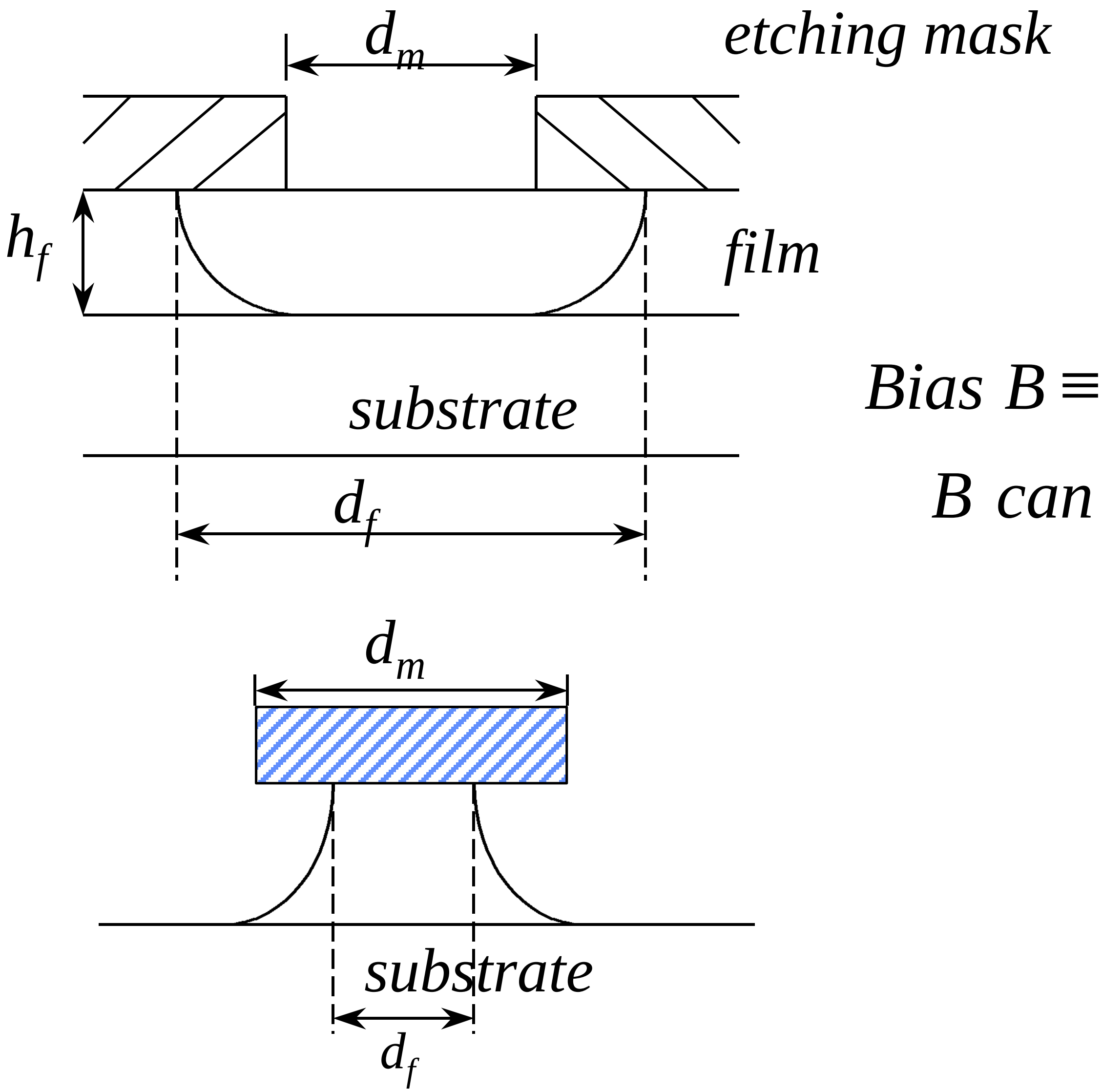
Etching

- **Etching Terminologies**
- **Etching Considerations for IC**
- **Wet Etching**
- **Reactive Ion Etching (plasma etching)**

Etch Process - Figures of Merit

- Etch rate
- Etch rate uniformity
- Selectivity
- Anisotropy

(1) Bias



$$\text{Bias } B \equiv d_f - d_m$$

$$B \text{ can be} > 0 \text{ or} < 0.$$

* *Complete Isotropic etching*

Vertical Etching = Lateral Etching Rate

$$B = 2 \cdot h_f$$

* *Complete Anisotropic Etching*

Lateral Etching rate = 0

B = 0

(2) Degree of Anisotropy

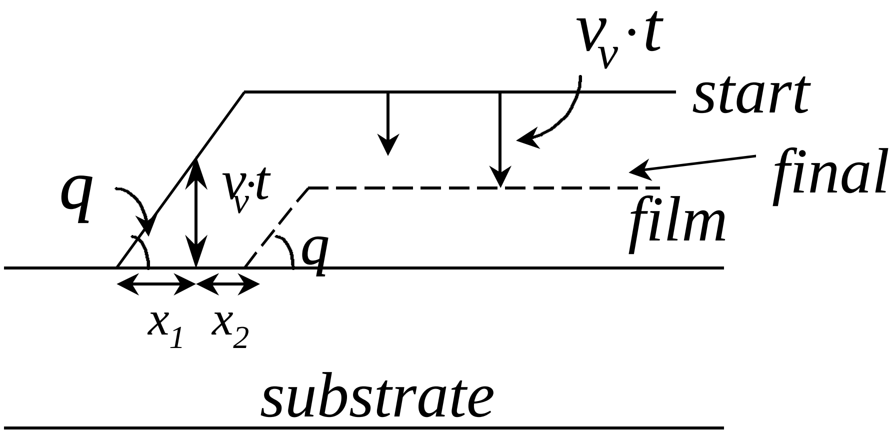
$$A_f \equiv 1 - \frac{|B|}{2h_f}$$

$$0 \leq A_f \leq 1$$

isotropic *anisotropic*

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

Etching of Steps with a Slope



$$x_1 = v_v \cdot t \cot q$$

$$x_2 = v_l \cdot t$$

Let etching time = t

v_v = *vertical etch rate*

v_l = *lateral etch rate*

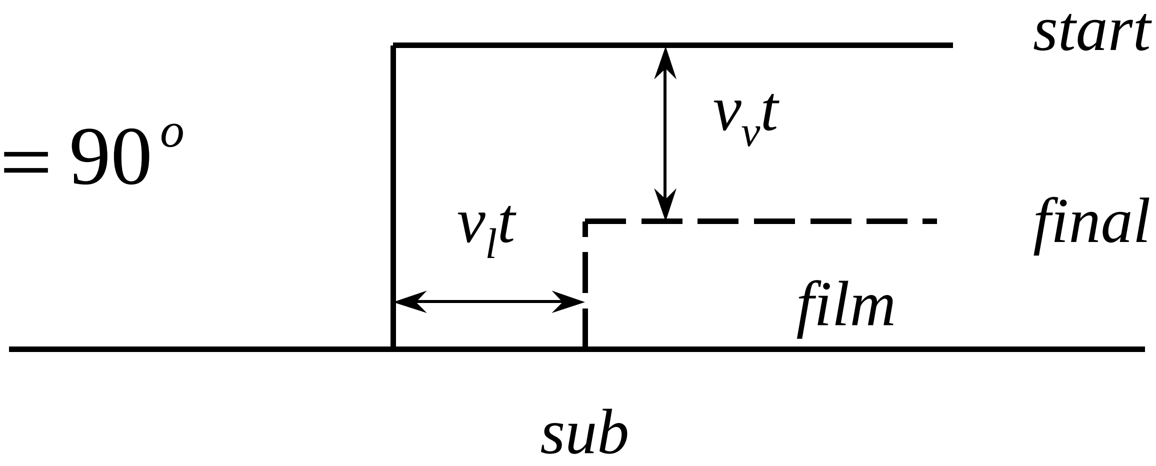
$\therefore$ *To minimize x* $\Rightarrow$ *make è large*

$$x = x_1 + x_2$$

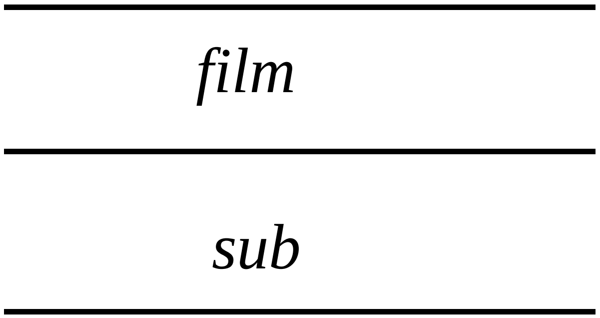
$$= \left(v_v \cot q + v_l\right) \cdot t$$

Example

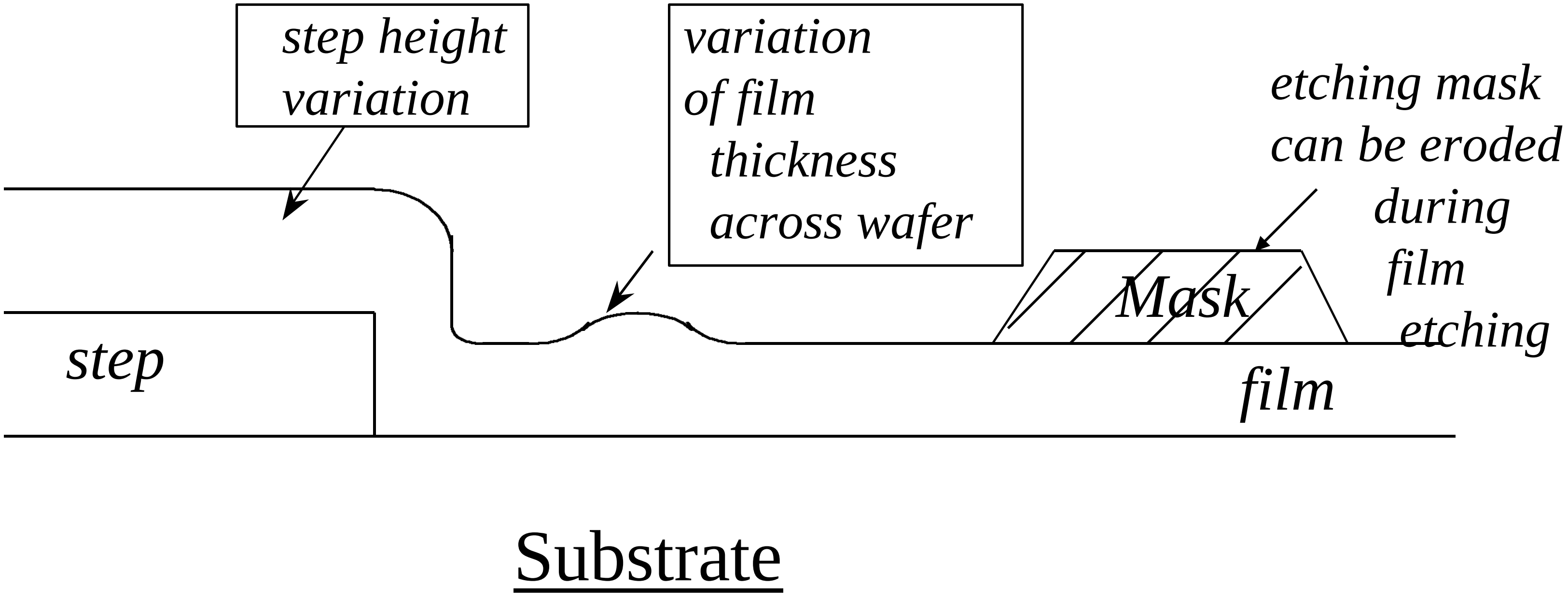
$q = 90^o$



$q = 0^o$



Worst-Case Design Considerations for Etching



step height variation

variation of film thickness across wafer

etching mask can be eroded during film etching

Mask

step

film

Substrate

(a) Film thickness variation:

target thickness value

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

variation factor

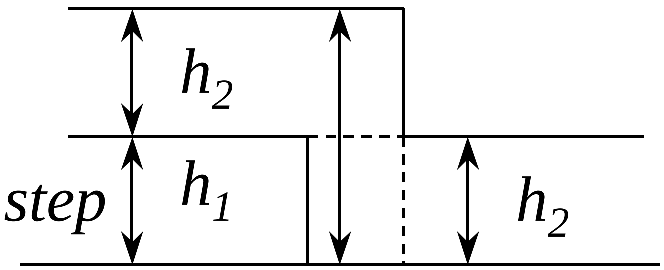
(b) Film etching rate variation

$$v_{f(\min)} = v_f\left(1 - f_f\right) \leftarrow \textit{variation}$$

$\therefore$ *Worst – case etching time required to etch the film*

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

(c) Overetching around step

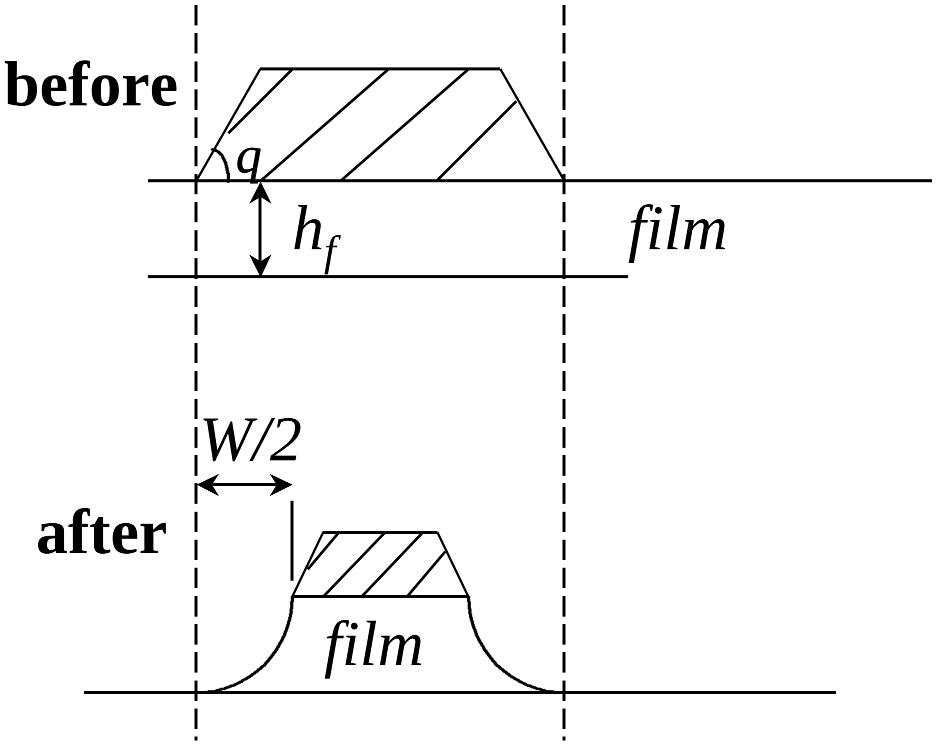


Overetch time (fraction)

$$= \frac{h_1 + h_2}{h_2}$$

$$\therefore \overset{\overset{\text{total}}{\swarrow}}{t_T} = \frac{h_f(1+d)}{v_f(1-f_f)}\cdot(1+\Delta) \qquad \left(\Delta = \frac{h_1}{h_2}\right)$$

(d) With Mask Erosion



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

Let v_f *be the vertical etching rate of the film.*

(ignoring lateral film rate for simplicity)

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

$$= \left(\frac{v_{m\perp}}{v_f}\right) \cdot h_f \cdot \frac{(1+d)(1+\Delta)}{\left(1-f_f\right)} \left[\cot \mathbf{q} + \frac{v_{m//}}{v_{m\perp}}\right]$$

Goal : Minimize W

$$\textit{Small}\ \ W \qquad \mathbf{q} \rightarrow 90^o$$

$$v_f >> \mathbf{n}_{m\perp}$$

$$h_f\ \textit{small}$$

Etching Selectivity S_{fm}

$$S_{fm} \equiv \frac{V_{f\perp}}{V_{m\perp}} \left(\textit{vertical components only}\right)$$

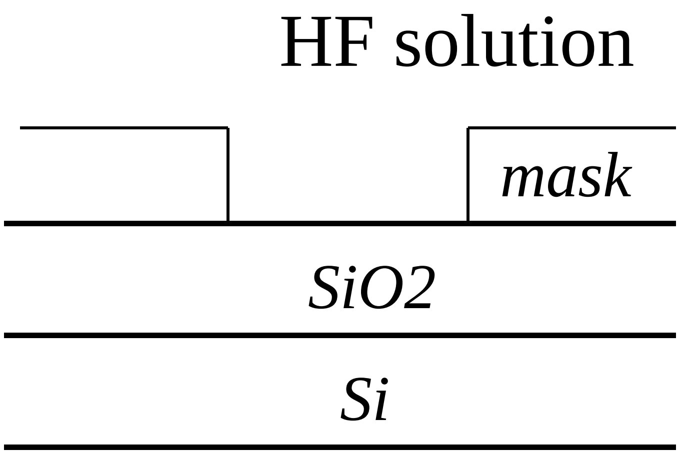
Wet Etching

S_{fm} is controlled by: chemicals, concentration, temp.

RIE

S_{fm} is controlled by:
plasma parameters, plasma chemistry
gas pressure , flow rate & temperature

Examples



SiO2/Si etched by HF solution

S_{fm} Selectivity is very large (~ infinity)

SiO2/Si etched by RIE (e.g. CF4)

S_{fm} Selectivity is finite (~ 10)

For a given allowable W/2 , what is the **minimum** selectivity required?

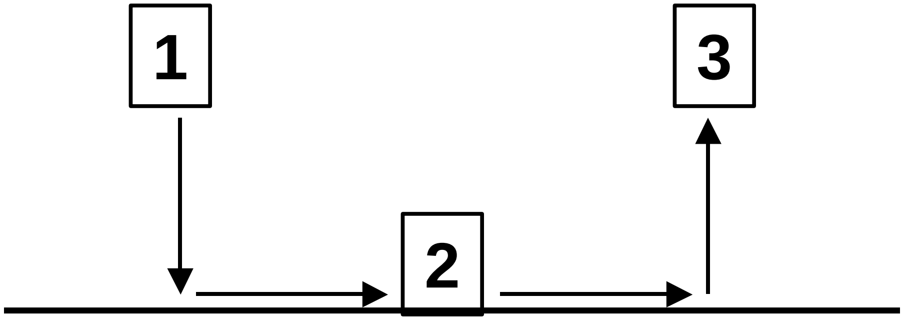
$$S_{fm(\min)} = \frac{h_f}{\left(w/2\right)} \frac{(1+d)(1+\Delta)}{\left(1-f_f\right)} \left[\cot q + \frac{v_{m//}}{v_{m\perp}}\right]$$

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

$$v_{m\perp(\max)} = v_{m\perp}\left(1+f_m\right)$$

$$\therefore S_{fm(\min)} = \frac{h_f}{W/2} \underbrace{\frac{(1+d)(1+\Delta)(1+f_m)}{1-f_f}}_{U_{fm} = uniformity\ \ factor} \left[\cot q + \frac{v_{m//}}{v_{m\perp}}\right]$$

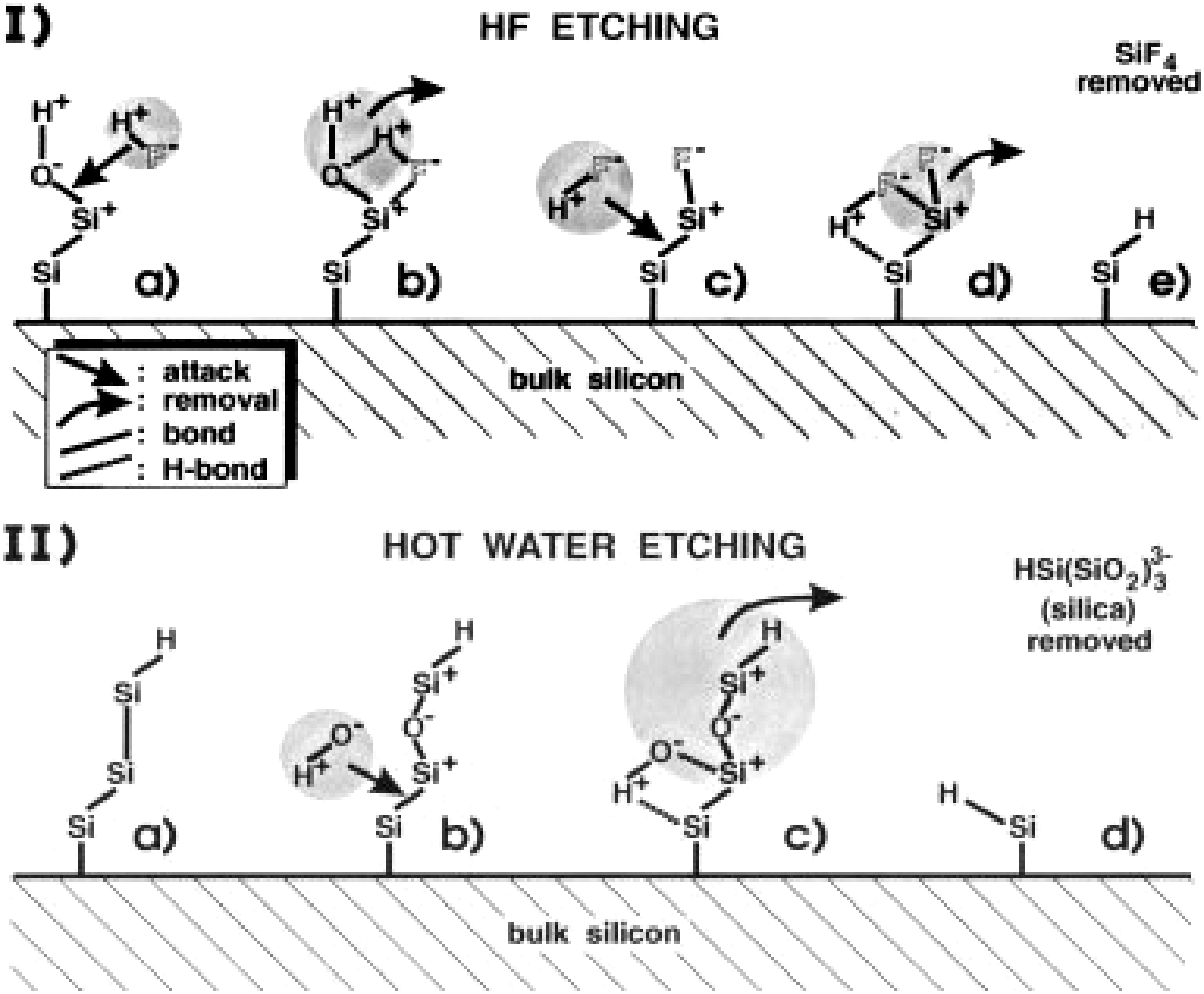
Wet Etching



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


I)
HF ETCHING
SiF4 removed
H+
H+
O-
F-
Si+
Si
a)
H+
H+
O-
F-
Si+
Si
b)
F-
H+
F-
Si+
Si
c)
F-
F-
H+
Si+
Si
d)
H
Si
e)
: attack
: removal
: bond
: H-bond
bulk silicon
II)
HOT WATER ETCHING
HSi(SiO2)3 3-
(silica)
removed
H
Si
Si
Si
a)
O-
H+
H
Si+
O-
Si+
Si
b)
H
Si+
O-
O-
Si+
H+
Si
c)
H
Si
d)
bulk silicon

Wet Etching (cont.)

- Wet etch processes are generally isotropic
- Wet etch processes can be highly selective
- Acids are commonly used for etching:

$$HNO_3 \Leftrightarrow H^+ + NO_3^-$$

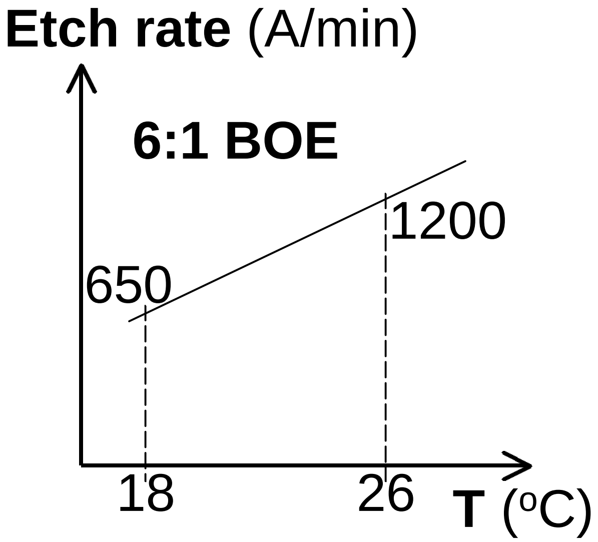
$$HF \Leftrightarrow H^+ + F^-$$

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^{o}C: ~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

$\mathbf{H_3PO_4 + CH_3COOH + HNO_3 + H_2O}$

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

(~30°C)

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

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

Wet Etch Processes (cont.)

(4) Silicon

(i) Isotropic etching

Use $HF + HNO_3 + H_2O$

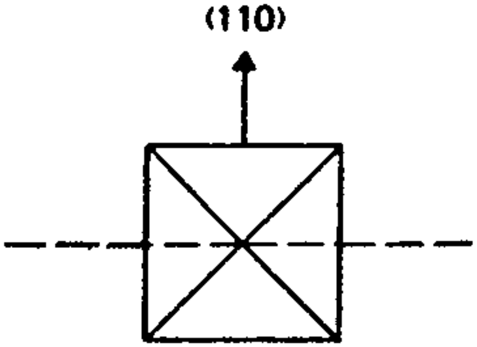
$$3Si + 4HNO_3 \rightarrow 3SiO_2 + 4NO + 2H_2O$$

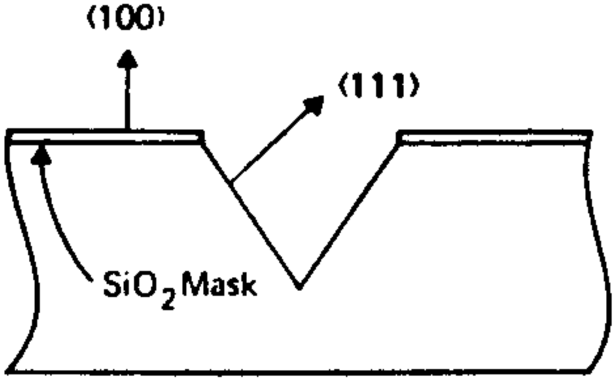
$$3SiO_2 + 18HF \rightarrow 3H_2SiF_6 + 6H_2O$$

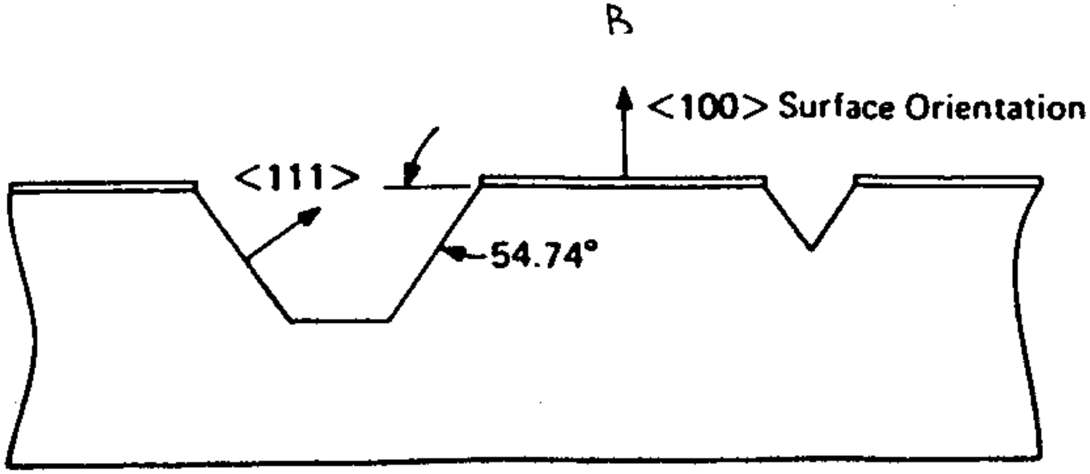
(ii) Anisotropic etching (e.g. KOH, EDP)

Effect of Slow {111} Etching

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







[110]-Oriented Silicon

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

=> possible to etch pits with vertical sidewalls!

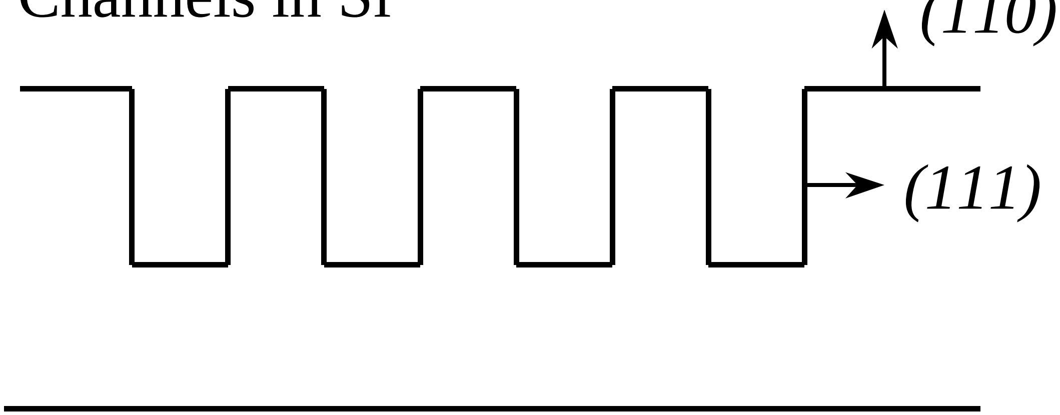
- Bottom of pits are
  - flat ({110} plane) if KOH is used

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

    {110} etches slower than {100}

Anisotropic Si Etching: Applications

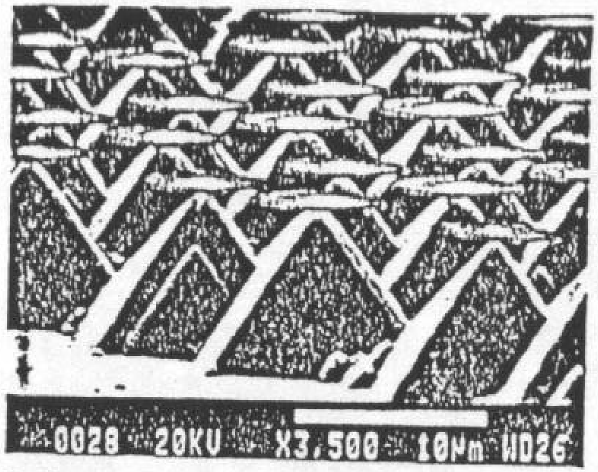
(1) Channels in Si



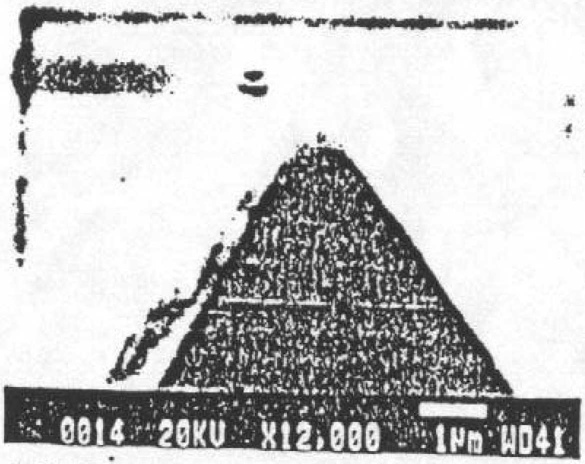
(2) Si membrane

(3) Field-Emission Tips

Tungsten Field Emitter

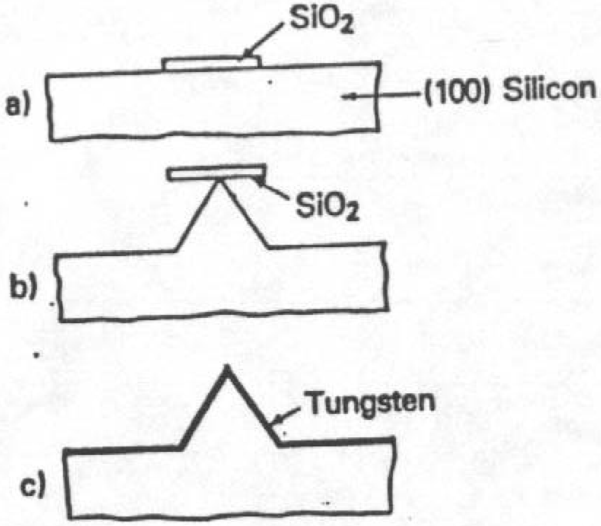


Before tungsten conversion



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