Lecture 3: Benefits of Scaling II

- Announcements:
- As announced last time, I am on travel right now
- This is a pre-recorded video
- The website for this course is up; go to https://inst.eecs.berkeley.edu/~ee247b/sp17/
- The notes from last time are online, as well as the video – both in the Lecture link table
- Modules 1 & 2 are online (also, in the Lecture link table)
- Get your computer accounts by following the instructions at the end of the Course Info Sheet (the new one recently uploaded)
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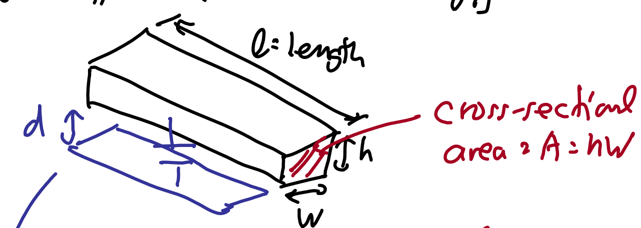
- Today:
- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Benefits of Miniaturization
  - Examples
    - GHz micromechanical resonators
    - Chip-scale atomic clock
    - Micro gas chromatograph
- ------------------------------------
- Last Time:
- Going through Module 2, looking at a micromechanical circuit (specifically, a micromechanical filter)
- Continue with this now, going through Module 2, slides 9-30

Review Electrical Resistance First

(then attack the thermal R analogy)

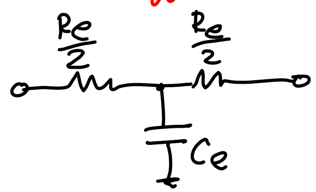


$R_e \triangleq$ electrical resistance $= \frac{l}{\sigma A}$ ← electrical conductivity

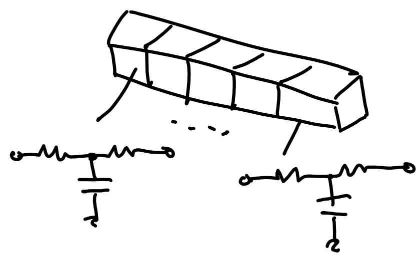
C_e: capacitance $= \frac{\epsilon_0 WL}{d}$ ← permittivity

↳ Stored Energy (charge energy): $\frac{1}{2}CV^2 = E$

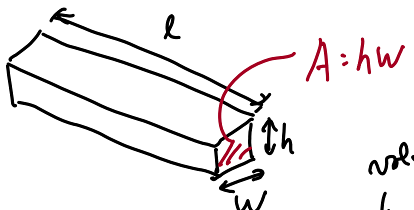
↑ voltage across the capacitor



⇒ if want to be more exact:



Thermal Ckt.



⇒ thermal capacitance: $C_{th} = \rho V C_p$

- V ← volume
- C_p ← specific heat
- ρ ← density
- ↘ stores thermal energy

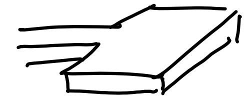
⇒ thermal resistance:

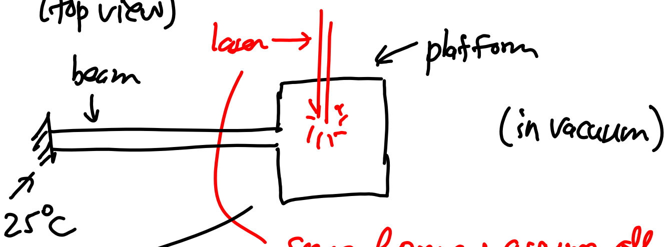
$$R_{th} = \frac{l}{kA}$$

- l ← length
- A ← cross-sectional area
- k ← thermal conductivity

Examples

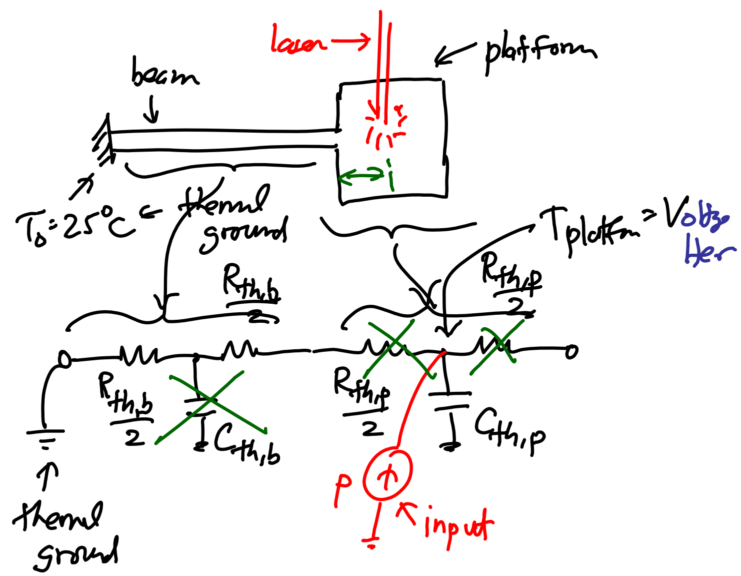
Ex. MEMS type structure (top view)





Source of power: assume all energy of laser is absorbed

What is the temperature on the platform?



Analogies:

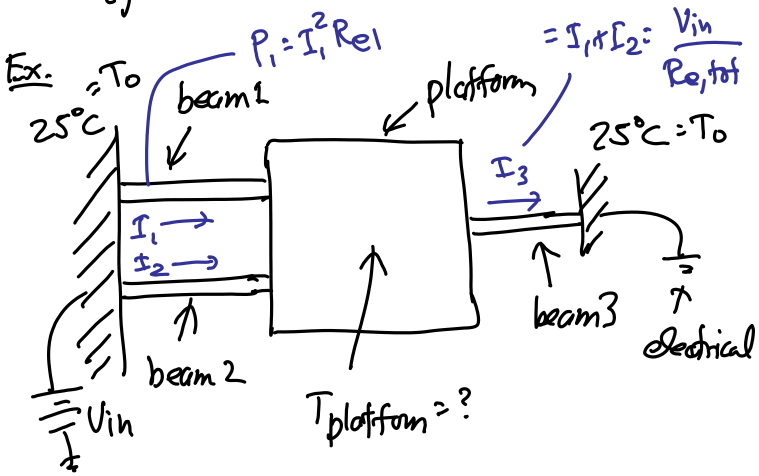
(temperature) T → V (voltage)
(power) P → I (current)

thermal ← → electrical

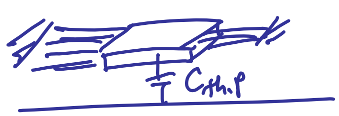
To Analyze:

1. Remove small elements to simplify the ckt.
2. $T_{platform} = P R_{th,b}$ (in steady-state)
   (just like $V = IR$ in an electrical system)

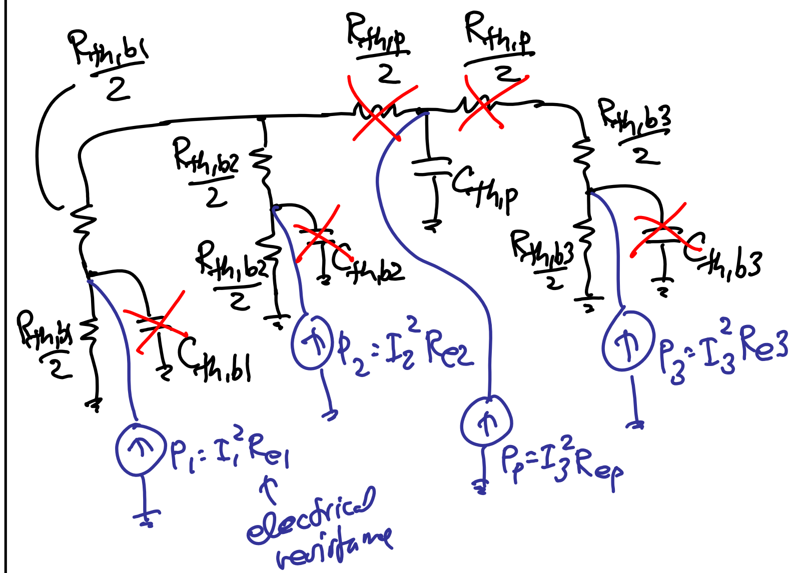
Ex.



⇒ coupled thermal, electrical system



⇒ Draw the thermal ckt:

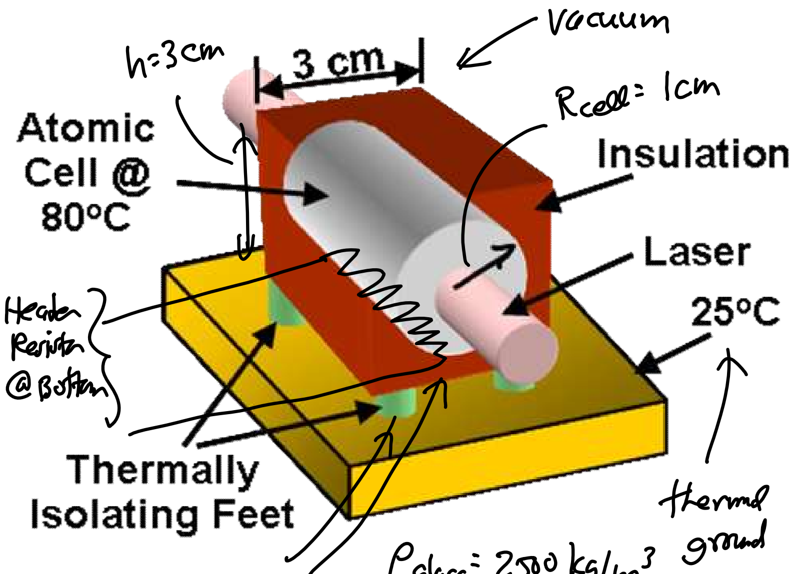


To Analyze:

1. $I_3 = I_1 + I_2 = \frac{V_{in}}{R_{e,tot}}$ (electrical analysis)
2. Get P_i's. (powers)
3. Use superposition to solve the thermal ckt.
   handle one power source at a time & sum the temperatures (i.e., thermal voltages) to get the total temperature at any node

Example: Thermal Clock.

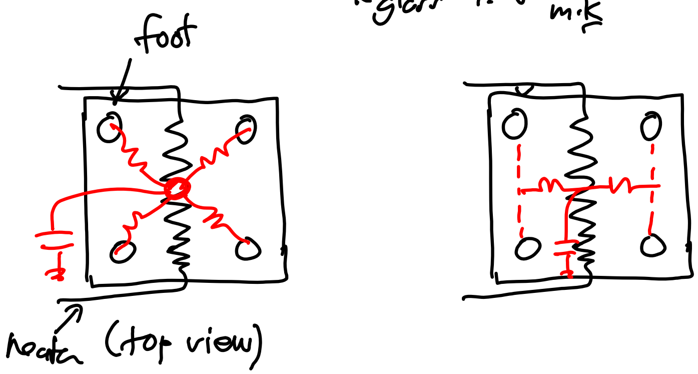
⇒ determine the power needed to get this atomic cell to 80°C (from RT) & how fast

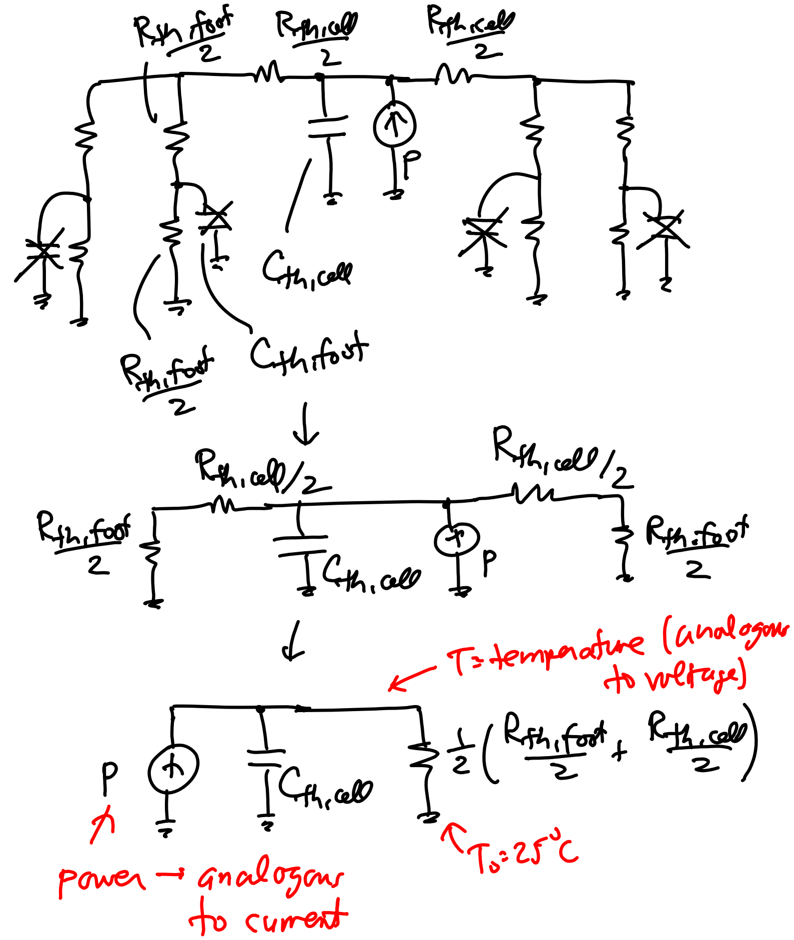


all glass: $\rho_{glass} = 2500\ kg/m^3$

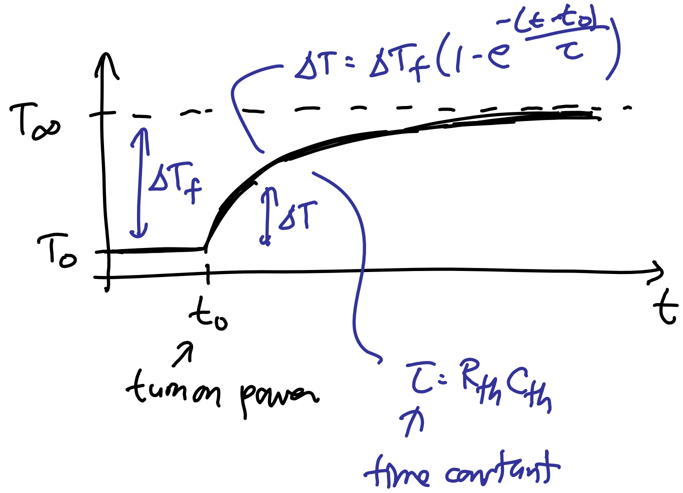
$c_{p,glass} = 0.5\ J/(g\cdot K)$

$K_{glass} = 1.05\ \frac{W}{m\cdot K}$



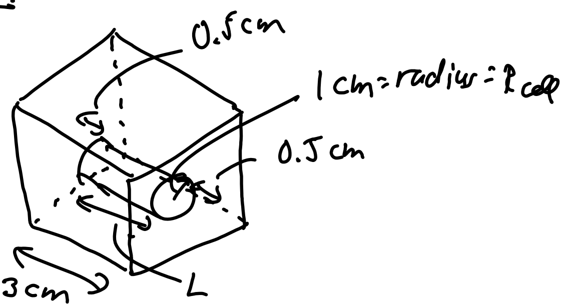


$\Delta T = T - T_0 = P R_{th}$ (in steady-state)



Find $C_{th,cell}$:

First, find the cell volume:

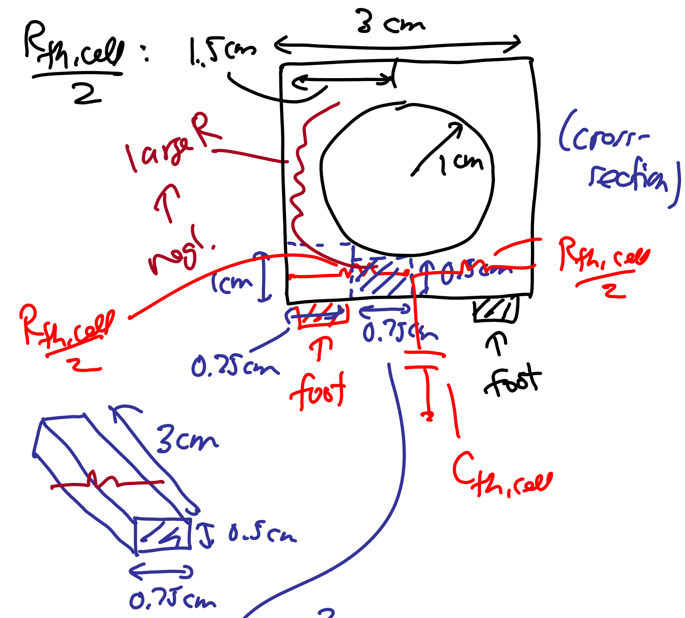


$$V_{cell} = hWL - \pi R_{cell}^2 \cdot L$$
$$= (3cm)(3cm)(3cm) - \pi(1cm)^2(2cm) = 20.7\ cm^3$$

$$C_{th,cell} = \rho_{glass} V_{cell} C_{p,glass}$$
$$= \left(2500 \frac{kg}{m^3}\right)\left(1000 \frac{g}{kg}\right)\left(\frac{1}{100^3} \frac{m^3}{cm^3}\right) \times (20.7\ cm^3)\left(0.5 \frac{J}{g \cdot K}\right)$$

$$\Rightarrow C_{th,cell} = 25.9\ J/K$$

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



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

$$\left[R_{th} = \frac{l}{kA}\right]$$

$$\therefore \frac{R_{th,cell}}{2} = \frac{3}{8} \frac{1}{1.05} \times \left(100 \frac{cm}{m}\right)$$
$$= 35.7\ K/W$$