Lecture 4: Benefits of Scaling III

- Announcements:
- HW#1 online; due Friday next week
- We'll go 1.5 hours today; but I would like to go 1.5 hours all days starting next week until we make up the first week
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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
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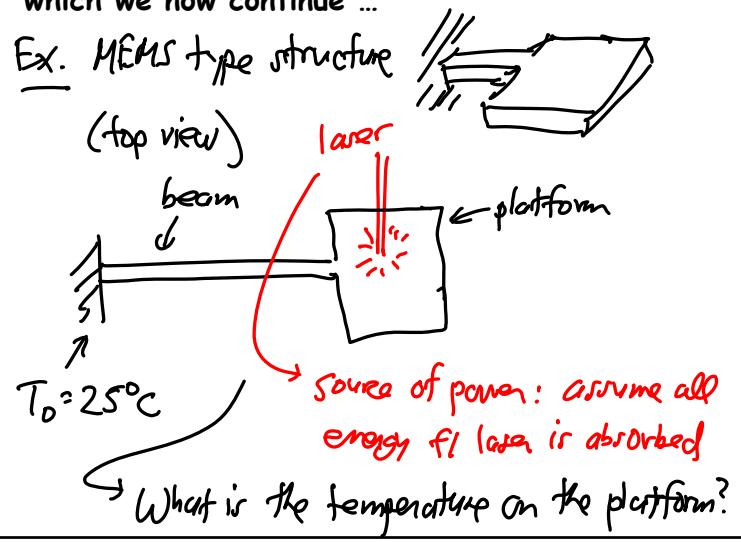
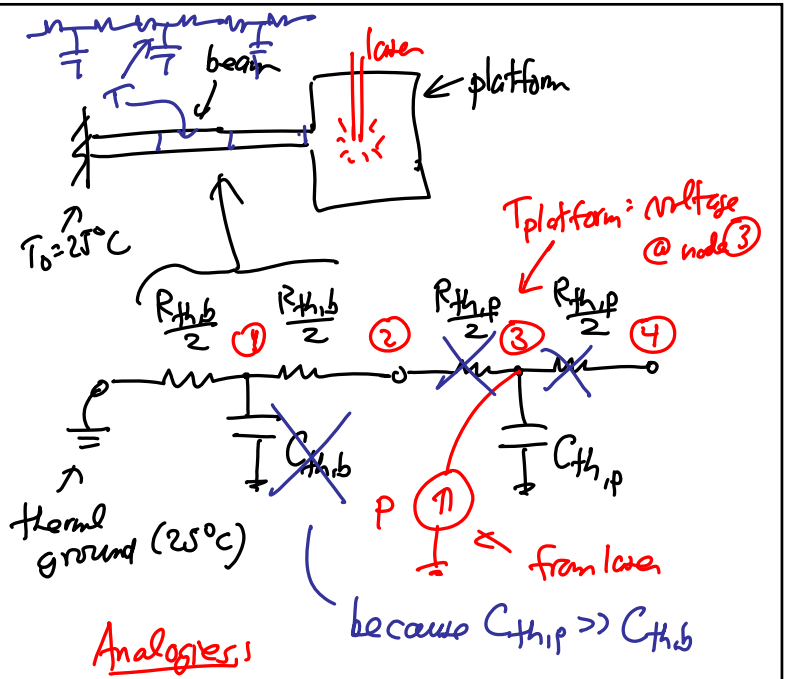
- Last Time: Covering thermal circuit modeling … which we now continue …





Analogies:

(temperature) T ⟶ V (voltage)

(power) P ⟶ I (current)

To Analyze:

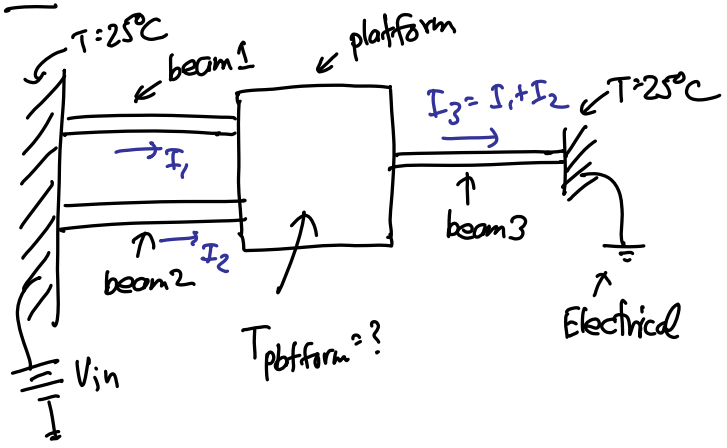
① Remove small elements to simplify the ckt.

② $T_{platform} = PR_{th,b}$

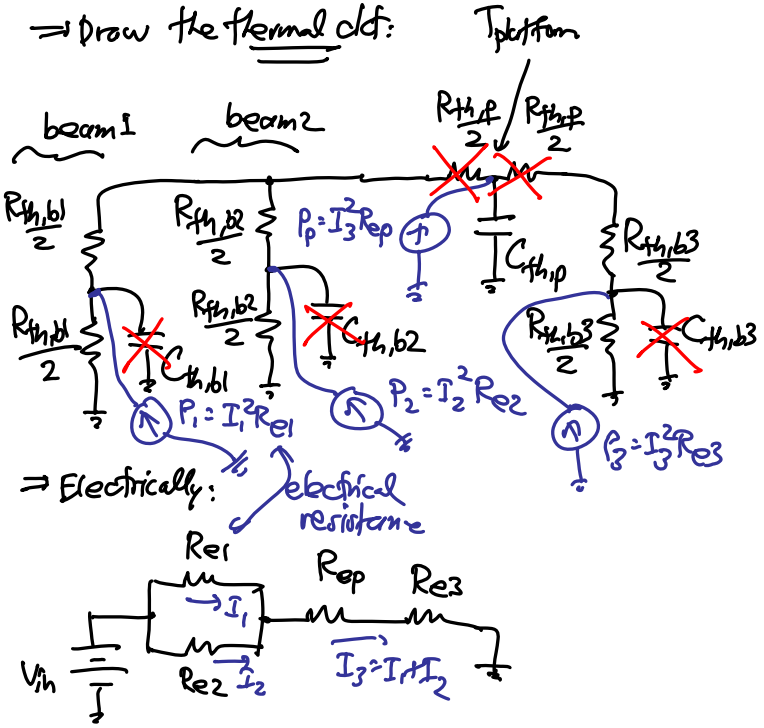
(just like V = IR in an electrical system)

$\tau = R_{th,b} C_{th,p}$

Ex.



⇒ Draw the thermal ckt:



To Analyze:

① Electrical Analysis: $I_3 = I_1 + I_2 = \frac{V_{in}}{R_{e,tot}}$

② Get powers, P_i's. $= \frac{V_{in}}{R_{e1} \| R_{e2} + R_{ep} + R_{e3}}$

③ Use superposition to solve the thermal ckt.

→ handle one power source @ a time, then sum the temperatures (i.e., thermal voltages) to get the total temp. @ any node.

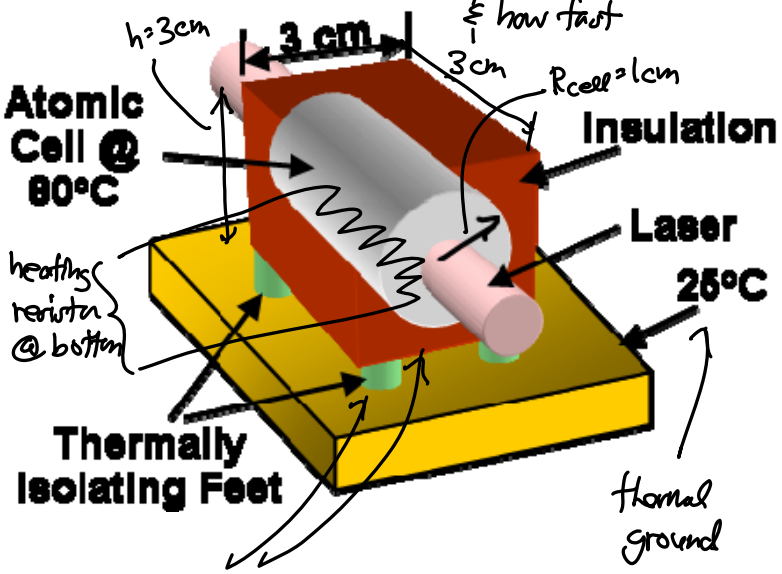
$P_1 \rightarrow T_{platform,1}$
$P_2 \rightarrow T_{platform2}$
$\vdots$
$P_3 \rightarrow T_{platform3}$

$T_{platform} = \sum_{i=1}^{3} T_{platform\,i}$

Use for τ: $C_{th,p}$ and $R_{th,b1} \| R_{th,b2} \| R_{th,b3}$

Example. (Thermal Ckt.)

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

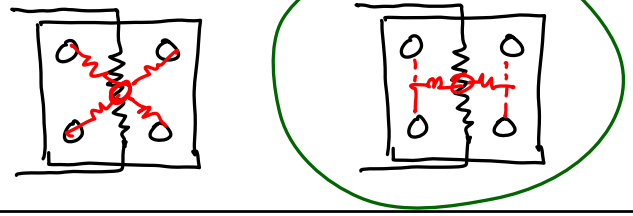


All glass: $\rho_{glass} = 2500\ kg/m^3$

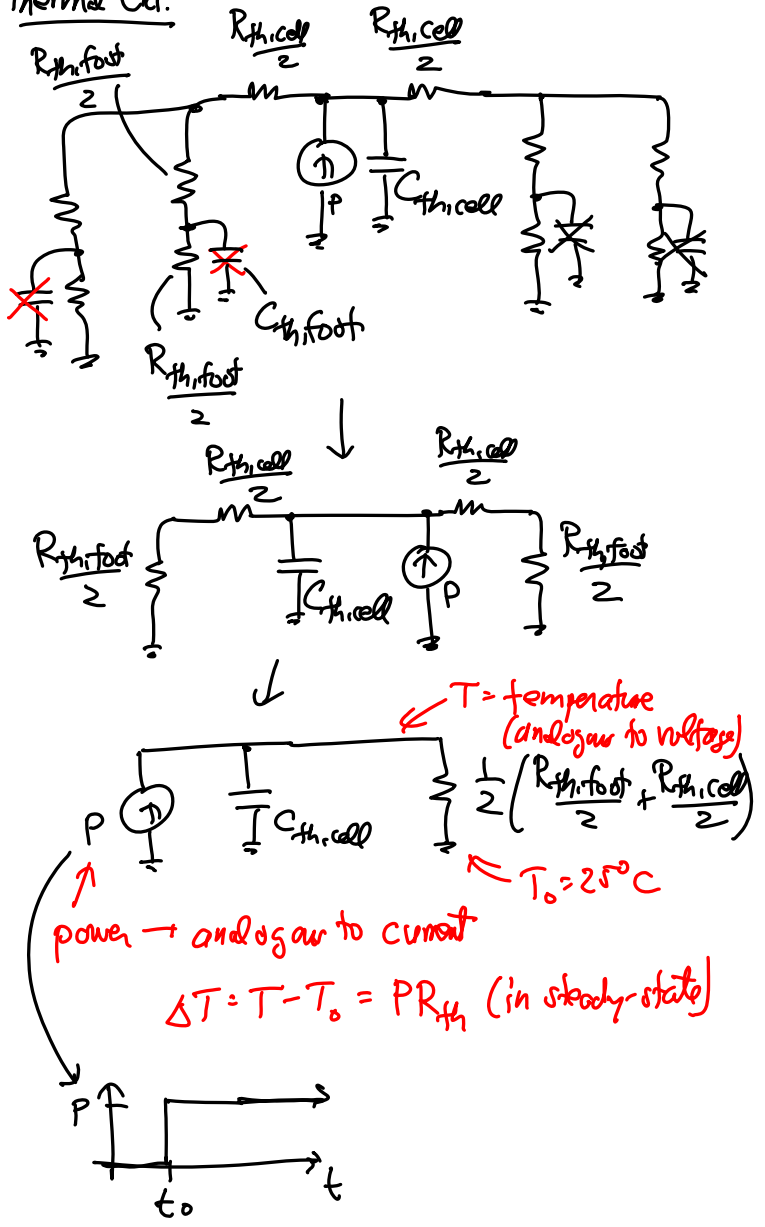
$C_{p,glass} = 0.5\ J/(g \cdot K)$

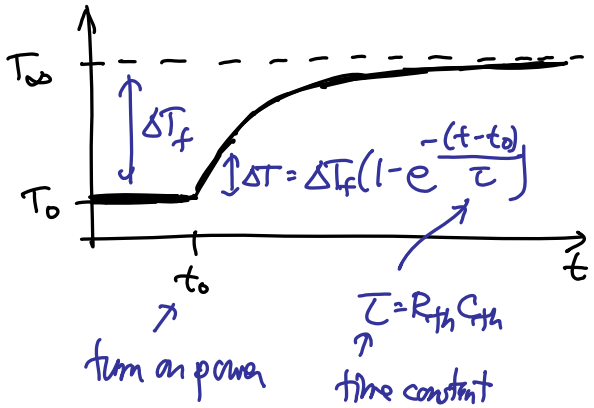
$k_{glass} = 1.05\ \frac{W}{m \cdot K}$

Top View:



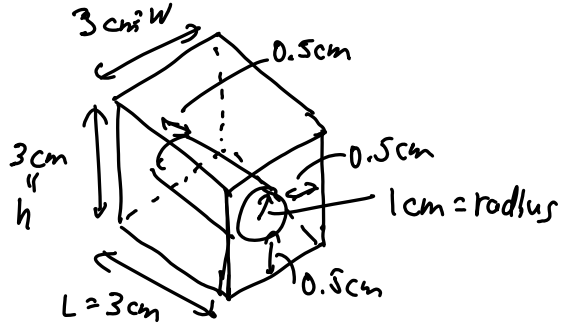
Thermal Ckt:





Find $C_{th,cell}$:

⇒ must find the cell volume



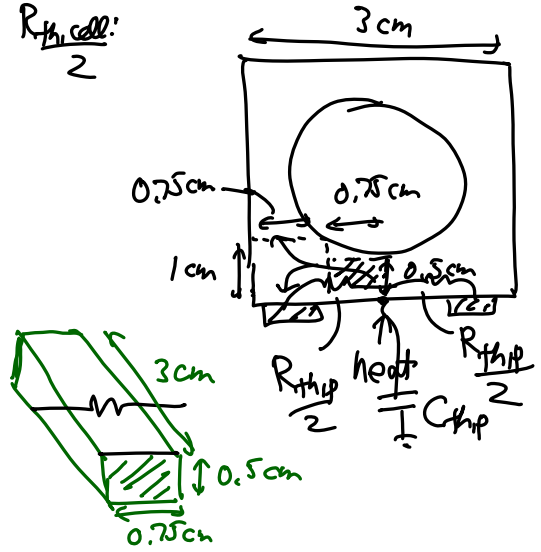
$V_{cell} = hWL - \pi R_{cell}^2 L_{cyl.}$

$= (3\,cm)(3\,cm)(3\,cm) - \pi(1\,cm)^2(2\,cm) = 20.7\,cm^3$

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

$= \left(2500 \frac{kg}{m^3}\right)\left(1000 \frac{g}{kg}\right)\left(\frac{1}{100^3 \frac{cm^3}{m^3}}\right)$
$\times (20.7\,cm^3)\left(0.5 \frac{J}{g \cdot K}\right) \Big\} = \underline{25.9\,J/K}$

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



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

$\left[R_{th} = \frac{\ell}{kA_\perp}\right]$

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

$= \underline{35.7\,K/W}$