Lecture 5: Scaling Benefits IV & Process Modules I

- Announcements:
- We will go 1.5 hours today
- HW#1 due this coming Friday
- Lecture Modules 3 & 4 on Process Modules online
- Reminder: Videos for the lectures are not on the course website, but rather on the Webcast Berkeley site: webcast.Berkeley.edu
- You can also find them on YouTube and iTunes
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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
  - ↳ Photolithography
  - ↳ Etching
  - ↳ Oxidation
  - ↳ Film Deposition
  - ↳ Ion Implantation
  - ↳ Diffusion
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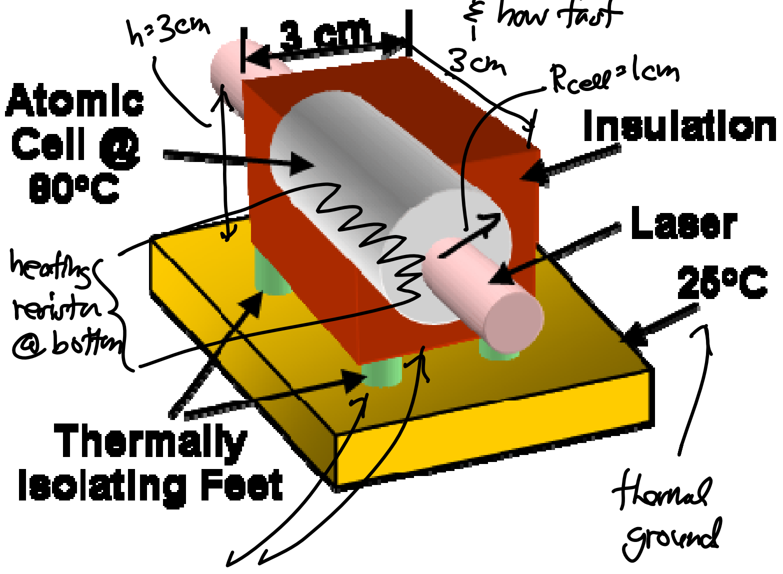
- Last Time: Thermal circuit modeling

Example. (Thermal Ckt.) (in vacuum)

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



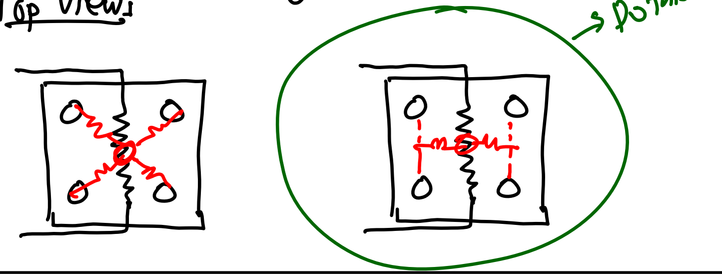
All glass!

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

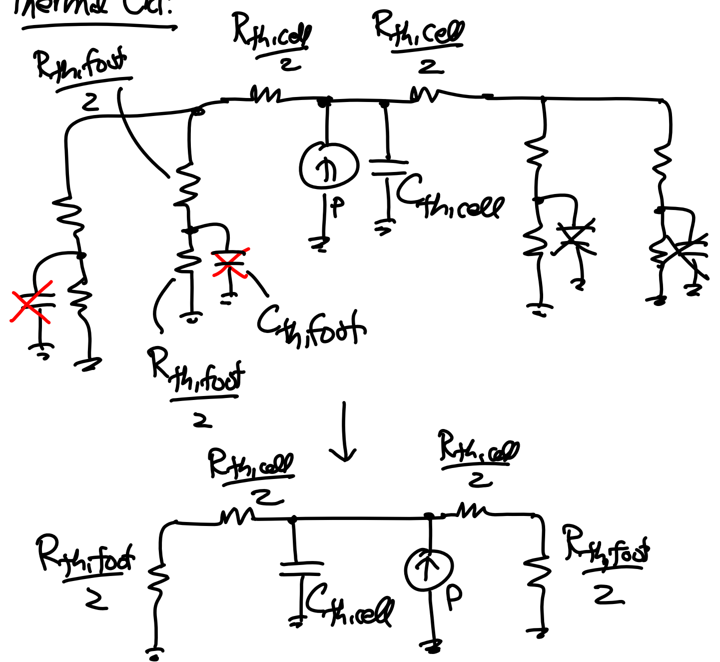
$C_{p,glass} = 0.5\ J/(g\cdot K)$

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

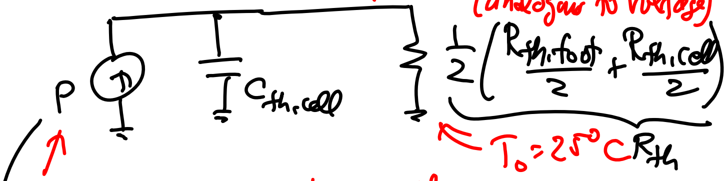
Top Views



Thermal Ckt:



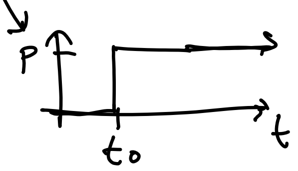
T = temperature (analogous to voltage)

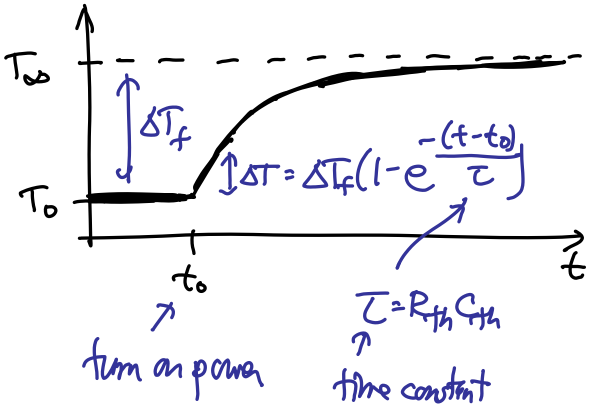


$T_o = 25°C$

power → analogous to current

$\Delta T = T - T_o = PR_{th}$ (in steady-state)

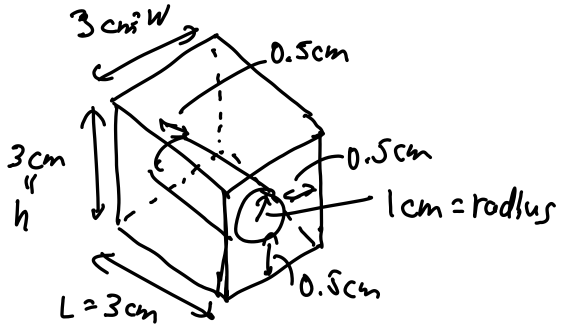




$\Delta T = \Delta T_f\left(1 - e^{\frac{-(t-t_o)}{\tau}}\right)$

Find $C_{th,cell}$:

→ must find the cell volume



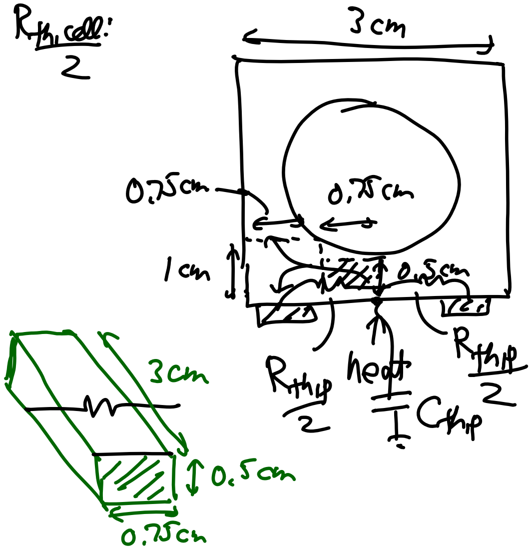
$V_{cell} = hWL - \pi R_{cell}^2 L_{cyl}$

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

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

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

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

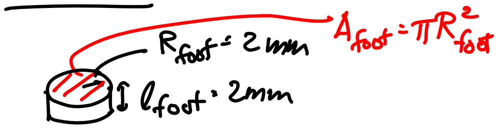


$$\frac{R_{th,cell}}{2} = \frac{\frac{3}{4}}{k(3)(\frac{1}{2})} + \frac{\frac{3}{4}}{k(3)(1)} = \frac{1}{k}\left(\frac{1}{8}+\frac{1}{4}\right) = \frac{3}{8}\frac{1}{k}$$

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

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

Find $R_{th,foot}$:



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

Then:

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

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

⇒ Find the power req'd to maintain $T_\infty = 80°C$ in steady-state:

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

⇒ Find the time constant: K/W J/K

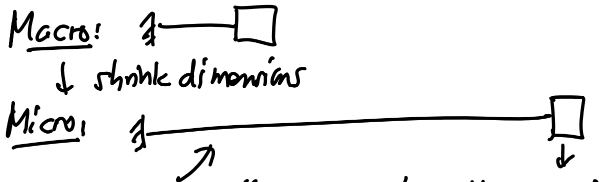
$$\tau = R_{th}C_{th,cell} = (55.8)(25.9) = \boxed{24\ min.}$$

↳ It takes ~3τ to reach steady-state
∴ must wait 72min. before using this atomic cell

How about using MEMS?

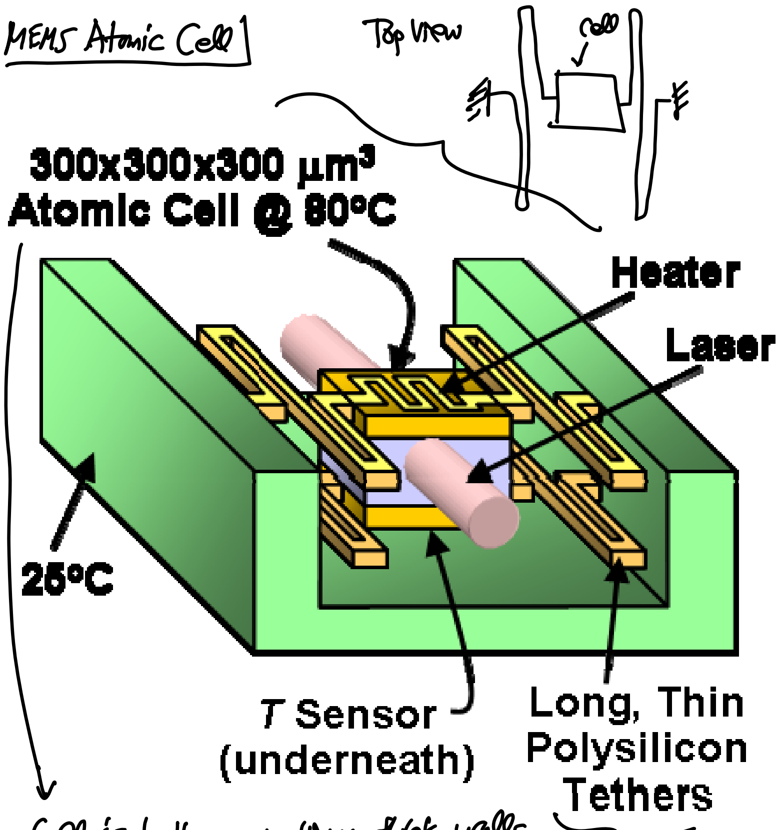
(how about scaling this?)

⇒ much smaller cell volume → $V\downarrow \rightarrow C_{th}\downarrow$
→ weight ↓



can do this → use long, thin supports to suspend the cell

MEMS Atomic Cell



300x300x300 µm³ Atomic Cell @ 80°C

Heater

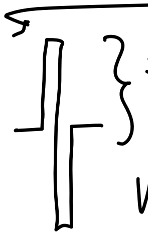
Laser

25°C

T Sensor (underneath)

Long, Thin Polysilicon Tethers

Cell is hollow w/ 10µm-thick walls.



500µm-long, 10µm-thick, 20µm-wide

$$V_{cell} = (300\mu)(300\mu)(300\mu) - (280\mu)(280\mu)(280\mu)$$
$$= 5.048\times10^{-12}\,m^3$$

(much smaller than macro!)

$$C_{th,cell} = \rho_{glass} V_{cell} C_{p,glass}$$
$$= \left(2500\,\frac{kg}{m^3}\right)\left(5.048\times10^{-12}\,m^3\right)\left(500\,\frac{J}{kg\cdot K}\right)$$
$$= 6.31\times10^{-6}\,\frac{J}{K}$$

← 4 million x smaller than macro!

$$R_{th,supp} = \frac{l_{supp}}{K_{polysi} W_{supp} h_{supp}} = \frac{500\mu}{\left(30\,\frac{W}{m\cdot K}\right)(20\mu)(10\mu)}$$

$$\rightarrow R_{th,supp} = \underline{83,333\,K/W}$$

↖ 548x larger than macro!

and…

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

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

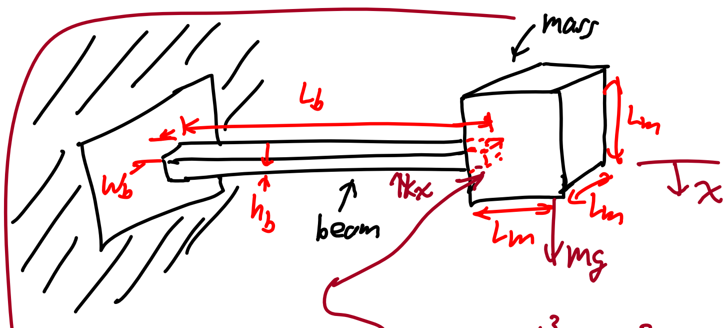
All due to scaling!

Remarks (What makes this possible?)

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

② Scaling allows the use of $\underbrace{\text{long, thin tethers}}_{R_{th}\uparrow\uparrow}$

Long, thin tethers

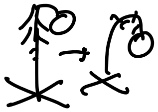


$k \triangleq$ stiffness @ attachment pt. $= \frac{1}{4}EW_b\frac{h_b^3}{L_b^3} \sim S\frac{S^3}{S^3} \sim S$

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

@ static equilibrium:

Force due to gravity = Spring Force



acceleration due to gravity

$mg = kx$ ——— *

displacement → droop

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

For the atomic cell supports:

$R_{th} = \frac{L_b}{kW_bh_b}$ → want to raise this for lower power consumption

& but maintain the same (or smaller) droop x

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

$$\underbrace{\frac{L_b}{W_bh_b}}_{\sim R_{th}} = \frac{1}{4}E\frac{h_b^2}{L_b^2}\underset{\substack{\uparrow\\ \text{const.}}}{x}\frac{1}{\rho L_m^3 g} \sim \frac{S^2}{S^2}\frac{1}{S^3} \sim \frac{1}{S^3}$$

as $S\downarrow \Longrightarrow \frac{L_b}{W_bh_b} \sim R_{th}\uparrow\uparrow\uparrow$

Process Module Overview:

- Lecture Topics:
  - ↳ Photolithography
  - ↳ Etching
  - ↳ Oxidation
  - ↳ Film Deposition
  - ↳ Ion Implantation
  - ↳ Diffusion
- As stated earlier, this is now assumed knowledge
- I will gloss over this material to review it a bit, but will not go over it in detail
- You can watch my lectures from EE245, Spring 2012, on the Webcast Berkeley site for more in depth coverage: Lectures 6-8
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Process Modules

⇒ there are actually only a few basic modules used for processing

↓

Combination of these in the correct sequence yields an integrated circuit technology that provides transistors, MEMS, nanodevices, etc.

⇒ For each module, need to understand:

① Physics and engineering of each module in detail.

② Interactions between modules.

③ The affect of each module on the finished device.