Lecture 5: Process Modules I

- **Announcements**:
- New version of HW#1 on line
  - Basically fixed to add boundary conditions for problem 2 (to make is easier for you)
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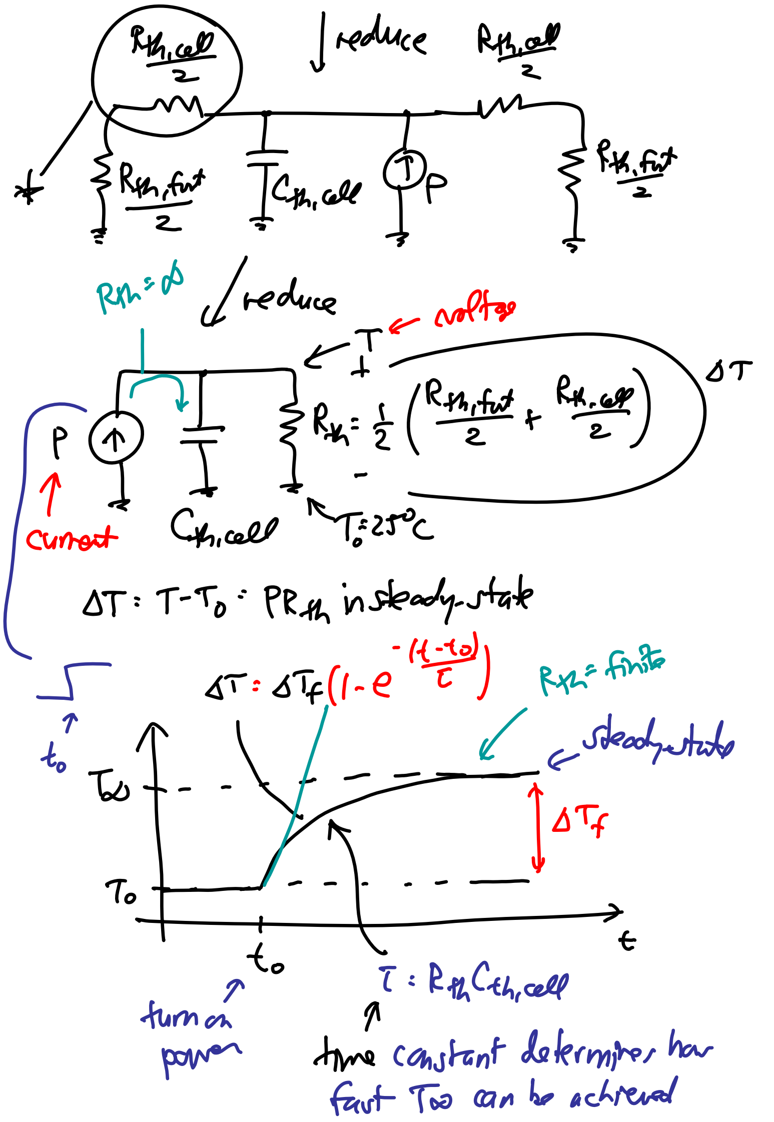
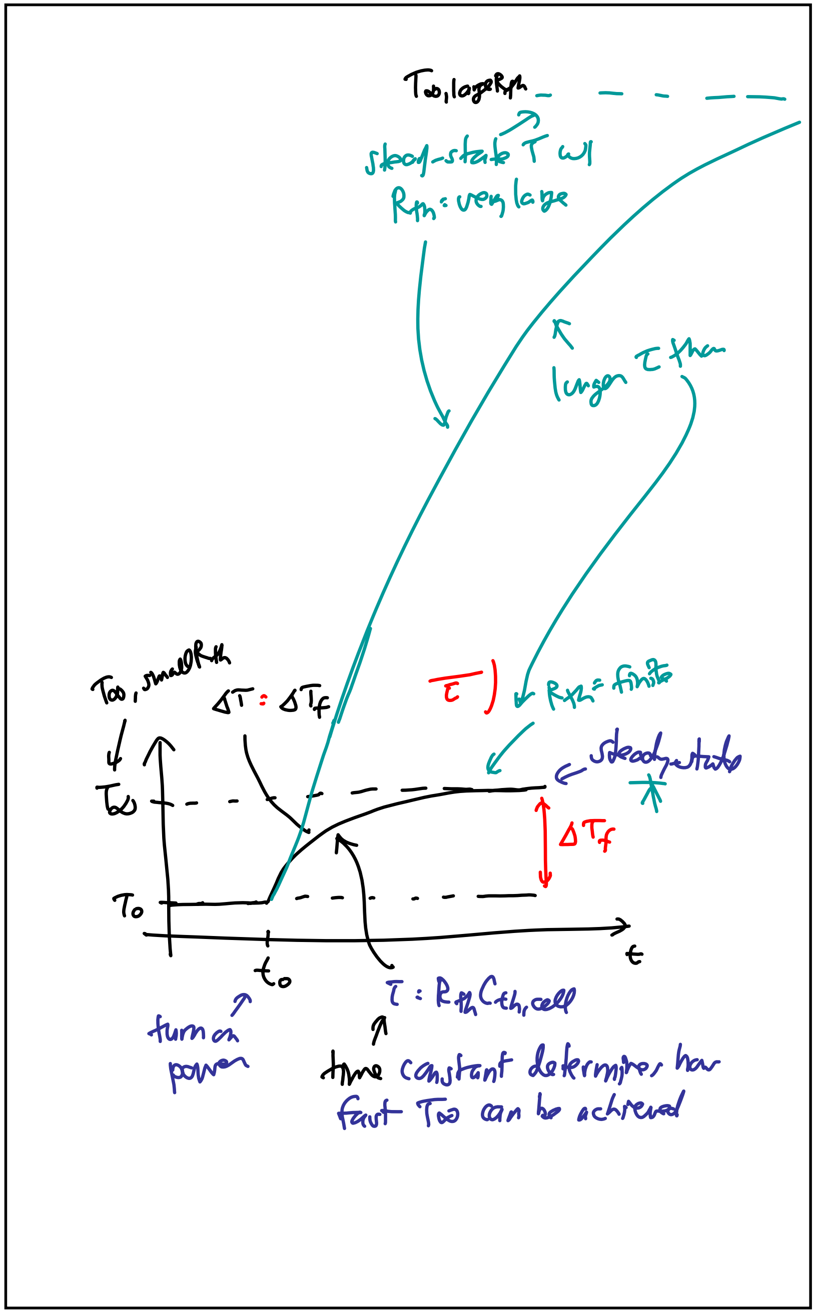
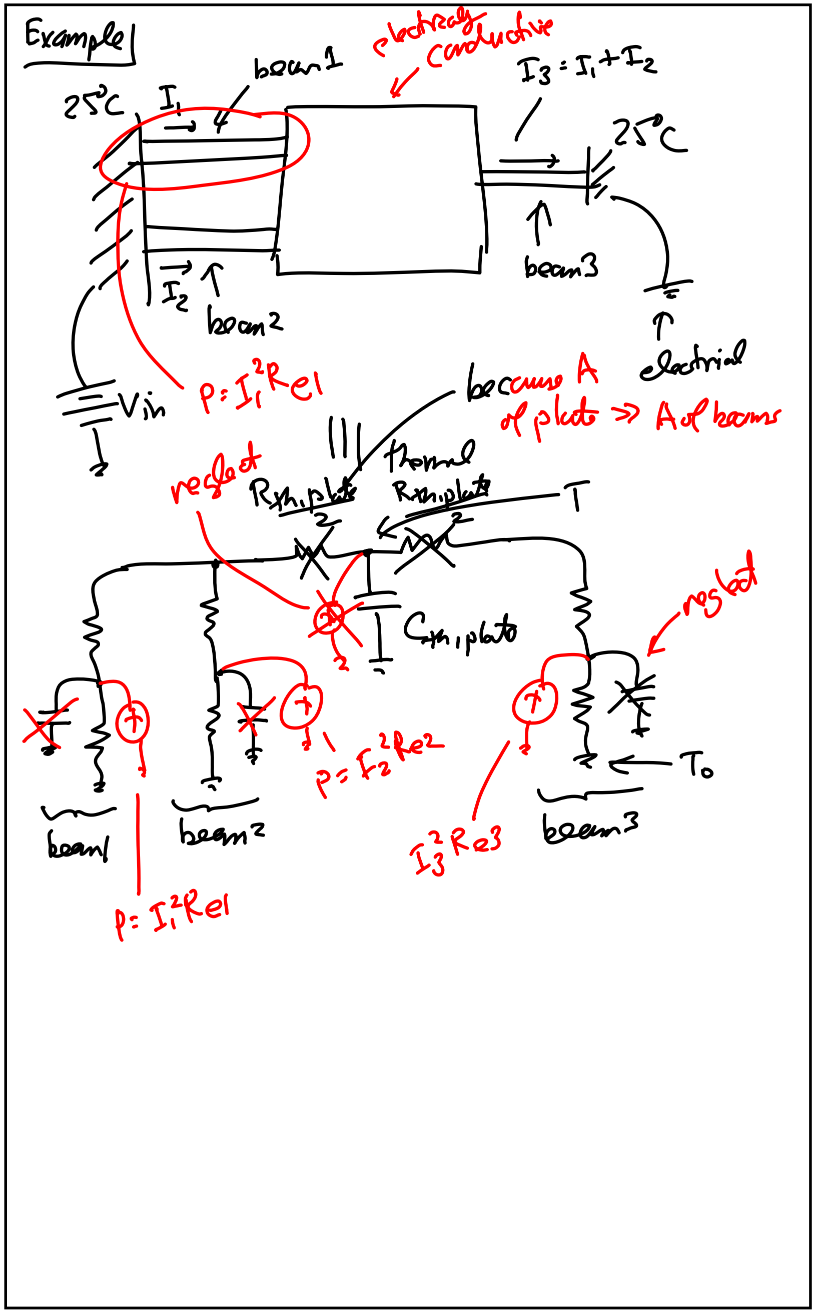
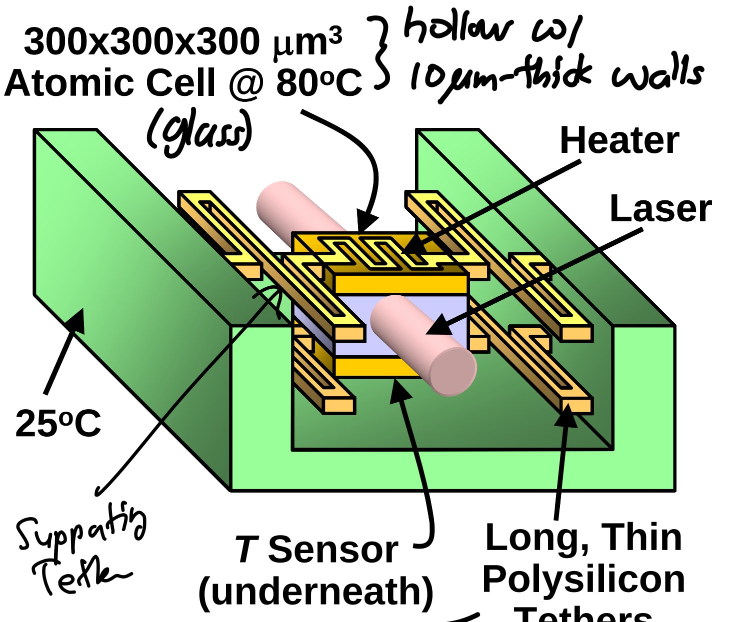
- **Today**:
- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Benefits of Miniaturization
  - Examples
    - GHz micromechanical resonators
    - Chip-scale atomic clock
    - Thermal Circuits
    - Micro gas chromatograph
- Senturia, Chpt. 3; Jaeger, Chpt. 2, 3, 6
  - Example MEMS fabrication processes
  - Oxidation
  - Film Deposition
    - Evaporation
    - Sputter deposition
    - Chemical vapor deposition (CVD)
    - Plasma enhanced chemical vapor deposition (PECVD)
    - Epitaxy
    - Atomic layer deposition (ALD)
    - Electroplating
- ------------------------------------
- **Last Time**:
- Covering thermal circuit modeling …




T∞, large Rth
steady-state T w/ Rth = very large
larger τ than
T∞, small Rth
ΔT = ΔTf
τ
Rth = finite
steady-state
T∞
ΔTf
To
t
to
turn on power
τ = Rth Cth,cell
time constant determines how fast T∞ can be achieved


Example
beam1
electrically conductive
I3 = I1 + I2
25°C
I1
25°C
beam3
I2
beam2
Vin
P = I1² Re1
because A of plate >> A of beams
electrical
thermal
neglect
Rth,plate/2
Rth,plate/2
T
Cth,plate
neglect
beam1
beam2
P = I2² Re2
I3² Re3
beam3
To
P = I1² Re1



500µm-long, 10µm-thick, 20µm-wide

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

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

↳ of course, much smaller than macro

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

$= (2500 \frac{kg}{m^3})(5.048 \times 10^{-12} m^3)$

$\times (500 \frac{J}{kg \cdot K})$

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

↳ 4 million x smaller than macro!

$R_{th,supp} = \frac{L_{supp}}{k_{polySi} \cdot W_{supp} \cdot h_{supp}}$

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

↗ 548x larger

and...

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

$\tau = \boxed{0.13 s}$ ← 7300x faster!

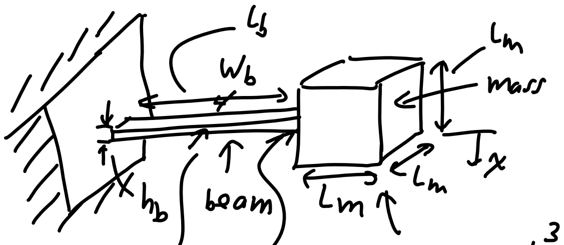
All due to scaling!

↳ What makes this possible? → $\underline{\underline{\text{scaling}}}$!

① Scaling reduces $C_{th} \sim l^3 \sim S^3$

② Scaling allows the use of long, thin tethers!

↳ tethers can support "more" when things are scaled!



mass $= m = \rho L_m^3 \sim S^3$

$k \triangleq$ stiffness @ this pt. $= \frac{1}{4} E W_b \frac{h_b^3}{L_b^3} \sim S \frac{S^3}{S^3} \sim S$

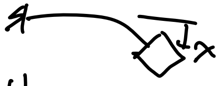
@ static equilibrium

Force Due to Gravity = Spring Force

$mg = kx$

acceleration due to gravity

displacement ← want to minimize to avoid



$x = \frac{m}{k} g \sim \frac{S^3}{S} \sim S^2$

as $S\downarrow \rightarrow x\downarrow$ (and fast)

$R_{th} \sim \frac{L_b}{W_b h_b} \Rightarrow$ want to raise this

S

constant → constant droop

$\rho L_m^3 g = \frac{1}{4} E W_b \frac{h_b^3}{L_b^3} x$

by the 3rd pow!

$\frac{L_b}{W_b h_b} = \frac{1}{4} E \frac{h_b^2 x}{L_b^2} \frac{1}{\rho L_m^3 g} \sim \frac{\cancel{S^2}}{\cancel{S^2}} \frac{1}{S^3} \sim \frac{1}{S^3}$

as $S\downarrow \rightarrow \left\{ \frac{L_b}{W_b h_b} \text{ to maintain } x \right\} \uparrow$