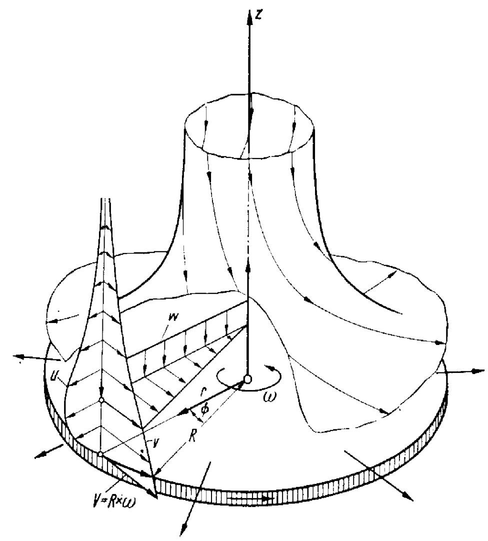
A. (15 points) With the Czochralski Crystal Growth of Silicon, the growth rate of the 110 crystal face is determined by boundary layer heat transfer into the melt with a temperature difference of 2C at 10 rpm. What is the crystal growth rate for a 30 cm diameter boule?



B. (15 points) Compare the results in part A to the results you predict when boundary layer mass transfer is responsible for the growth rate of the 110 crystal face. Which rate is the slowest and likely to be the rate-determining step.

Data for Silicon : Viscosity of the melt=0.1 poise, Density =2.33 gm/cm3 both melt and crystal, Mole weight = 28 gm/mole, Melting Point 1685 K, Heat of fusion = 5.05 kjoule/mole, thermal conductivity =1.48 watt/(cm K), Heat capacity= 0.71 joule/(gm K), self diffusion coefficient for silicon in the melt = 8x10-4 cm2/s.

A) Crystal Growth via BL MT

Silicon Properties

$\frac{1}{6}\cdot \mathrm{Hz} = 10\frac{1}{\mathrm{min}} = \mathrm{rpm}$

$\omega := 2\cdot\pi\cdot\frac{1}{6}\cdot\mathrm{Hz}$

$D_{boule} := 30\cdot\mathrm{cm}$

$C_p := 0.71\cdot\frac{\mathrm{joule}}{\mathrm{gm}\cdot\mathrm{K}}$

$T := T_{eq} - 2\cdot\mathrm{K}$

$\rho := 2.33\cdot\frac{\mathrm{gm}}{\mathrm{cm}^3}$

$\mu := 0.1\cdot\mathrm{poise}$

$Mw := 28\cdot\frac{\mathrm{gm}}{\mathrm{mole}}$

$T_{eq} := 1685\cdot\mathrm{K}$

$\nu := \frac{\mu}{\rho}$

$\nu = 4.292\times 10^{-6}\,\frac{\mathrm{m}^2}{\mathrm{s}}$

$k := 1.48\cdot\frac{\mathrm{watt}}{\mathrm{cm}\cdot\mathrm{K}}$

$D := 8\cdot 10^{-4}\cdot\frac{\mathrm{cm}^2}{\mathrm{s}}$

$\Delta H_f := 50550\cdot\frac{\mathrm{joule}}{\mathrm{mole}}$

$S(T) := \exp\left(\frac{-\Delta H_f}{R_g\cdot T_{eq}}\cdot\frac{T - T_{eq}}{T}\right)$

$S(T) = 1.004$

$C_{eq} := \frac{\rho}{Mw}$

$Flux_C(S) := 0.62\cdot D^{\frac{2}{3}}\cdot C_{eq}\cdot\nu^{\frac{-1}{6}}\cdot\omega^{\frac{1}{2}}\cdot(S-1)$

$Flux_C(S(T)) = 0.033\,\frac{\mathrm{mol}}{\mathrm{m}^2\mathrm{s}}$

$GrowthRate_C(S) := \frac{Flux_C(S)\cdot Mw}{\rho}$

$GrowthRate_C(S(T)) = 3.982\times 10^{-4}\,\frac{\mathrm{mm}}{\mathrm{s}}$

Problem 2 B Crystal Growth via BL HT
uses Data from 2A

$$\alpha := \frac{k}{\rho \cdot C_p}$$

$$h := 0.62 \cdot \left[\left(\frac{\omega}{\nu} \right)^{\left(\frac{1}{2}\right)} \cdot \left(\frac{\nu}{\alpha} \right)^{\left(\frac{1}{3}\right)} \cdot k \right]$$

$$T = 1.683 \times 10^{3} K$$

$$Flux_H(T) := \frac{h \cdot \left(T_{eq} - T\right)}{\Delta H_f}$$

$$Flux_H(T) = 0.652 \frac{mol}{m^2 s}$$

$$GrowthRate_H(T) := \frac{Flux_H(T) \cdot Mw}{\rho}$$

$$GrowthRate_H(T) = 7.83 \times 10^{-3} \frac{mm}{s}$$

BL-MT gives the slower growth rate,
thus MT is rate determining.