a)

- Reactions are as follows:

$$6 \, HF_{(g)} + SiO_{2(s)} \longrightarrow H_2SiF_6^{(l)} + 2 H_2O^{(l)} \qquad \_\_(i)$$
$$H_2SiF_6^{(l)} \longrightarrow SiF_4 \, (g) + 2 HF \, (g) \qquad \_\_(ii)$$
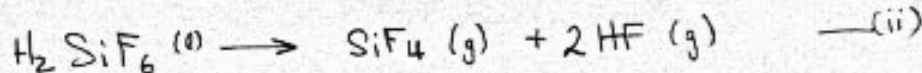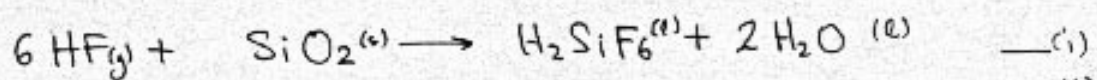
- Thus, net reaction: add (i) & (ii) to get

$$\boxed{4HF + SiO_2 \longrightarrow SiF_4 + 2H_2O}$$
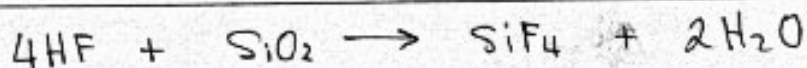
- Process flow diagram is as follows:
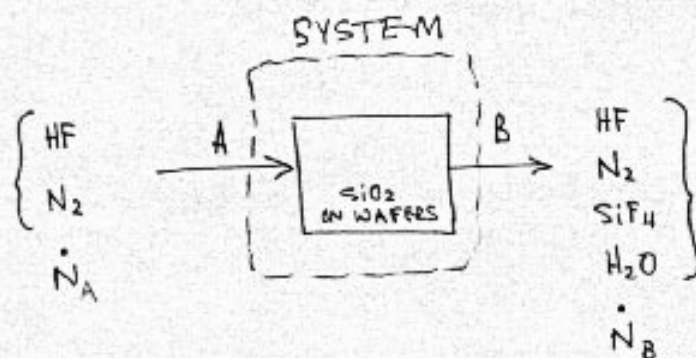
with x as mole fraction:
$$(X_{HF})_A = 0.5$$
$$(X_{N_2})_A = 0.5$$
$$(X_{HF})_A \dot{N}_A = 0.01 \, mole/min$$
$$\underbrace{\qquad\qquad} = \dot{n}_{HF_0}$$
molar flow of HF in stream A.

- What is $\dot{\varepsilon}$? Well, we know that 10% of the HF is consumed. Thus 90% of it remains in stream B. Mathematically,

$$\dot{n}_{HF} - \dot{n}_{HF_0} = \nu_{HF} \dot{\varepsilon} \qquad (S+VN \ 15.4)$$
$$0.9 \, \dot{n}_{HF_0} - \dot{n}_{HF_0} = \nu_{HF} \dot{\varepsilon}$$
$$(-0.1) \, \dot{n}_{HF_0} = \nu_{HF} \dot{\varepsilon}$$

so,
$$\boxed{\dot{\varepsilon} = \frac{(-0.1) \dot{n}_{HF_0}}{\nu_{HF}}}$$

- and since $\dot{n}_{HF_0}$ = molar flow of HF into process = 0.01 mole/min

— then

$$\dot{\varepsilon} = \frac{(-0.1)(0.01)}{(-4)}$$

$$= 2.5 \times 10^{-4} \text{ mole/min}$$

— Now draw up the mass balance table as suggested:

	Moles	A	B	Gen
a)	HF	$0.01 \frac{\text{mole}}{\text{min}}$	$-X_{HF} \dot{N}_B$	$\nu_{HF} \dot{\varepsilon}$
b)	SiF_4	0	$-X_{SiF_4} \dot{N}_B$	$\nu_{SiF_4} \dot{\varepsilon}$
c)	H_2O	0	$-X_{H_2O} \dot{N}_B$	$\nu_{H_2O} \dot{\varepsilon}$
d)	N_2	$0.01 \frac{\text{mole}}{\text{min}}$	$-0.01 \frac{\text{mole}}{\text{min}}$	0

N_2 does not take part in reaction

NOTE: I have used a capital N to indicate TOTAL STREAM FLOWS, $\dot{N}_A$ & $\dot{N}_B$. I use a small n to indicate COMPONENT FLOWS, eg $\dot{n}_{HF}$, $\dot{n}_{HF_o}$, $\dot{n}_{SiF_4}$. This is slightly different from class and the book — I think it makes things a little clearer.

— The table above gives you 3 equations to be solved, namely:

$$0.01 - X_{HF} \dot{N}_B + \nu_{HF} \dot{\varepsilon} = 0 \qquad \underline{\qquad} a)$$

$$- X_{SiF_4} \dot{N}_B + \nu_{SiF_4} \dot{\varepsilon} = 0 \qquad \underline{\qquad} b)$$

$$- X_{H_2O} \dot{N}_B + \nu_{H_2O} \dot{\varepsilon} = 0 \qquad \underline{\qquad} c)$$

(the equation for N_2, d), contains no variables).

- We could go ahead and try to solve these, but it is easier if we notice that $(x_i \dot{N}_B)$ in each equation represents the <u>MOLAR FLOW OF COMPONENT i IN STREAM B</u>. So if we add these up, we will get the <u>TOTAL MOLAR FLOW OF STREAM B</u>.

- Mathematically,

$$\text{Total molar flow of B} = \dot{N}_B$$
$$= \dot{N}_B (1)$$
$$= \dot{N}_B \sum_i x_i$$
$$= \sum_i (x_i \dot{N}_B)$$

(cloud note: $\sum_i x_i = 1$)

- Hence, from equation a):

a)
$$0.01 - x_{HF} \dot{N}_B + \nu_{HF} \dot{\varepsilon} = 0$$
$$\therefore \quad x_{HF} \dot{N}_B = 0.01 + \nu_{HF} \dot{\varepsilon}$$
$$= (0.01) + (-4)(2.5 \times 10^{-4})$$
$$= \underline{0.009 \text{ mole/min } HF}$$

- And,

b)
$$- x_{SiF_4} \dot{N}_B + \nu_{SiF_4} \dot{\varepsilon} = 0$$
$$\therefore \quad x_{SiF_4} \dot{N}_B = (+1)(2.5 \times 10^{-4})$$
$$= \underline{2.5 \times 10^{-4} \text{ mole/min } SiF_4}$$

c)
$$- x_{H_2O} \dot{N}_B + \nu_{H_2O} \dot{\varepsilon} = 0$$
$$\therefore \quad x_{H_2O} \dot{N}_B = (+2)(2.5 \times 10^{-4})$$
$$= \underline{5.0 \times 10^{-4} \text{ mole/min } H_2O}$$

– Thus,

$$\dot{N}_B = \sum_i x_i \dot{N}_B$$

$$= \underbrace{(0.009)}_{HF} + \underbrace{(2.5\times10^{-4})}_{SiF_4} + \underbrace{(5.0\times10^{-4})}_{H_2O} + \underbrace{(0.01)}_{N_2}$$

$$= \underline{0.0198 \text{ mole/min total flow}}$$

– Mole fractions are then easily calculated from:

$$X_{HF} = \frac{(X_{HF}\dot{N}_B)}{\dot{N}_B} = \frac{(0.009)}{(0.0198)} = \underline{45.57\%}$$

$$X_{SiF_4} = = \frac{(2.5\times10^{-4})}{(0.0198)} = \underline{1.27\%}$$

$$X_{H_2O} = = \frac{(5.0\times10^{-4})}{(0.0198)} = \underline{2.53\%}$$

$$X_{N_2} = = \frac{(0.01)}{(0.0198)} = \underline{50.63\%}$$

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b) For surface area of $1m^2$:

Etching rate of $SiO_2 = |\nu_{SiO_2}\dot{\varepsilon}|$

$$= |(-1)(2.5\times10^{-4}\text{ mole/min})|$$

$$= \underline{2.5\times10^{-4} \text{ mole/min}}$$

– Need to convert

$$\frac{mole}{min} \xrightarrow[\substack{\uparrow \\ MW \\ = 60\ g/mole}]{} \frac{g}{min} \xrightarrow[\substack{\uparrow \\ \rho_{SiO_2} \\ = 2.2\ g/cm^3}]{area} \frac{cm}{min} \longrightarrow \frac{\mathring{A}}{min}$$

from CRC,
Merck Index,
Semiconductor text

Thus,

$$\text{Etch rate} = \frac{|v_{SiO_2, \dot{\varepsilon}}| \cdot MW_{SiO_2}}{\rho_{SiO_2} \cdot A}$$

$$= \frac{\left(2.5 \times 10^{-4} \frac{\text{mole}}{\text{min}}\right)\left(60 \frac{g}{\text{mole}}\right)}{\left(2.2 \frac{g}{\text{cm}^3}\right)\left(1 \text{ m}^2\right)\left(\frac{10^4 \text{ cm}^2}{1 \text{ m}^2}\right)}$$

$$= \underline{6.818 \times 10^{-7} \frac{\text{cm}}{\text{min}}} \longrightarrow$$

Typically, report as $\mathring{A}/\text{min}$:

$$= \left(6.818 \times 10^{-7} \cdot \frac{\text{cm}}{\text{min}}\right)\left(\frac{1 m}{10^2 \text{ cm}}\right)\left(\frac{10^{10} \mathring{A}}{1 m}\right)$$

$$= \underline{\underline{68 \ \mathring{A}/\text{min}}} \longrightarrow$$