Lecture 6: Process Modules

- Announcements:
  - HW#1B due Wednesday next week at 8 a.m.
  - Lecture Modules 3 & 4 on Process Modules online
  - Lecture Module 5 on Surface Micromachining online

- 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

- Last Time:
  - Finished thermal circuit modeling
  - Now, spend a brief amount of time in Micro Gas Analyzers, then proceed with Process Modules

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, Fall 2012 on the Webcast Berkeley site for more in depth coverage: Lectures 6-8

⇒ There are actually only a few basic modules
⇒ needed 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.
**Process Modules**

1. **Photolithography**
   - Light illuminates指定图案
   - 光敏树脂 (PR)
   - 薄膜被图案化（如氧化物）
   - 光敏树脂 (PR)
   - 玻璃/氧化物膜

2. **Etch oxide (using dry or wet etching)**
   - Si-substrate
   - 氧化硅膜

3. **Acetone or PRS 3000**
   - （用于去除PR）
   - 氧化硅膜现在图案化

4. **KOH developer**
   - 加入KOH
   - Now, the PR is patterned
   - Ready for the next step: Etching

**Number of Masking Steps**

- NMOS: 4-6 masks
- 1990 CMOS: 8-11 masks
- Today's CMOS: > 20 masks
- Bipolar: 11-13 masks
- BiCMOS: 20 masks

**Add developer (KOH)**

- 加入KOH
- 现在PR被图案化

**Use**

- 光敏树脂 (PR)
- 薄膜被图案化

**Case:**

- Positive Resist
- Exposed positive resist remover in developer

**Notes**

- 上面称为掩模步骤
- 通常根据特定工艺的复杂度来计算成本

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- 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

Etching

Isotropic Etch
- Etch in any direction (e.g., straight down)
- Films to be etched

Anisotropic Etch
- Etch in only one direction

Patterened PR
- Films to be etched

Si-substrate
- Undercutting
- Not desirable when resolution is important
- Very desirable in MEMs, when a structure must be released

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

Si-substrate
- Undercutting

SiO₂ (1 mm - 1 μm)
- SiO₂ is used to stand up on boat
- Result: SiO₂ (1 mm - 1 μm)
- Dry wet oxidation

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Remarks:
- Uniformity can be better than 2% across the wafer from lot to lot
- Need to flow the O₂ fairly fast in order to minimize reactant losses from the first boat to the last one

Thin-Film Deposition:
- For deposition of films like Al (and other metals), SiO₂, Si₃N₄, and polysilicon
- Deposition, not thermal growth

Example: Evaporation

Example: Sputtering

• Also, have chemical vapor deposition (CVD)
  - Chemical reaction involved in deposition of a given thin film
  - High temperature, but not nearly as high as often required for thermal growth

Chemical Vapor Deposition

Remarks:
- Lot's of materials can be deposited in a similar manner: polysilicon, SiO₂, Si₃N₄, tungsten
- Compared to sputtering, CVD is less expensive since one can coat many wafers at once; sputtering generally does it one at a time
- For higher temperature, CVD films are much more conformal than sputtered films
• Diffusion:
  • Process of introducing dopants into selected areas on an IC
  • Example:

\[ \text{diffusion} \rightarrow \text{B}_2\text{H}_6 + \text{O}_2 \rightarrow \text{B}_2\text{O} + \text{H}_2 \text{O} \at \text{high temperature} \sim 800 \text{C} - 1200 \text{C} \]

\[ \text{SiO}_2 \leq \text{B} \leq \text{SiO}_2 \]

\( \text{n-Si substrate} \)

1. Form borosilicate glass with high B concentration
2. Boron diffuses in → this becomes p-type

⇒ diffusion requires:
1. concentration gradient
2. movement (velocity)

⇒ Example: Fish Tank

1. When separatin removed...
2. Fish will go to the other side
3. Until the concentration is the same on both sides

But they can't if they're dead!