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EE C245 - ME C218 Introduction to MEMS Design Fall 2010

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Lecture Module 6: Bulk Micromachining

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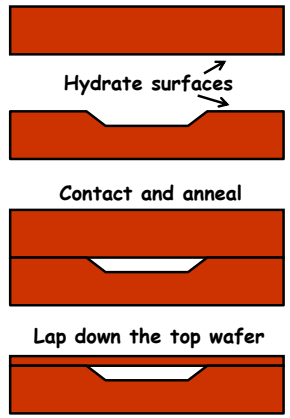
Wafer Bonding

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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: O₂ 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!



Hydrate surfaces

Contact and anneal

Lap down the top wafer

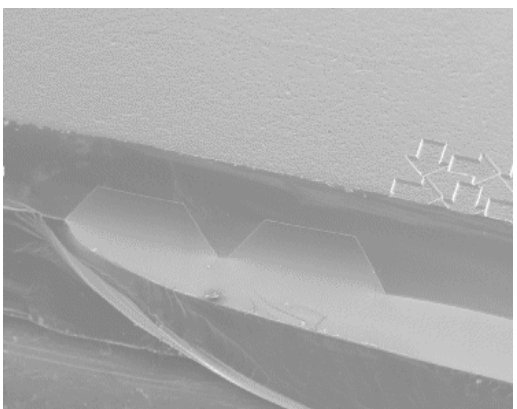
Works for Si-to-Si bonding and Si-to-SiO₂ bonding

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Fusion Bonding Example

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



[Univ. of Southampton]

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Anodic Bonding

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- 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

The schematic shows a Silicon wafer on a Hot plate with a Glass layer on top. A voltage source is connected to the Silicon (positive) and the Glass (negative). The graphs show: Temperature rising to 400°C; Pressure applied during heating; Voltage applied to the Silicon; Current peaking during the initial phase and then dropping to zero.

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Anodic Bonding (cont.)

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- Advantage:** high pressure of electrostatic attraction smooths out defects
- Below:** 100 mm wafers, Pyrex glass 500 μm-thick, 430°C, 800V, N₂ @ 1000 mbar

The images show the bond front spreading over time: 1. after 5 sec (Only center bond pin active), 2. after 20 sec (All bond pins active), 3. after 2.5 min (Bond front spreads), 4. after 8 min (Bond 98% completed).

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Metal Layer Bonding

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- 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

The diagram shows a cross-section of a metal layer being bonded to a substrate.

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Thermocompression Bonding

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- Below:** Transfer of hexsil actuator onto CMOS wafer

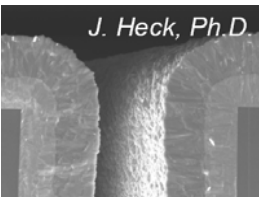
The SEM image shows a hexsil actuator structure on a CMOS wafer. Metadata: 20KV X200 0007 100.0U H5.0. [Singh, et al, Transducers'97]

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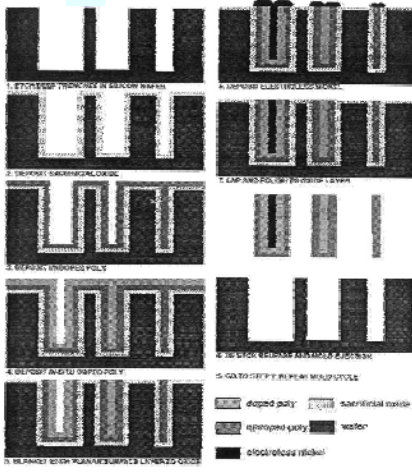
Hexsil MEMS

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- 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



J. Heck, Ph.D.



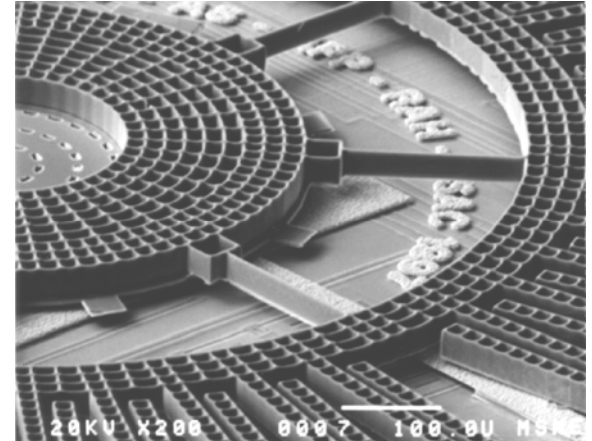
Legend:
 - etched poly: etched
 - deposited poly: deposited
 - sacrificial oxide: sacrificial oxide
 - wafer: wafer
 - photoresist (mask): photoresist (mask)

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Hexsil MEMS Actuator

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- Below:** Transfer of hexsil actuator onto CMOS wafer



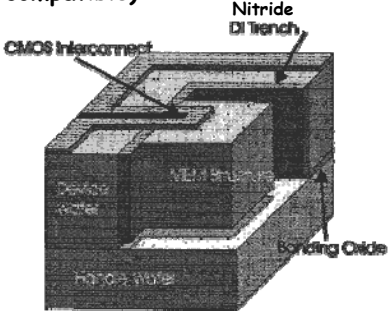
[Singh, et al, Transducers'97]

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Silicon-on-Insulator (SOI) MEMS

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



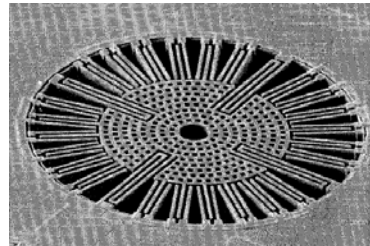
Labels in schematic:
 CMOS Interconnect, Nitride DI Trench, MEMS Structure, Bonding Oxide

	Cross Section	Top View
Silicon		
SiO ₂		
SOI starting material		
Nitride		
Trench and Backfill		
Integrated Circuitry		
Structure definition and release		

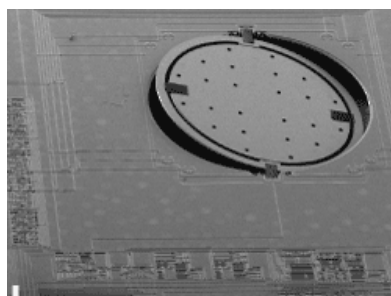
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SOI MEMS Examples

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[Brosnihan]

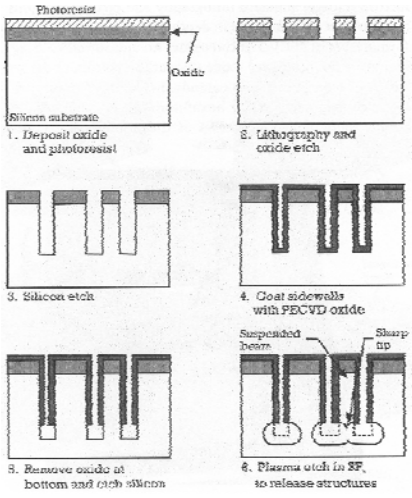
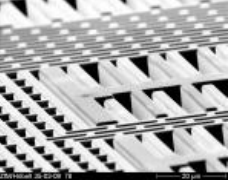
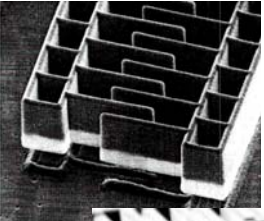


Micromirror
[Analog Devices]

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The SCREAM Process

- **SCREAM: Single Crystal Reactive Etching and Metallization process**



The diagram illustrates the SCREAM process in six steps:

1. Deposit oxide and photoresist
2. Lithography and oxide etch
3. Silicon etch
4. Coat sidewalls with PECVD oxide
5. Remove oxide at bottom and etch silicon
6. Plasma etch in SF₆ to release structures

Labels in the diagrams include: Photocast, Oxide, Silicon substrate, Suspended beam, and Sharp tip.

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