Lecture 5: Benefits of Scaling IV, Process Modules I

- Announcements:
  - Module 2, 3 and 4 are online
  - HW#1 due Wednesday, 2/10, at 12 noon

- 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

- Last Time:
  - Going through Module 2 ("Benefits of Scaling") and finished thermal circuits
  - Continue with this now

Discussion 1: Thermal Circuits

- Announcements:
  - HW#1 is online

- Today:
  - Look at HW#1
  - Micro-Scale CSAC Physics Package Thermal Ckt.
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**Thermal Ckt.**

Eliminate, save beam volume << physical package volume

**Reduced Thermal Ckt.**

**Solved State:**

\[ T = T_0 + \frac{1}{\eta} P R_{\text{th,b}} \]

\[ \eta = \frac{1}{4} R_{\text{th,b}} C_{\text{th,p}} \]

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**Thermal Capacitance**

\[ C_{\text{th,p}} = P_{\text{joule}} V_p C_{p,j,gas} \]

\[ V_p = \text{volume of the cell} \]

\[ = (200\mu)(200\mu)(300\mu) - (280\mu)(280\mu)(280\mu) \]

\[ = 5.04\times10^{-12}\text{m}^3 \text{ (much smaller than macro!) } \]

\[ C_{\text{th,p}} = (2500 \text{ kg/m}^3)(5.04\times10^{-12}\text{m}^3)(500 \frac{J}{g\cdot K}) \]

\[ = 6.21\times10^{-6} \frac{J}{K} \leftarrow 4 \text{ million } x \text{ smaller than macro!} \]

**Thermal Resistance**

\[ R_{\text{th,b}} = \frac{L_b}{k_{\text{poly}} W_b h_b} = \frac{500\mu}{(30 \text{ W/m.K})(20\mu)(10\mu)} \]

\[ = R_{\text{th,b}} = 83,333 \text{ K/W} \]

Thus, the power required to maintain 30°C:

\[ P = \frac{4(T-T_0)}{R_{\text{th,b}}} = \frac{4(80-30)}{83,333} = 2.64 \text{ mW} \]

\[ \eta = \frac{1}{4} (83,333)(6.31\times10^{-6}) \approx 0.035 \]

All advantages due to scaling:

\[ 24 \text{ mW, from macro!} \]

\[ 24 \text{ mW, from macro!} \]
Ask about using MEMS?

Some question as: "How about scaling this dam?"

**Macro:**
- Shorter dimensions
- Small cantilever
- Small Poisson's ratio

**Micro:**
- Can do this in volume
- Use larger support

Remarks: (What makes this possible?)

1. Scaling reduces $C_h l^2 \rightarrow s^3$
   - $C_h \rightarrow C_h / l$

2. Scaling allows the use of long, thin tendons

Let's go deeper

Often

**Long, Thin Tendons: Permissible After Scaling**

- $F_L = kx$
- $m = m
- $F_g = mg$
- Acceleration due to gravity

- Mass $= \rho L_m s^3$
- Density $= \rho$

At static equilibrium:

- Force due to gravity $= F_g = F_s = Spring Force$

- Acceleration due to gravity

- $x = \frac{mg \cdot x}{k}$

- $x = \frac{m g \cdot s^2}{k} \cdot \frac{s}{s}$

- $s = s \rightarrow x = l$
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• Go through slides 30-31 and 37-48 in Module 2 to finish up Thermal Circuits and cover Micro Gas Analyzers

Process Modules:
• Lecture Modules 3 & 4 on Process Modules online
• 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
• Process Module Details lecture videos online
  • These are in Lecture 7.x in the lecture table
  • These give more details than I will give in class
  • Watch these if your background in microfabrication is weak
    — Very helpful to understand course material
    — Very helpful for upcoming homework

Process Module Overview:
• Lecture Topics:
  • Photolithography
  • Etching
  • Oxidation
  • Film Deposition
  • Ion Implantation
  • Diffusion
• The above lecture topics essentially name the important process modules available
• Combination of these in the correct sequence yields an integrated circuit technology that provides transistors, MEMS, nanodevices, etc.
• For each module, need to understand:
  • Physics and engineering of each module in detail
  • Interactions between modules
  • The effect of each module on the finished device
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**Photolithography**

1. Light
2. Designated Pattern (emulsion or chrome)
3. Mask (glass/quartz)
4. Photosensitive organic polymer
5. Add developer (KOH)
6. Etch oxide (using dry or wet etching)
7. PR products underlying oxide from etching
8. Acetone or PR 3000 (to remove the PR)
9. oxide film now patterned
10. Above: collectively called a masking step

**Number of Masking Steps**
- NMOS: 4-6 masks
- 1990 CMOS: 8-11 masks
- Today's CMOS: >25 masks
- Bipolar: 11-13 masks
- BiCMOS: 20 masks

- Combination of bipolar & CMOS (mainly for RF/RF/low noise apps)

**Computer Aided Design (CAD)**

- Specified by CAD software

**Si-substrate**

- Exposed PR
- Mask (glass/quartz)
- Photolithographic pattern
- Oxide film to be patterned (e.g., oxide)
- Photosensitive organic polymer
- Add developer (KOH)
- Etch oxide (using dry or wet etching)
- PR products underlying oxide from etching
- Acetone or PR 3000 (to remove the PR)
- Oxide film now patterned

**Case:** Positive Resist
- Exposed positive resist removed in developer

**Conclusion:**
- Now, the PR is patterned
- Ready for the next step: Etching
- Isotropic Etchant Examples:
  - Wet etchants
  - Dry plasma etch

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

- Remarks:
  - Wet etching is fairly cheap
  - Dry etching requires a plasma, so requires some expensive equipment
  - Don’t always want straight sidewalls

- Go through Module 4, slides 15-21, 36-47