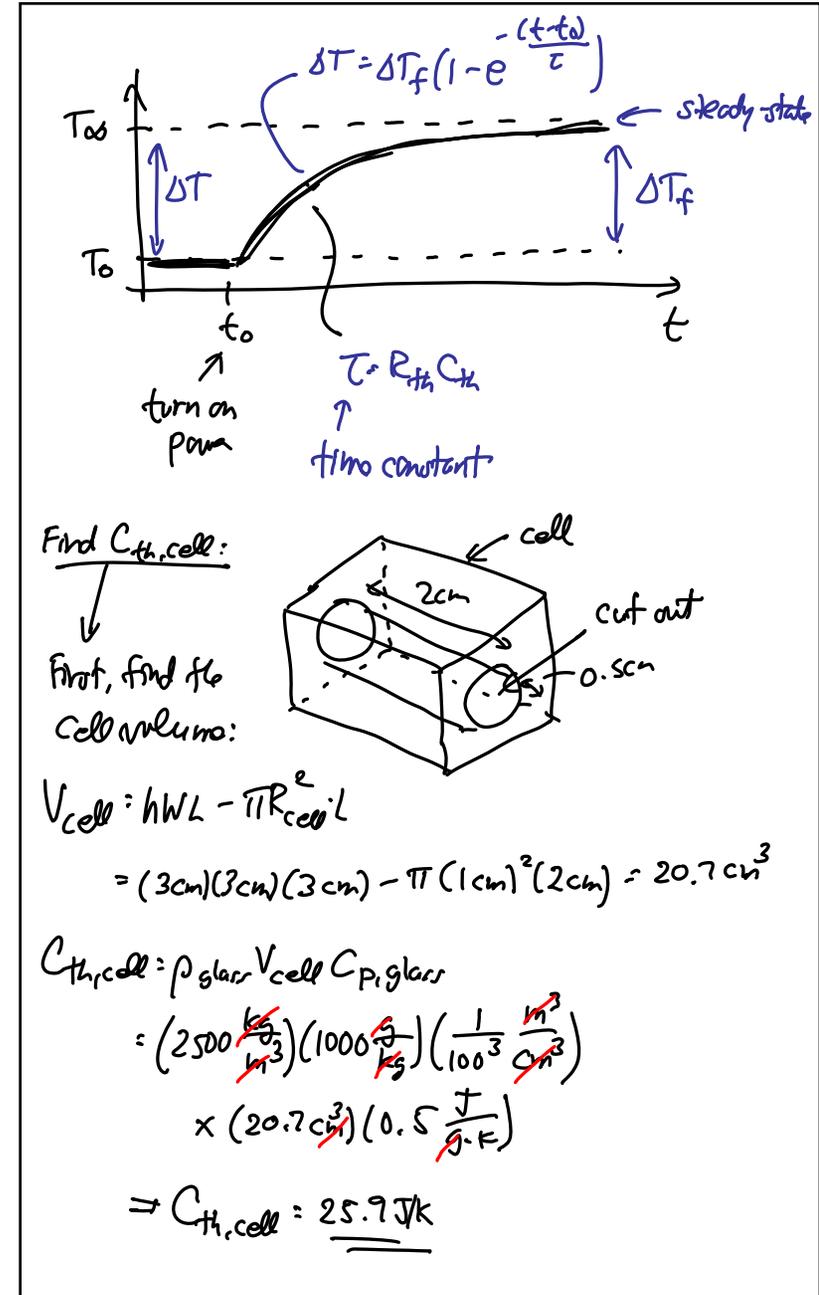
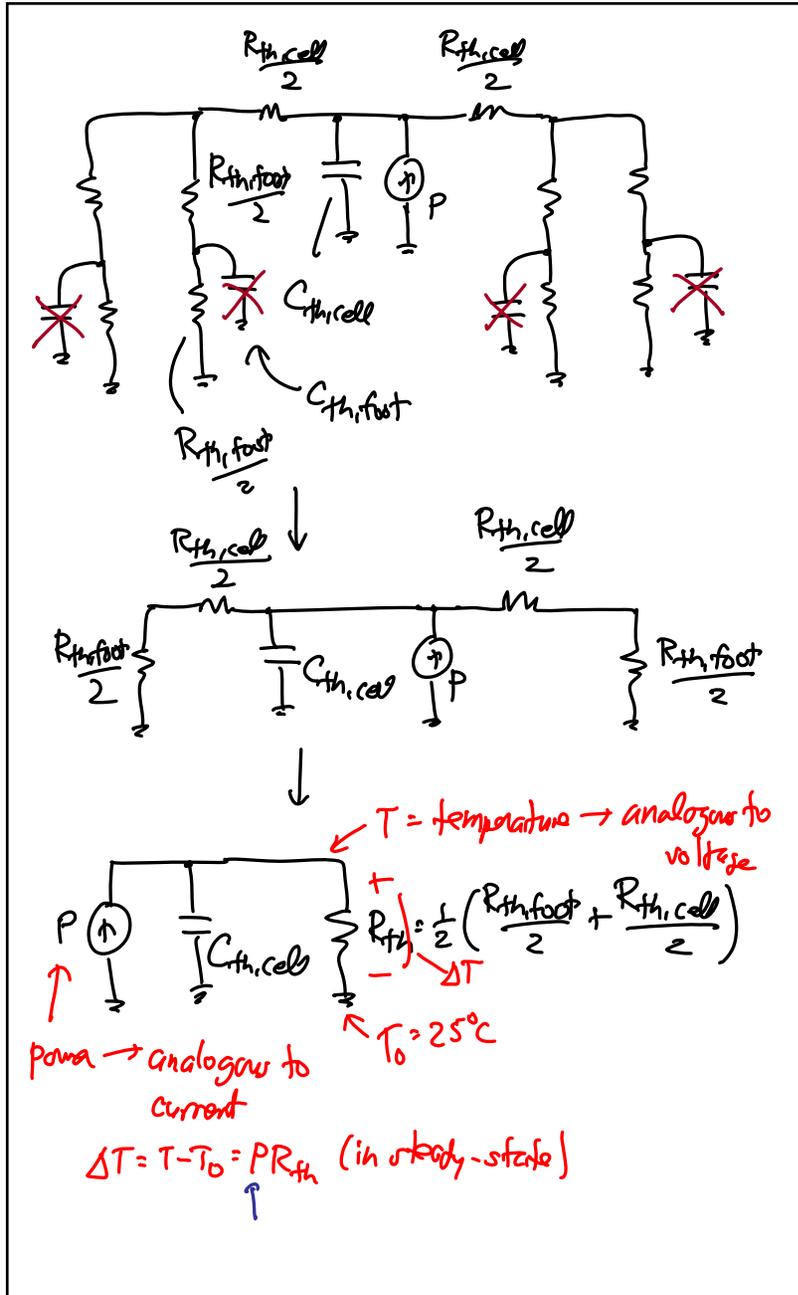


Lecture 5: Process Modules I

- Announcements:
- Make-up lecture (for last Thursday): Can't get a room, so will just go 30 min. longer for three days
- HW#1 due today at 7 p.m.
- HW#2 is online
- -----
- Today:
- Reading: Senturia, Chapter 1
- Lecture Topics:
 - ↳ Benefits of Miniaturization
 - ↳ Examples
 - GHz micromechanical resonators
 - Chip-scale atomic clock
 - Thermal Circuits
 - Micro gas chromatograph
- Senturia, Chpt. 3; Jaeger, Chpt. 2, 3, 6
 - ↳ Example MEMS fabrication processes
 - ↳ Oxidation
 - ↳ Film Deposition
 - Evaporation
 - Sputter deposition
 - Chemical vapor deposition (CVD)
 - Plasma enhanced chemical vapor deposition (PECVD)
 - Epitaxy
 - Atomic layer deposition (ALD)
 - Electroplating
- -----
- Last Time: Thermal circuit modeling

Example. Thermol Clot.
 ⇒ determine the power needed to get this atomic cell to 80°C (from RT) in 1 hour fast

$\rho_{\text{glass}} = 2500 \text{ kg/m}^3$
 $C_{p,\text{glass}} = 0.5 \text{ J/(g}\cdot\text{K)}$
 $k_{\text{glass}} = 1.05 \frac{\text{W}}{\text{m}\cdot\text{K}}$



Find $\frac{R_{th,cell}}{2}$:

3cm
1cm
0.5cm
0.75cm
0.75cm
heat
 $\frac{R_{th,cell}}{2}$
3cm
0.5cm
0.75cm
 $\frac{R_{th,cell}}{2}$
 $C_{th,cell}$

$$\frac{R_{th,cell}}{2} = \frac{\frac{3}{8}}{k(3)(\frac{1}{2})} + \frac{\frac{3}{4}}{k(3)(1)} = \frac{1}{k} \left(\frac{1}{8} + \frac{1}{4} \right) = \frac{3}{8} \frac{1}{k}$$

$(R_{fr} = \frac{l}{kA}) \therefore \frac{R_{th,cell}}{2} = \frac{3}{8} \frac{1}{1.05} \times (100 \frac{cm}{m}) = 35.7 k/W$

Find $R_{th,foot}$:

$A_{foot} = \pi R_{foot}^2$
 $R_{foot} = 2mm$
 $l_{foot} = 2mm$
 glass

$$\therefore R_{th,foot} = \frac{l_{foot}}{kA_{foot}} = \frac{2mm}{(1.05 \frac{W}{m \cdot K}) \pi (2mm)^2} = 151.6 k/W$$

Then:

$$R_{th} = \frac{1}{2} \left(\frac{R_{th,foot}}{2} + \frac{R_{th,cell}}{2} \right)$$

$$= \frac{1}{2} \left(\frac{151.6}{2} + 35.7 \right) \Rightarrow R_{th} = 55.8 k/W$$

\Rightarrow Find power req'd to maintain $T_{\infty} = 80^{\circ}C$ in steady-state:

$$P = \frac{T_{\infty} - T_0}{R_{th}} = \frac{(80 - 25)}{55.8} = 0.99W \sim 1W$$

\Rightarrow Find the time constant:

$$\tau = R_{th} C_{th,cell} = 24 min.$$

\rightarrow It takes $\sim 3\tau$ to reach steady-state
 \therefore must wait 72 min. before using this atomic clock!

How about the MEMS case?

- \Rightarrow much smaller cell volume \rightarrow weight \downarrow
- \Rightarrow Can use long, thin support struts: $L \uparrow, A \downarrow$

MEMS Atomic Cell

300x300x300 μm^3 Atomic Cell @ 80°C } Hollow w/ 10 μm -thick walls

500 μm -long, 10 μm -thick, 20 μm -wide

$$V_{\text{cell}} = (300\mu)(300\mu)(300\mu) - (280\mu)(280\mu)(280\mu)$$

$$= 5.048 \times 10^{-12} \text{ m}^3$$

↳ of course, much smaller than macro

$$C_{\text{th, cell}} = \rho_{\text{glass}} V_{\text{cell}} C_{p, \text{glass}}$$

$$= (2500 \frac{\text{kg}}{\text{m}^3})(5.048 \times 10^{-12} \text{ m}^3)(500 \frac{\text{J}}{\text{kg}\cdot\text{K}})$$

$$\Rightarrow C_{\text{th, cell}} = \underline{\underline{6.31 \times 10^{-6} \frac{\text{J}}{\text{K}}}}$$

↳ 4 million x smaller than macro!

$$R_{\text{th, supp}} = \frac{l_{\text{supp}}}{k_{\text{poly, Si}} \cdot W_{\text{supp}} \cdot h_{\text{supp}}}$$

$$= \frac{500\mu}{(30 \frac{\text{W}}{\text{m}\cdot\text{K}})(20\mu)(10\mu)} = \underline{\underline{83,333 \text{ K/W}}}$$

↑
548x larger!

and...

$$P = \frac{(80-25)}{83,333} = \underline{\underline{2.64 \text{ mW}}} \leftarrow 548x \text{ smaller!}$$

$$\tau = \underline{\underline{0.13 \text{ s}}} \leftarrow 7300x \text{ faster}$$

All due to Scaling!

What makes all of this possible?

- ① Scaling reduces $C_{\text{th}} \sim l^3 \sim s^3$
 $s \downarrow \rightarrow C_{\text{th}} \downarrow \downarrow$
- ② Scaling allows the use of long, thin tethers $\rightarrow R_{\text{th}} \uparrow$

$k \triangleq \text{stiffness @ this point} = \frac{1}{4} E W_b \frac{h_b^3}{L_b^3} \sim S \frac{S^3}{S^3} \sim S$
 $\rightarrow \text{mass: } \rho L_m^3 \sim S^3$
 @ static equilibrium:
 Force Due to Gravity = Spring force
 $m g = k x$
 acceleration due to gravity \rightarrow displacement
 $* x = \frac{m}{k} g \sim \frac{S^3}{S} \sim S^2$
 \downarrow
 as $S \downarrow \rightarrow x \downarrow$
 $R_{th} \sim \frac{L_b}{W_b h_b} \rightarrow$ want to raise this (for lower power cons.)
 but maintain the same drop x

$* \rho L_m^3 g = \frac{1}{4} E W_b \frac{h_b^3}{L_b^3} x$
 $\frac{L_b}{W_b h_b} = \frac{1}{4} E \frac{h_b^2}{L_b^2} \frac{1}{\rho L_m^2 g} \xrightarrow{\text{const.}} \sim \frac{S^2}{S^2} \frac{1}{S^3} \sim \frac{1}{S^3}$
 $\rightarrow \text{as } S \downarrow \rightarrow \frac{L_b}{W_b h_b} \sim R_{th} \uparrow \uparrow \uparrow$