EE C245 – ME C218
Introduction to MEMS Design
Fall 2011

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Lecture Module 6: Bulk Micromachining

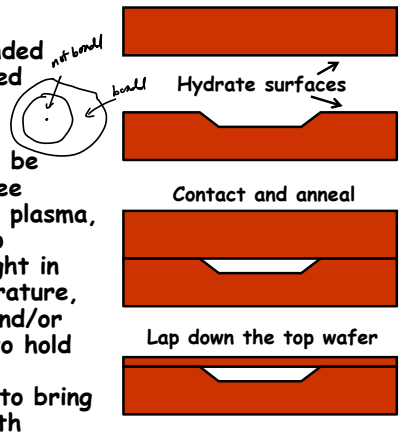
Lecture Outline

- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handouts: "Bulk Micromachining of Silicon"
- Lecture Topics:
  - Bulk Micromachining
  - Anisotropic Etching of Silicon
  - Boron-Doped Etch Stop
  - Electrochemical Etch Stop
  - Isotropic Etching of Silicon
  - Deep Reactive Ion Etching (DRIE)
  - Wafer Bonding

Wafer Bonding

Fusion Bonding

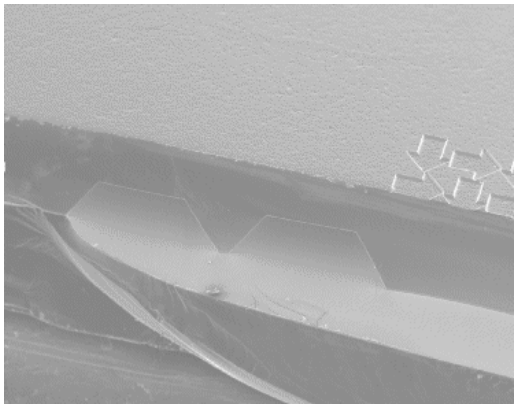
- Two ultra-smooth (<1 nm roughness) wafers are bonded without adhesives or applied external forces
- Procedure:
  - Prepare surfaces: must be smooth and particle-free
    - Clean & hydrate: O_2 plasma, hydration, or HF dip
  - When wafers are brought in contact at room temperature, get hydrogen bonding and/or van der Waals forces to hold them together
  - Anneal at 600-1200°C to bring the bond to full strength
- Result: a bond as strong as the silicon itself!



Works for Si-to-Si bonding and Si-to-SiO_2 bonding

Fusion Bonding Example

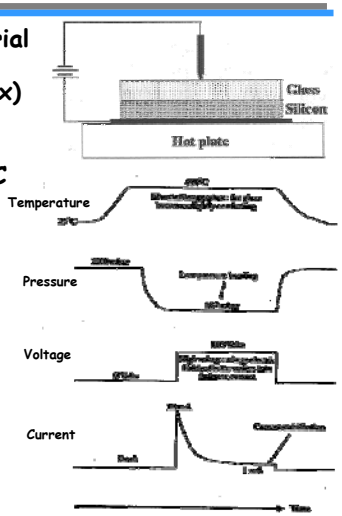
- Below: capacitive pressure sensor w/ fusion-bonded features



[Univ. of Southampton]

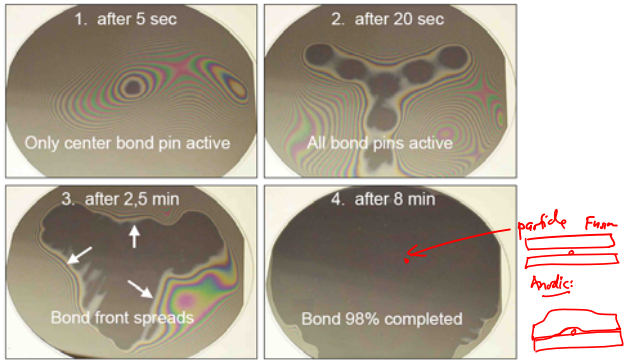
Anodic Bonding

- Bonds an electron conducting material (e.g., Si) to an ion conducting material (e.g., sodium glass = Pyrex)
- Procedure/Mechanism:
  - Press Si and glass together
  - Elevate temperature: 180-500°C
  - Apply (+) voltage to Si: 200-1500V
    - (+) voltage repels Na^+ ions from the glass surface
    - Get net (-) charge at glass surface
    - Attractive force between (+) Si and (-) glass → intimate contact allows fusing at elevated temp.
  - Current drops to zero when bonding is complete



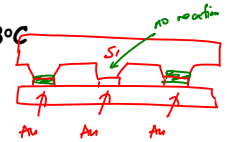
Anodic Bonding (cont.)

- Advantage: high pressure of electrostatic attraction smoothes out defects
- Below: 100 mm wafers, Pyrex glass 500 μm-thick, 430°C, 800V, N_2 @ 1000 mbar



Metal Layer Bonding

- Pattern seal rings and bond pads photolithographically
- Eutectic bonding
  - Uses eutectic point in metal-Si phase diagrams to form silicides
  - Au and Si have eutectic point at 363°C
  - Low temperature process
  - Can bond slightly rough surfaces
  - Issue: Au contamination of CMOS

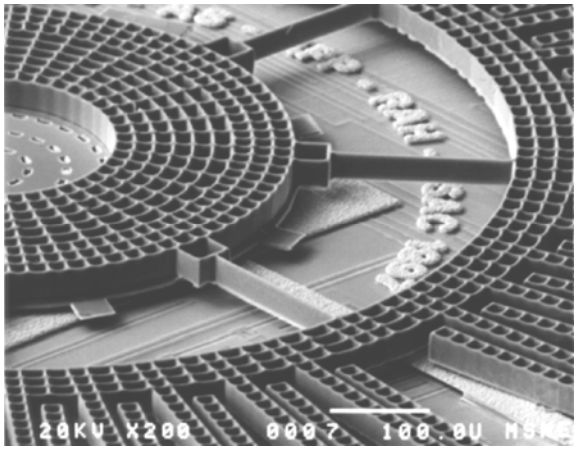


- Solder bonding
  - PbSn (183°C), AuSn (280°C)
  - Lower-T process
  - Can bond very rough surfaces
  - Issue: outgassing (not good for encapsulation)

- Thermocompression
  - Commonly done with electroplated Au or other soft metals
  - Room temperature to 300°C
  - Lowest-T process
  - Can bond rough surfaces with topography

Thermocompression Bonding

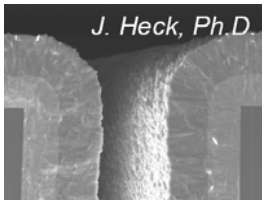
- Below: Transfer of hexsil actuator onto CMOS wafer

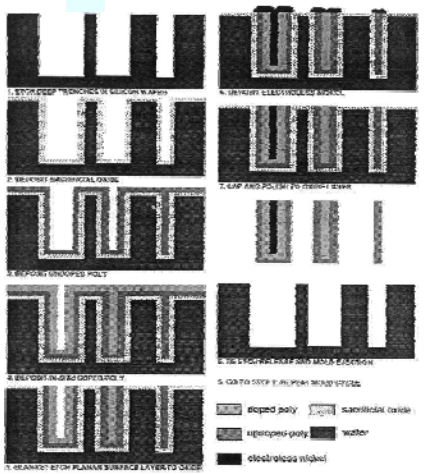


[Singh, et al, Transducers'97]

Hexsil MEMS

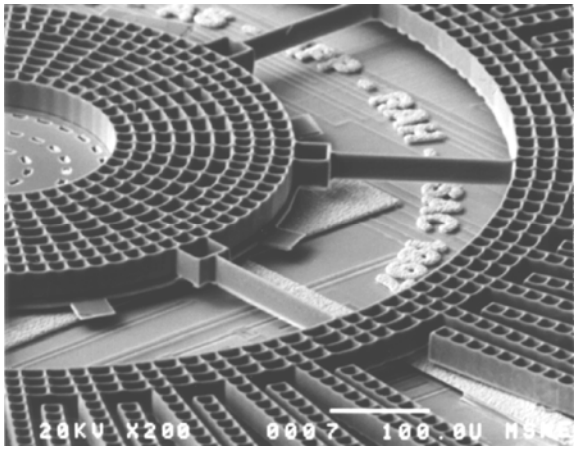
- Achieves high aspect ratio structures using conformal thin films in mold trenches
- Parts are demolded (and transferred to another wafer)
- Mold can be reused
- Design with honeycomb structure for strength





Hexsil MEMS Actuator

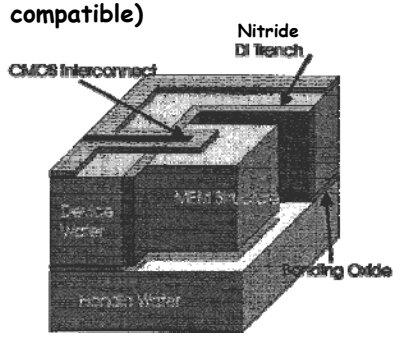
- Below: Transfer of hexsil actuator onto CMOS wafer

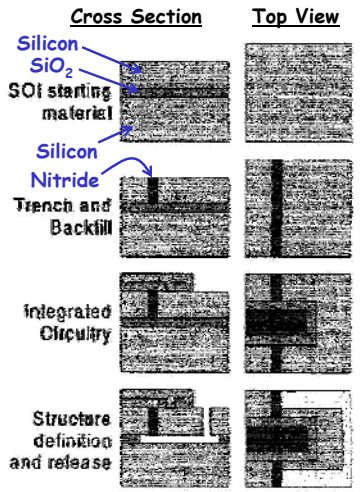


[Singh, et al, Transducers'97]

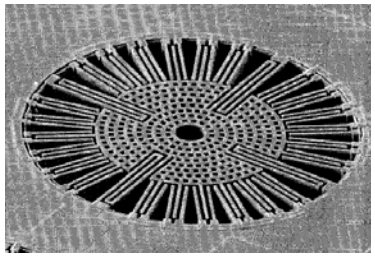
Silicon-on-Insulator (SOI) MEMS

- No bonding required
- Si mechanical structures anchored by oxide pedestals
- Rest of the silicon can be used for transistors (i.e., CMOS compatible)



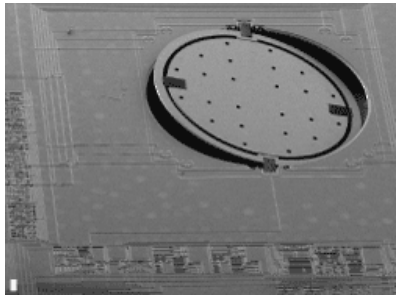


SOI MEMS Examples



[Brosnihan]

Micromirror
[Analog Devices]



The SCREAM Process

- SCREAM: Single Crystal Reactive Etching and Metallization process