Lecture 5: Benefits of Scaling IV, Process Modules I

- Announcements:
- Modules 1 & 2 are online
- HW#1 online and due Feb. 11 at 8 a.m.
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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
- Reading: Senturia, Chpt. 3; Jaeger, Chpt. 2, 3, 6
- Lecture Topics:
  - ↳ Example MEMS fabrication processes
  - ↳ Photolithography
  - ↳ Etching
  - ↳ Oxidation
  - ↳ Film Deposition
  - ↳ Diffusion
  - ↳ Ion Implantation
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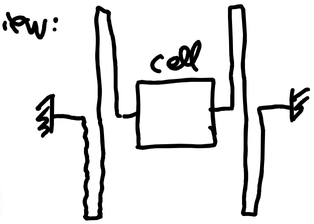
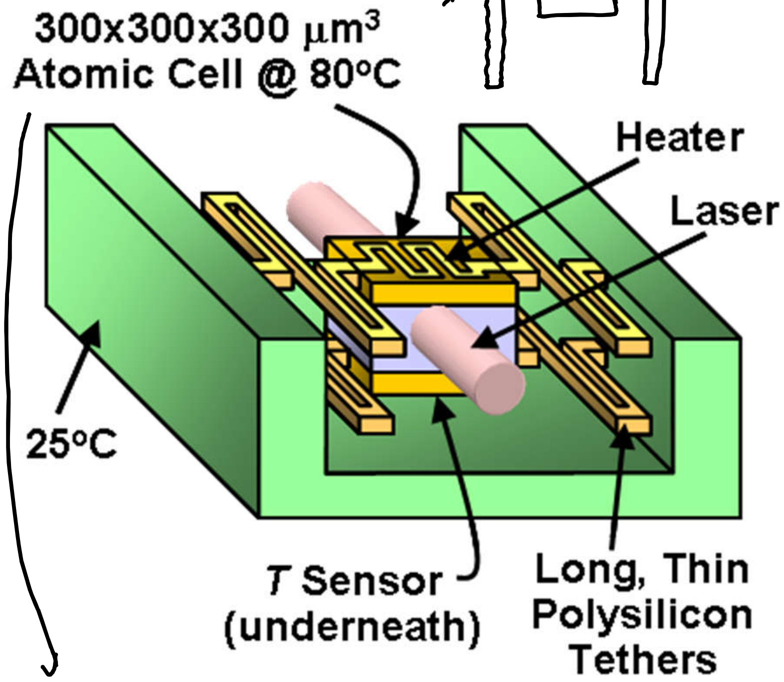
- Last Time:
- Going through Module 2
- Finished thermal circuits
- Continue with this now

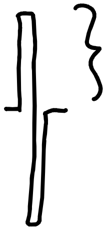
MEMS Atomic Cell

Top View:





Cell is hollow w/ 10μm-thick walls.



500μm-long, 10μm-thick, 20μm-wide

$V_{cell}: (300\mu m)^3 - (280\mu m)^3$

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

(much smaller than macro!)

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

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

$$= 6.31\times 10^{-6} \frac{J}{K}$$ ← 4 million x smaller than macro!

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

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

↑ 1493x larger than macro!

and...

$$P = \frac{(80-25)}{83,333} = \boxed{0.66mW}$$ ← 1493x smaller than macro!

$$\tau = \boxed{0.53s}$$ ← 2727x faster!

All due to scaling!

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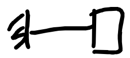
How about using MEMS?

↳ (how about scaling this?)

⇒ much smaller cell volume → weight↓

↗ $V\downarrow \rightarrow C_{th}\downarrow$



shrink dimensions

↗ can do this → use long, thin supports to suspend a smaller cell

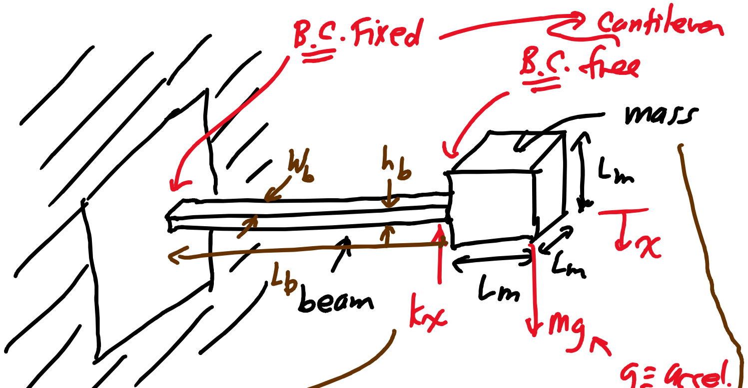
*

Remarks. (What's makes this possible?)

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

$\searrow s\downarrow \rightarrow C_{th}\downarrow\downarrow\downarrow$

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



$g \equiv$ accel. due to gravity

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

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

@ static equilibrium

Force due to gravity = Spring Force

acceleration due to gravity → $mg = kx$ ← displacement ——— *

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

$R_{th} = \frac{L_b}{K W_b h_b}$ → want to raise this (for lower power atomic cell)

but maintain the same droop x

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

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

?

as $S\downarrow \rightarrow \frac{L_b}{W_b h_b} \sim R_{th}\uparrow\uparrow\uparrow$

- Go through slides 30-31 and 37-48 in Module 2 to finish up Thermal Circuits and cover Micro Gas Analyzers

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 video lectures 7.x on the website to learn it more fully. These videos compile lectures from the old version of this course.
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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.

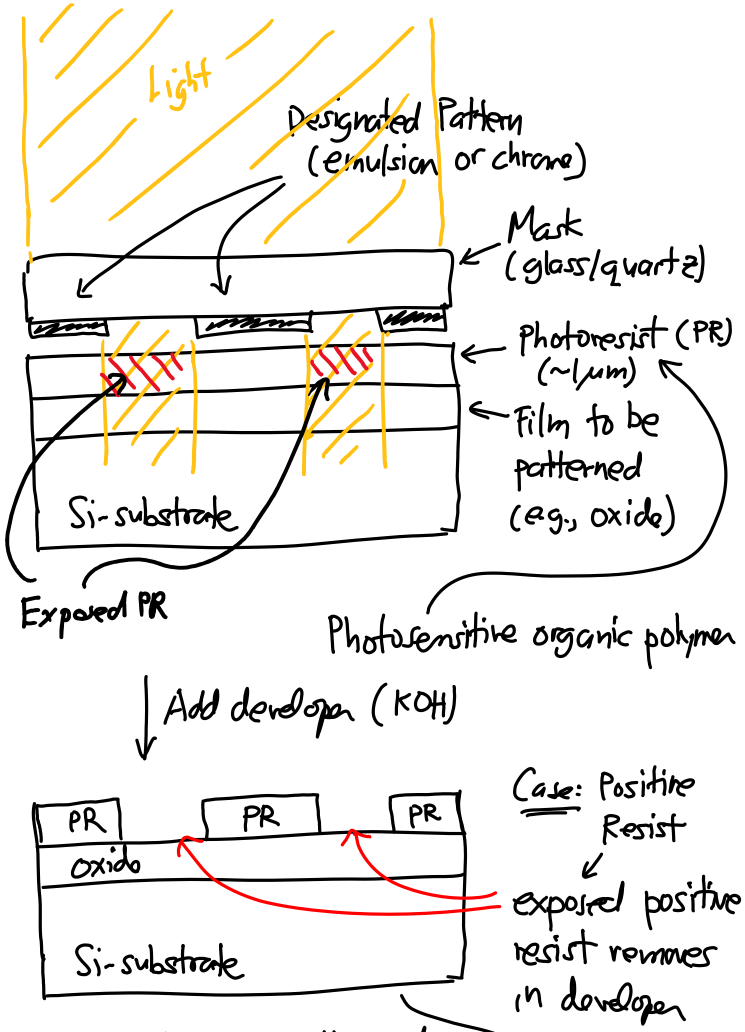
⇒ For each module, need to understand:

① Physics and engineering of each module in detail.

② Interactions between modules.

③ The effect of each module on the finished device.

Photolithography



⇒ Now, the PR is patterned

⇒ Ready for the next step: Etching

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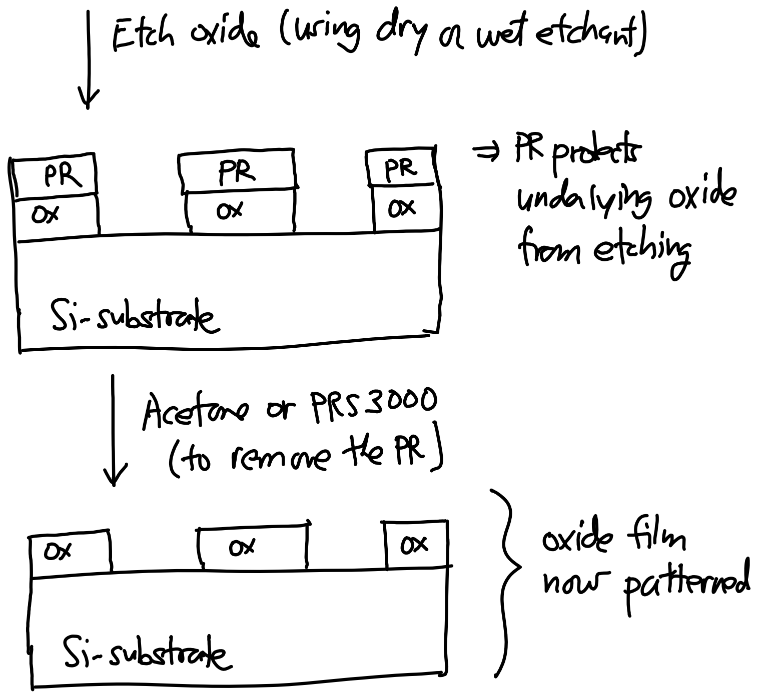


Etch oxide (using dry or wet etchant)

⇒ PR protects underlying oxide from etching

Acetone or PRS3000 (to remove the PR)

oxide film now patterned

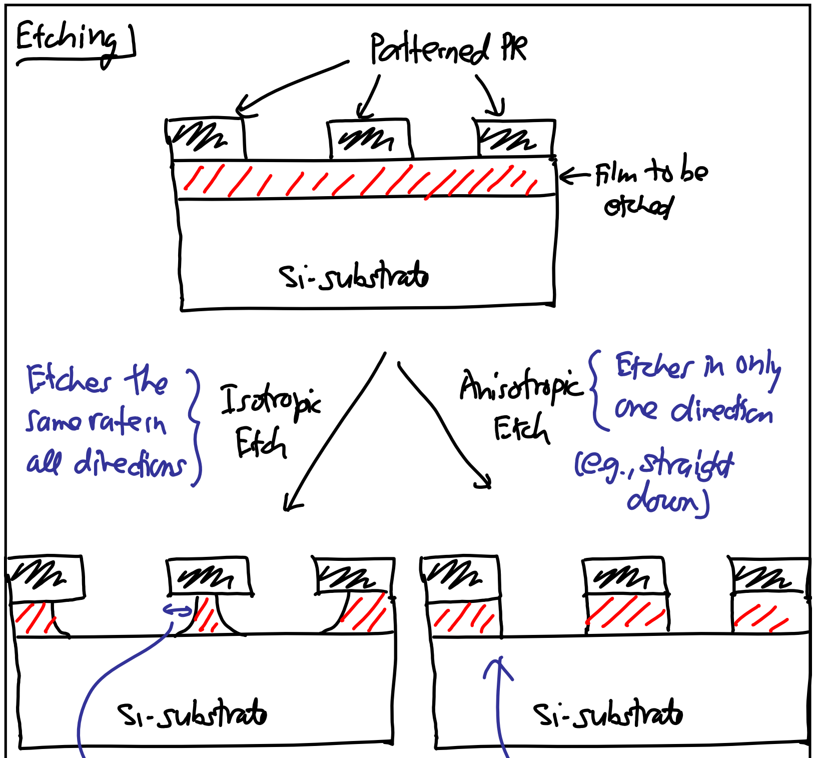
⇒ Above: collectively called a masking step

Usually gauge the cost & complexity of a given technology by the # masking steps!

Number of Masking Steps:

NMOS: 4-6 masks
1990 CMOS: 8–11 masks
today's CMOS: >28 masks
Bipolar: 11–13 masks
BiCMOS: 20 masks
combination of bipolar & CMOS (mainly for RF/wireless apps.)

Etching:



Etches the same rate in all directions } Isotropic Etch

Anisotropic Etch { Etches in only one direction (e.g., straight down)

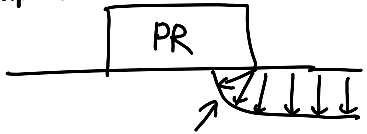
undercutting

not desirable when resolution is important

very desirable in MEMS, when a structure must be released

no undercutting → best resolution!

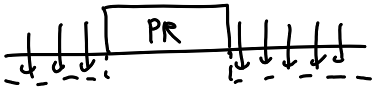
- Isotropic Etchant Examples:
  - Wet etchants
  - Dry plasma etch



get undercut & curved profile

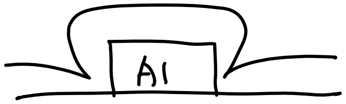
- Anistropic Etchant Examples:
  - Reactive ion etch
  - Ion milling

Use ions under E-fields to give the etch more directionality.

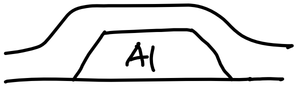


square profile & no undercut

- Go through Module 4, slides 15-21, 36-47
- **Remarks**:
  - Wet etching is fairly cheap
  - Dry etching requires a plasma, so requires some expensive equipment
  - Don't always want straight sidewalls



Too much topography → more difficult for subsequent films to conform



Sloped sidewalls allow better conformability

Silicon Oxidation