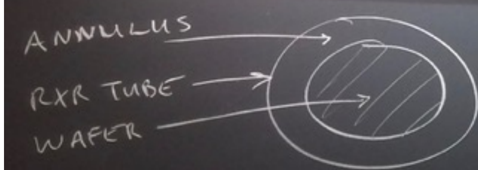
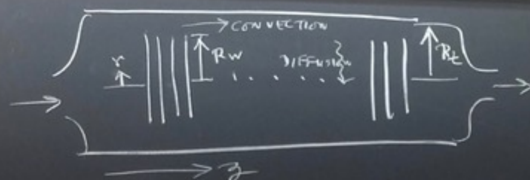
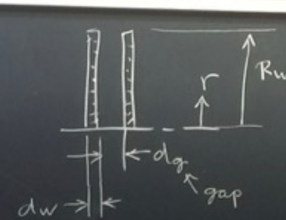
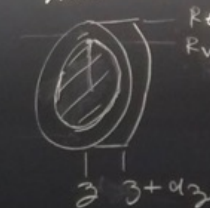






CONTROL VOL. FOR ANNULUS



SERIES RXN SCHEME

SILYLENE (C_2)

SILANE (C_1)

$$\underbrace{SiH_4(g) \xrightarrow{k_g} SiH_2(g)}_{\text{GAS PHASE RXN}} + \underbrace{H_2(g) \xrightarrow{k_w} Si(s) + 2H_2(g)}_{\text{RXN OVER SURFACE}}$$

TWO ZONES: CONVECTION & RXN IN ANNULUS

+ DIFFUSION + RXN BETWEEN WAFERS

BALANCE ON C_1 IN ANNULUS C_{10}

ACCUM = NET INTO CONTROL VOL. BY FLOW + GEN. BY RXN + GEN BY DIFFUSION OUT OF WAFER STACK

UNITS OF EQN.

$$\left[\frac{mol}{m \cdot s}\right]$$

SEE NOTES ON WEB FOR DETAILS

$$0 = -\underbrace{\pi\left(R_w^2 - R_t^2\right)}_{\text{VOL. OF ANNULUS PER UNIT LENGTH}} u \frac{\partial C_{10}}{\partial z} - \pi\left(R_w^2 - R_t^2\right) k_g C_{10} + \underbrace{2\pi R_w}_{\text{GEOMETRIC AREA OF WAFER STACK PER UNIT LENGTH}} D_1 \left[\frac{\partial C_1}{\partial r}\right]_{R_w}$$

MEAN FLOW VELOCITY

WE WANT TO INTEGRATE DOWN TUBE TO GET $C_{10}(z) \Longrightarrow \frac{dC_{10}}{dz} = f(\ldots ? \ldots)$

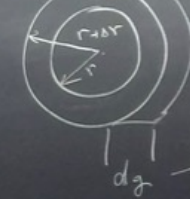
(EVENTUALLY WE WANT $C_{10}(z)$, $C_{20}(z)$, $C_1(r)$, $C_2(r)$, & LAYER THICKNESS VS. r & t & z)

HOW DO WE GET $\left[\frac{\partial C_1}{\partial r}\right]_{R_w}$? $\longrightarrow$ NEED $C_1(r)$ BETWEEN WAFERS $\longrightarrow$ THEN TAKE DERIVATIVE

HOW DO WE GET THIS?

WRITE BALANCE EQN ON C_1 BETWEEN WAFERS. $\longrightarrow$ CONTROL VOL.

SEE NOTES ON WEB FOR DETAILS



ASSUME NEG'L C_1 GRADIENT IN z DIRECTION

$$\frac{d^2\psi}{d\lambda^2} + \frac{1}{\lambda}\frac{d\psi}{d\lambda} - \phi^2\psi = 0$$

B.C. @ $\lambda = 0$ $\quad \dfrac{d\psi}{d\lambda} = 0$

@ $\lambda = 1$ $\quad \psi = 1$

$$\psi = \frac{C_1(\lambda)}{C_1(1)} = \frac{C_1(\lambda)}{C_{10}} \; ; \; \lambda = \frac{r}{R_w} \; ; \; \phi = R_w\sqrt{\frac{k_g}{D_1}}$$

THIELE MODULUS

$$\psi(\lambda) = \frac{I_0(\phi\lambda)}{I_0(\phi)}$$

MODIFIED (HYPERBOLIC) BESSEL FUNCTION OF THE FIRST KIND (I) OF ORDER ϕ (0)

BECAUSE OF CYLINDRICAL GEOM.

& GET $C_1(r)$ & $\left[\dfrac{dC_1}{dr}\right]_{R_w}$ FOR ANNULUS BALANCE

$$2D_1\left[\frac{d\psi}{d\lambda}\right]_{\lambda=1} = R_w^2\,\eta\,k_g(\psi = 1)$$

ORDER 1

$$\eta = \frac{2}{\phi^2}\left[\frac{d\psi}{d\lambda}\right]_{\lambda=1} = \frac{2}{\phi}\,\frac{I_1(\phi)}{I_0(\phi)}$$

WE WANT UNIFORMITY ACROSS RADIUS

WE WANT "FLAT" C_1 PROFILES vs. r

$\therefore$ WE WANT SMALL $\phi = R_w\sqrt{\dfrac{k_g}{D_1}}$ $\leftarrow$ CONSIDER LOWER T's

LARGE TO MAKE MANY CIRCUITS PER WAFER

$D \propto T^{3/2}$

$\therefore$ LOW P CVD $\rightarrow$ $D \propto \dfrac{1}{P}$

BALANCE ON C_1 IN ANNULUS C_{10}

ACCUM = NET INTO CONTROL VOL. BY FLOW + GEN. BY RXN + GEN BY DIFFUSION OUT OF WAFER STACK

SEE NOTES ON WEB FOR DETAILS

$$0 = -\underbrace{\pi\left(R_w^2 - R_t^2\right)}_{\text{VOL. OF ANNULUS PER UNIT LENGTH}} u \frac{\partial C_{10}}{\partial z} - \pi\left(R_w^2 - R_t^2\right) k_g C_{10} + \underbrace{2\pi R_w}_{\text{GEOMETRIC AREA OF WAFER STACK PER UNIT LENGTH}} D_1 \left[\frac{\partial C_1}{\partial r}\right]_{R_w}$$

MEAN FLOW VELOCITY

UNITS OF EQN. $\left[\frac{mol}{m \cdot s}\right]$

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Bessel I(0, x)

$x = \phi\lambda$

→ FROM PREVIOUS BOARD

$$\frac{dC_{10}}{dz} = -kC_{10}$$

$$k \equiv \frac{1}{u}\left[1 + \eta\left(\frac{R_w^2}{R_t^2 - R_w^2}\right)\right] k_g \Rightarrow$$

INTEGRATE DOWN RXR TO GET $C_{10}(z)$

NOW CAN CALCULATE CONC. OF SILANE, SiH_4, C_1 @ ANY PLACE IN RXR.

I.C. @ $z=0$ WE KNOW INLET $C_{10}(z=0)$ VALUE

& THEN USE THIS @ ANY z TO GET $C_1(r)$

NOW, LOOK @ SiH_2 (SILYLENE, C_2) FORMATION FROM SiH_4 (SILANE, C_1) & RXN TO FORM $Si(s)$

$$SiH_4 \xrightarrow{k_g} SiH_2 + H_2 \xrightarrow{k_s} Si(s) + H_2$$

BALANCE ON SiH_2 IN ANNULUS

$$u\frac{\partial C_{20}}{\partial z} - k_g C_{10} + \frac{2R_t k_s C_{20}}{(R_t^2 - R_w^2)} + \frac{2R_w D_2}{(R_t^2 - R_w^2)}\left[\frac{\partial C_2}{\partial r}\right]_{R_w} = 0$$

GET FROM $C_2(r)$ FROM BALANCE EQN ON C_2 BETWEEN WAFERS

BALANCE BETWEEN WAFERS

$$D_2\left[\frac{d^2C_2}{dr^2} + \frac{1}{r}\frac{dC_2}{dr}\right] + k_g C_1 - \left(\frac{2}{d_g}\right)k_s C_2 = 0$$

$$\Phi_s^2 = \frac{2R_w^2 k_s}{d_g D_2}$$

$$\Phi_g^2 = \frac{R_w^2 k_g}{D_1}$$

$$\varphi^2 = \frac{\Phi_s^2}{\Phi_g^2}$$

$$C_2(\lambda) = \left[C_{20} + \frac{C_{10}}{1-\varphi^2}\right]\left[\frac{I_0(\Phi_s\lambda)}{I_0(\Phi_s)}\right] + \left[\frac{C_{10}}{\varphi^2 - 1}\right]\left[\frac{I_0(\Phi_g\lambda)}{I_0(\Phi_g)}\right]$$

TAKE DERIVATIVE, PUT IN ANNULUS EQN, GET $\frac{dC_{20}}{dz} = k'C_{10} - k''C_{20}$

END UP WITH 2 ODE'S

$$\frac{dC_{10}}{dz} = -kC_{10}$$

$$\frac{dC_{20}}{dz} = k'C_{10} - k''C_{20}$$

we can evaluate the gradient in silylene at the wafer edge:

$$R_w\left[\frac{\partial C_2}{\partial r}\right]_{R_w}=\left[\frac{\partial C_2}{\partial \lambda}\right]_{\lambda=1}=\left[C_{20}+\frac{C_{10}}{1-\varphi^2}\right]\left[\frac{\Phi_s I_1(\Phi_s)}{I_0(\Phi_s)}\right]+\left[\frac{C_{10}}{\varphi^2-1}\right]\left[\frac{\Phi_g I_1(\Phi_g)}{I_0(\Phi_g)}\right]$$

$\phi_w \ll 1 \qquad \eta \to 1 \qquad I_0 \to 1 \qquad I_1 \to \frac{\phi_w}{2}$

$\phi_w \gg 1 \qquad \eta \to \frac{2}{\phi_w} \qquad I_0 \to I_1 \ \& \ \frac{I_1}{I_0} \to 1$