Effect of Slow {111} Etching with KOH or EDP

Mask opening aligned in <110> direction => {111} sidewalls







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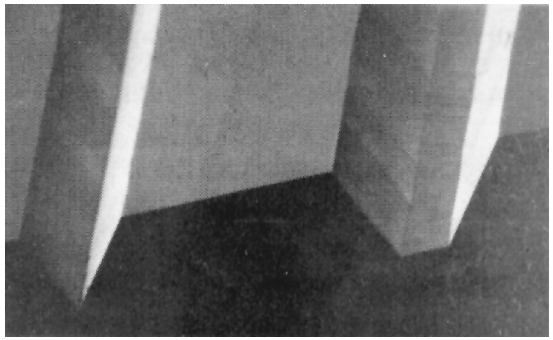
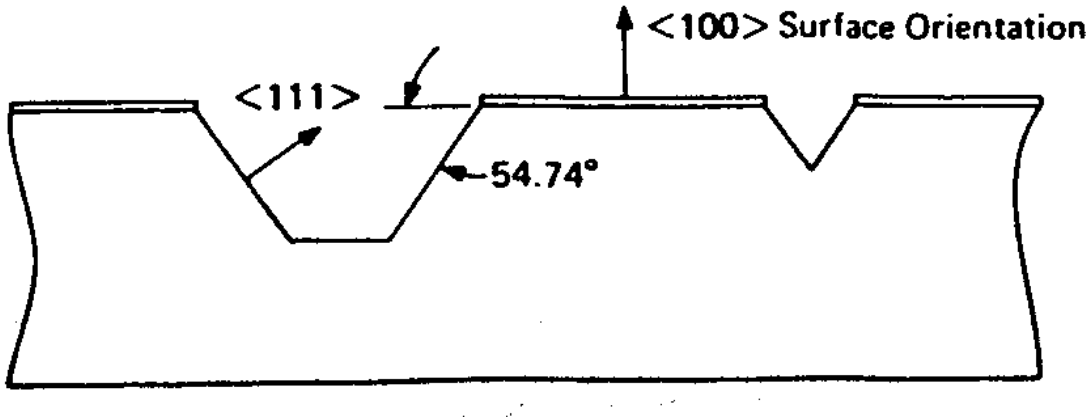
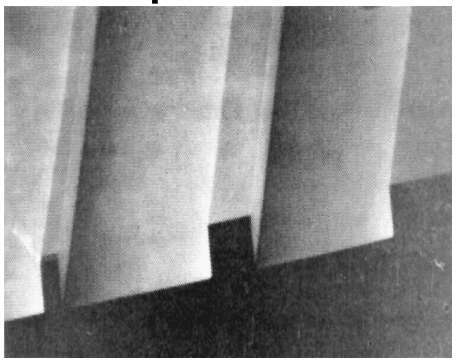


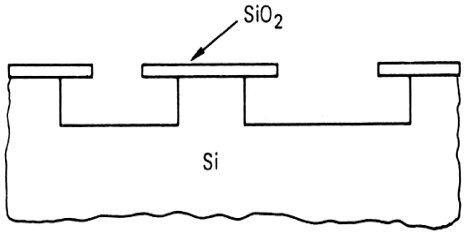


[110]-Oriented Silicon

{111} planes oriented perpendicular to the (110) surface

=> possible to etch pits with vertical sidewalls!



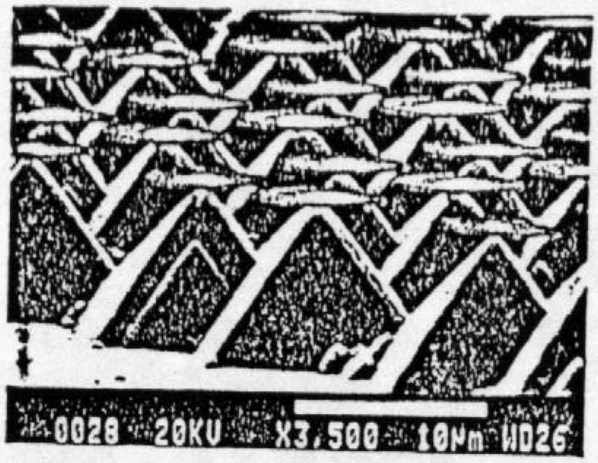


Bottom of pits are

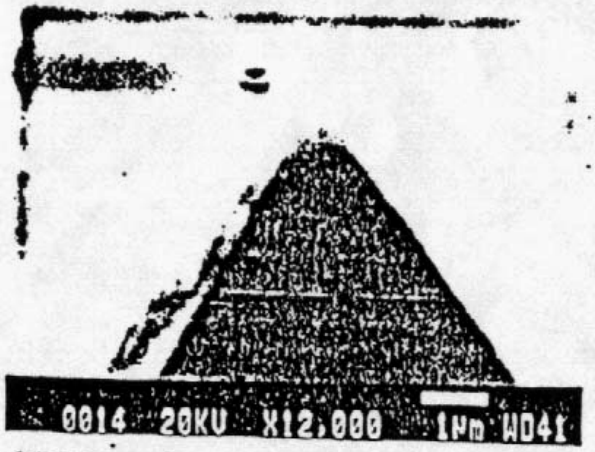
- flat ({110} plane) if KOH is used
  {100} etches slower than {110}
- V-shaped ({100} planes) if EDP is used
  {110} etches slower than {100}

(3) Field-Emission Tips

Tungsten Field Emitter

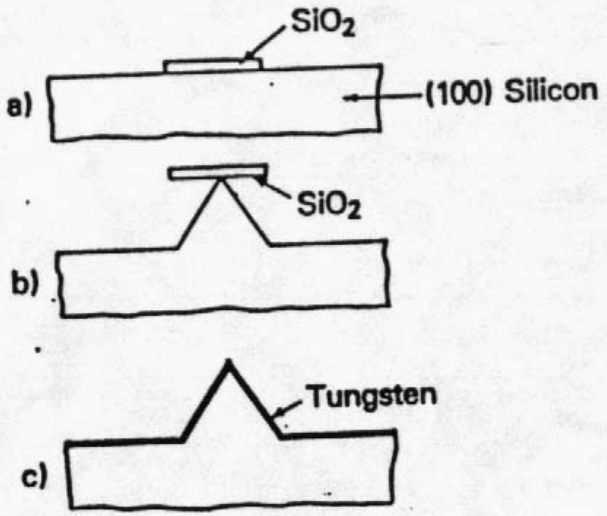


Before tungsten conversion



After tungsten conversion

Protruding From the Silicon Pyramid



EPW Etchant
- 660 ml ethylenediamine
- 140 gr pyrocatechol
- 330 ml water

110°C, 15 min.

Drawbacks of Wet Etching

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

=> Wet etching used for **noncritical** feature sizes