EE C247B – ME C218 Introduction to MEMS Design Spring 2019

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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

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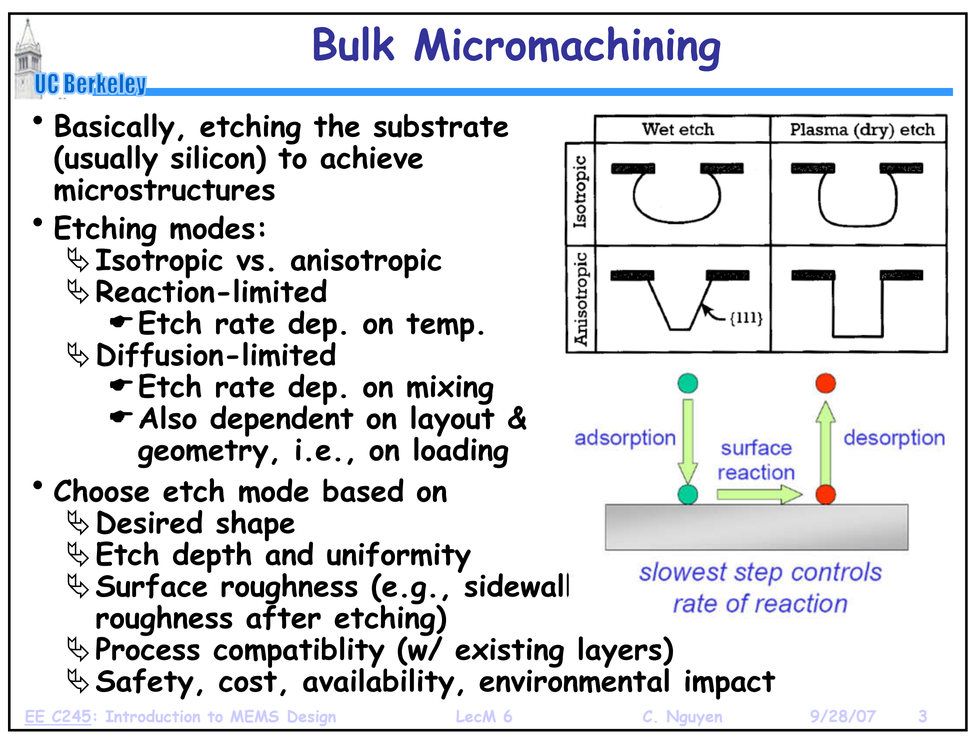

Mechanical Properties of Silicon

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- Crystalline silicon is a hard and brittle material that deforms elastically until it reaches its yield strength,at which point it breaks.
  - Tensile yield strength = 7 GPa (~1500 lb suspended from 1 mm^2)
  - Young's Modulus near that of stainless steel
  - {100} = 130 GPa; {110} = 169 GPa; {111} = 188 GPa
  - Mechanical properties uniform, no intrinsic stress
  - Mechanical integrity up to 500°C
  - Good thermal conductor
  - Low thermal expansion coefficient
  - High piezoresistivity

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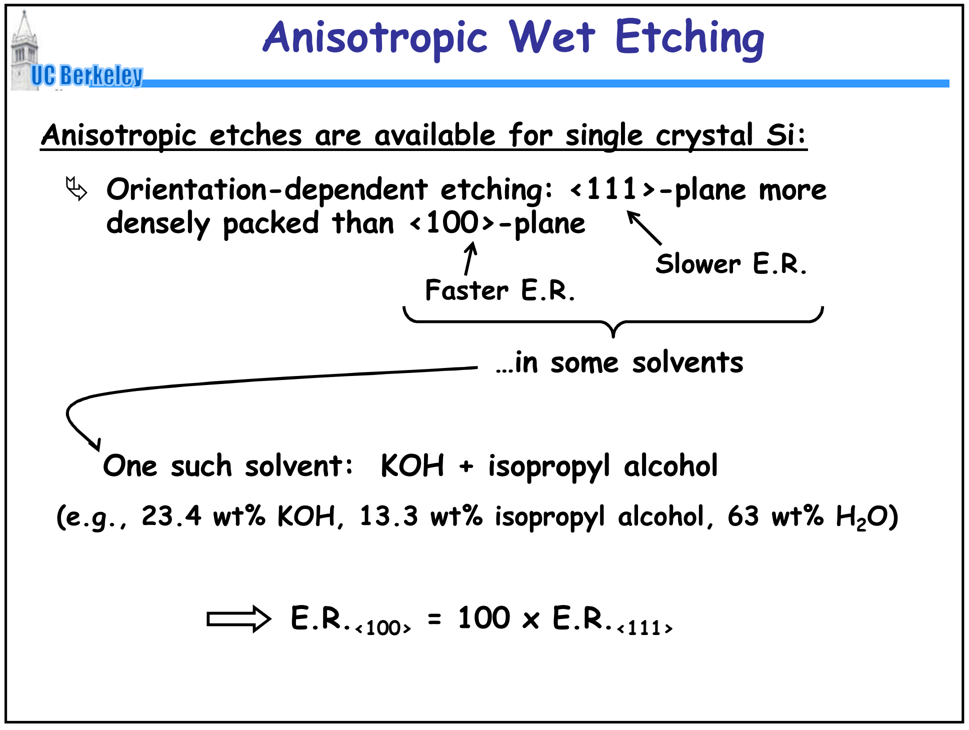

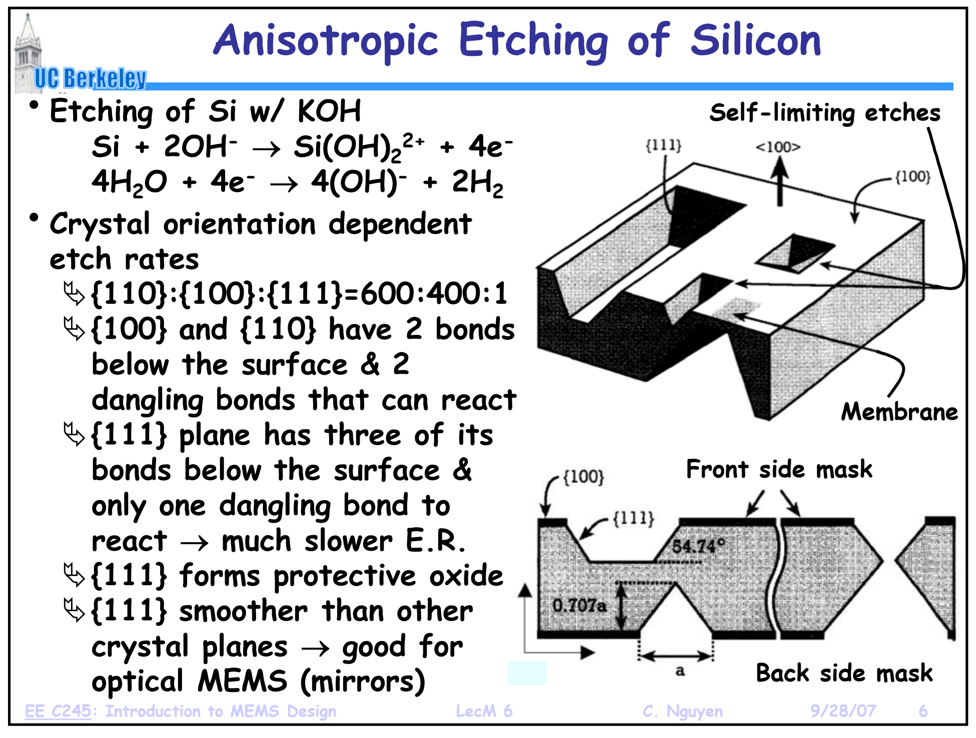

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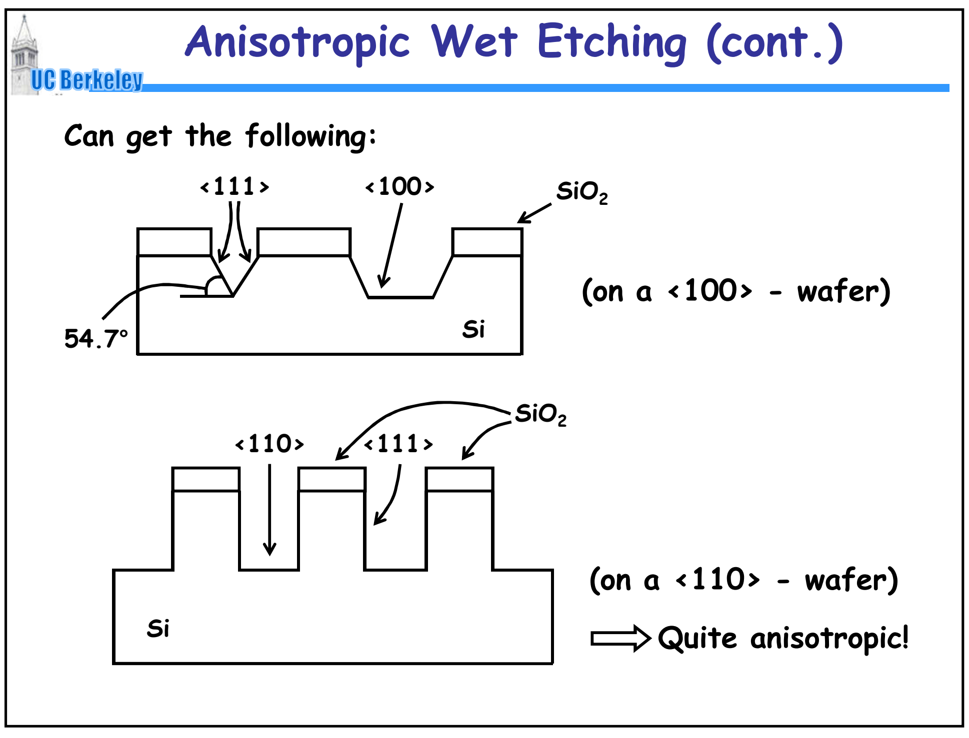

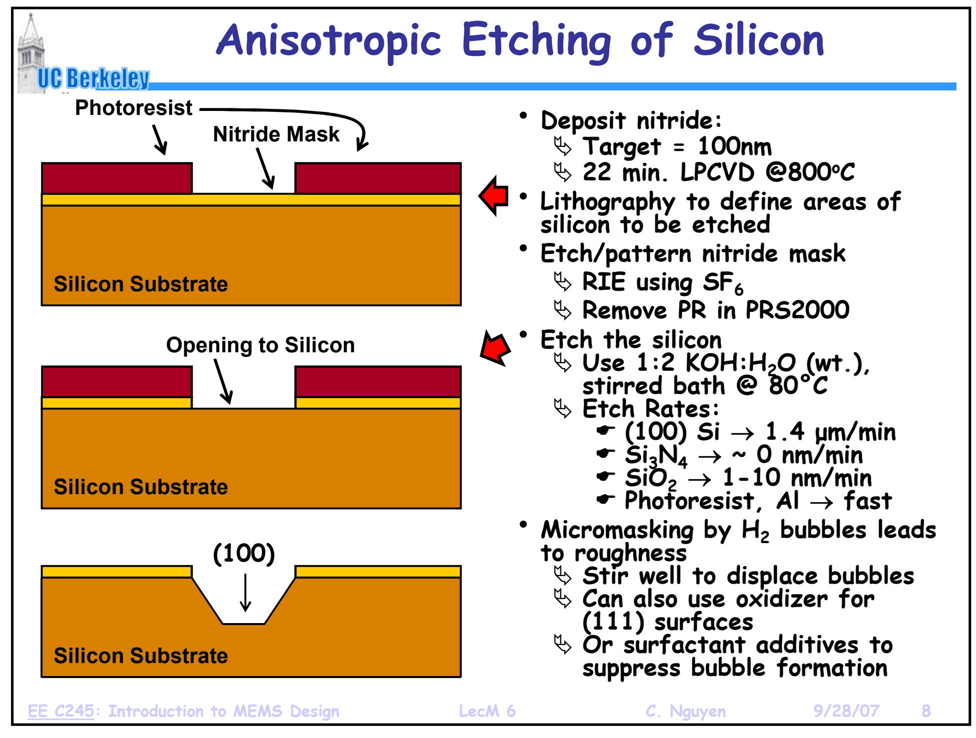

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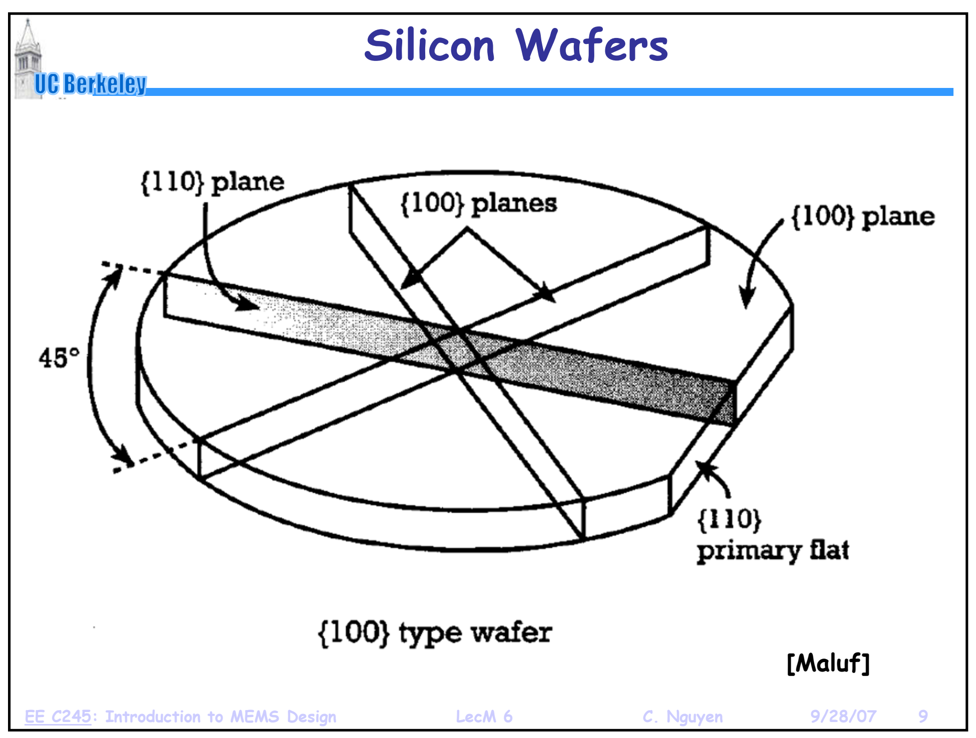

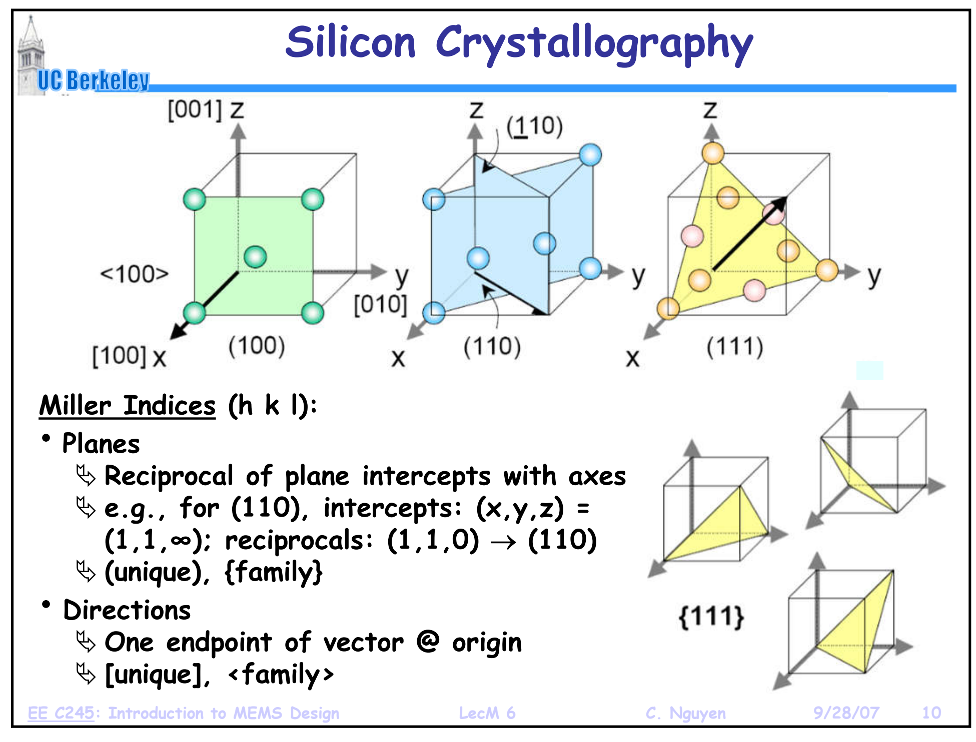

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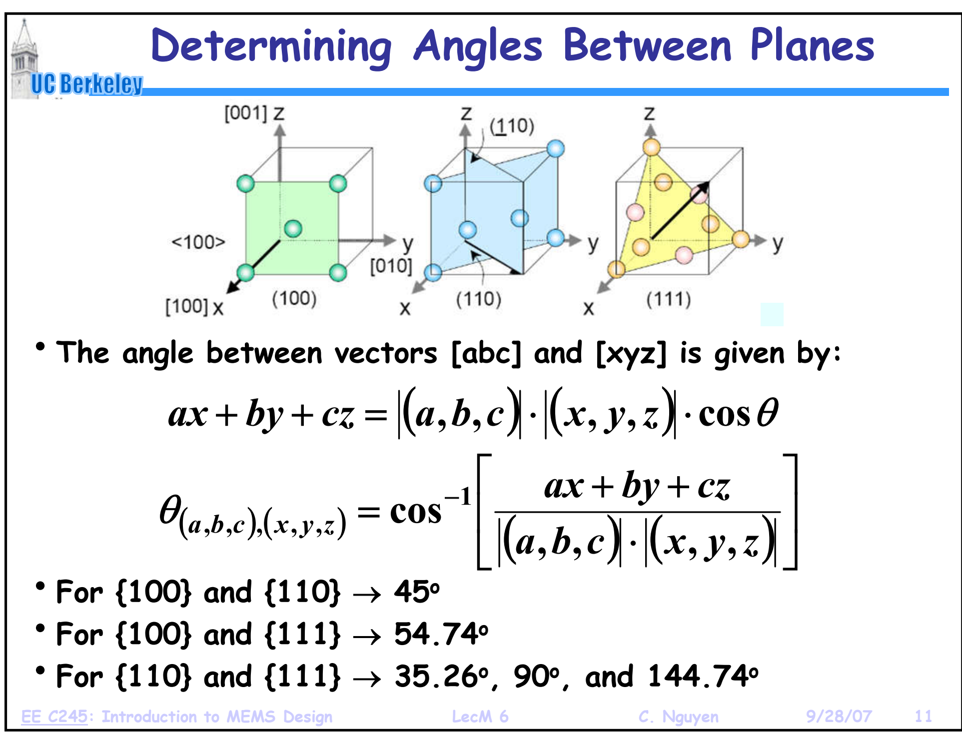
Determining Angles Between Planes
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[001] z
<100>
[100] x
(100)
y
[010]
z
(110)
x
(110)
y
z
x
(111)
y
• The angle between vectors [abc] and [xyz] is given by:
$ax + by + cz = |(a,b,c)| \cdot |(x,y,z)| \cdot \cos\theta$
$\theta_{(a,b,c),(x,y,z)} = \cos^{-1}\left[\frac{ax + by + cz}{|(a,b,c)| \cdot |(x,y,z)|}\right]$
• For {100} and {110} → 45°
• For {100} and {111} → 54.74°
• For {110} and {111} → 35.26°, 90°, and 144.74°
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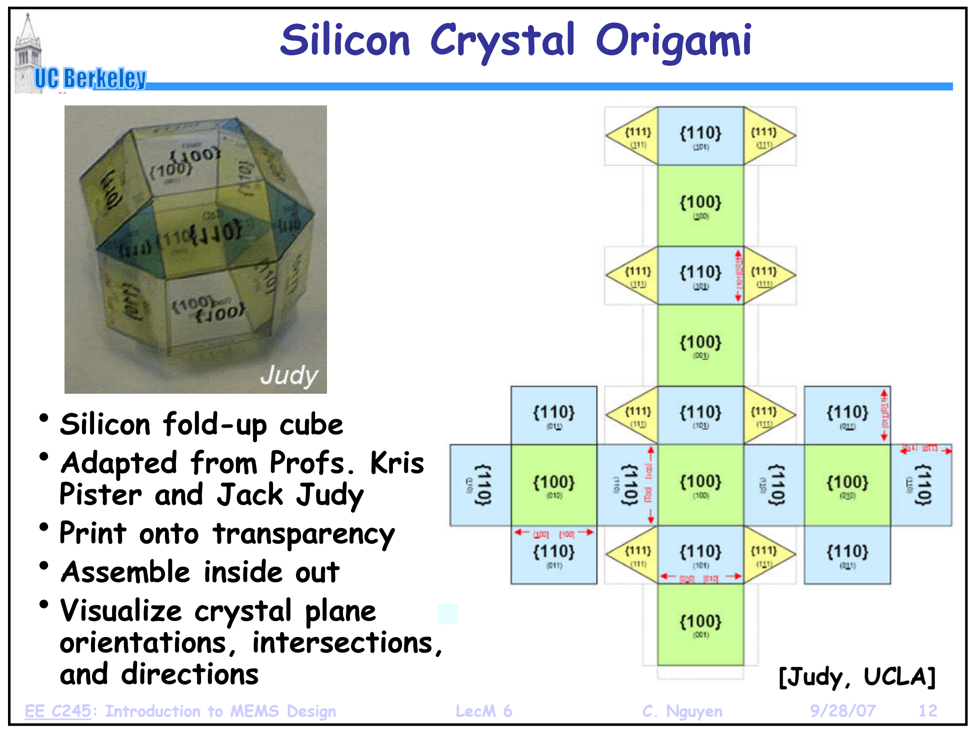
Silicon Crystal Origami
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Judy
• Silicon fold-up cube
• Adapted from Profs. Kris Pister and Jack Judy
• Print onto transparency
• Assemble inside out
• Visualize crystal plane orientations, intersections, and directions
{110}
{100}
{111}
[Judy, UCLA]
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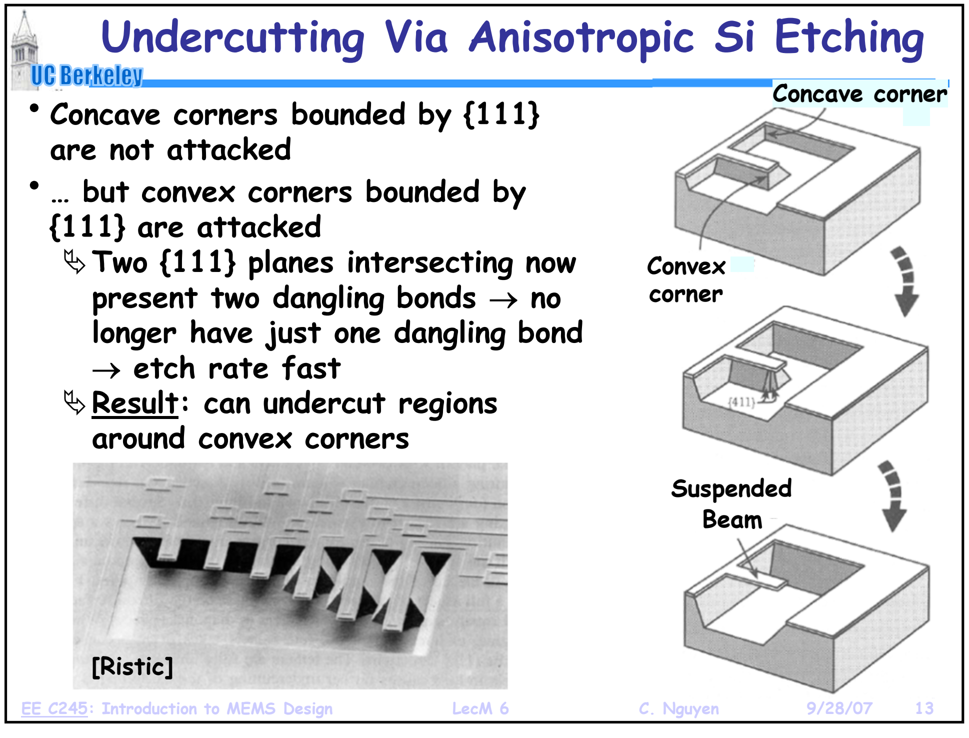

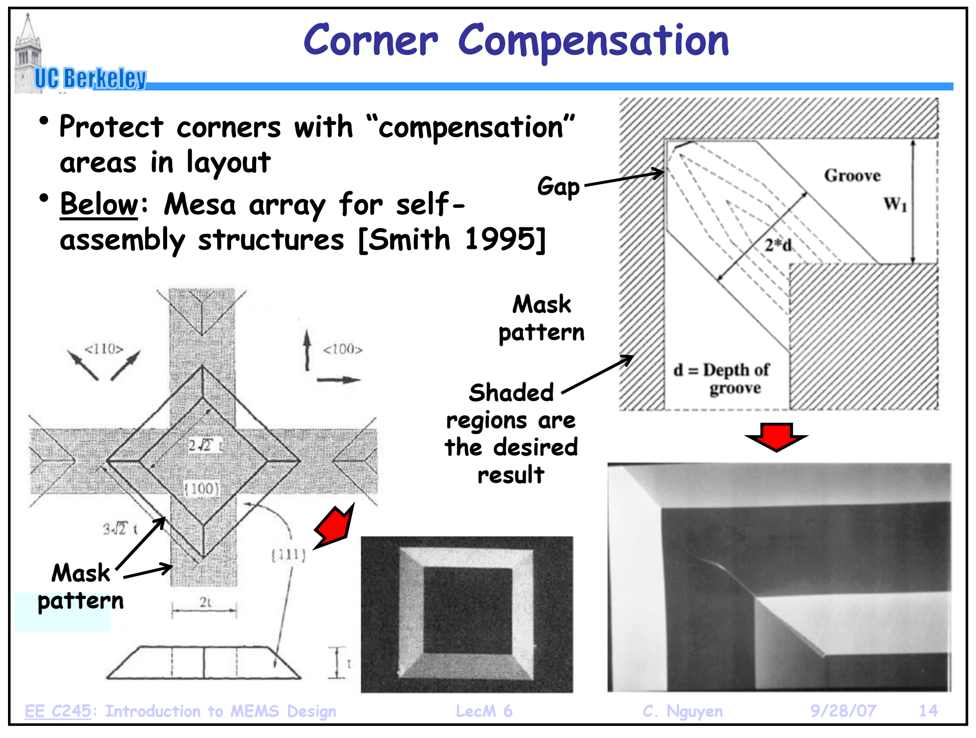

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Other Anisotropic Silicon Etchants

- TMAH, Tetramethyl ammonium hydroxide, 10-40 wt.% (90°C)
  - Etch rate (100) = 0.5-1.5 μm/min
  - Al safe when dual-doped w/ silicic acid & $(NH_4)_2S_2O_8$
  - IC compatible
  - Etch ratio (100)/(111) = 10-35
  - Etch masks: SiO_2 , Si_3N_4 ~ 0.05-0.25 nm/min
  - Boron doped etch stop, up to 40× slower
- EDP (115°C)
  - Carcinogenic, corrosive
  - Etch rate (100) = 0.75 μm/min
  - Al may be etched
  - R(100) > R(110) > R(111)
  - Etch ratio (100)/(111) = 35
  - Etch masks: SiO_2 ~ 0.2 nm/min, Si_3N_4 ~ 0.1 nm/min
  - Boron doped etch stop, 50× slower

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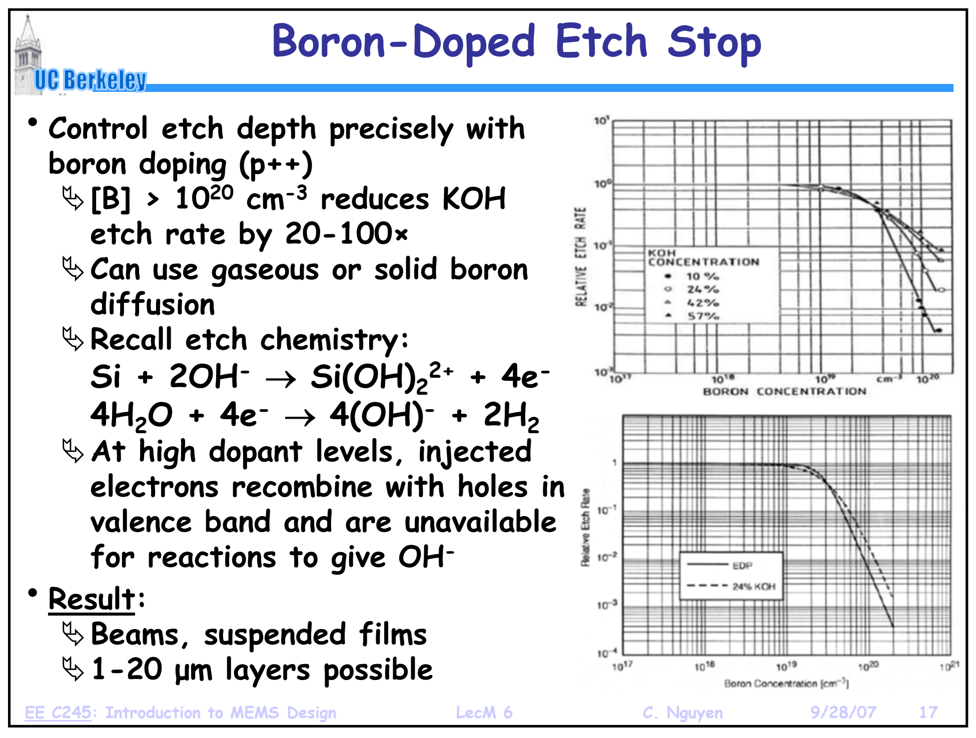

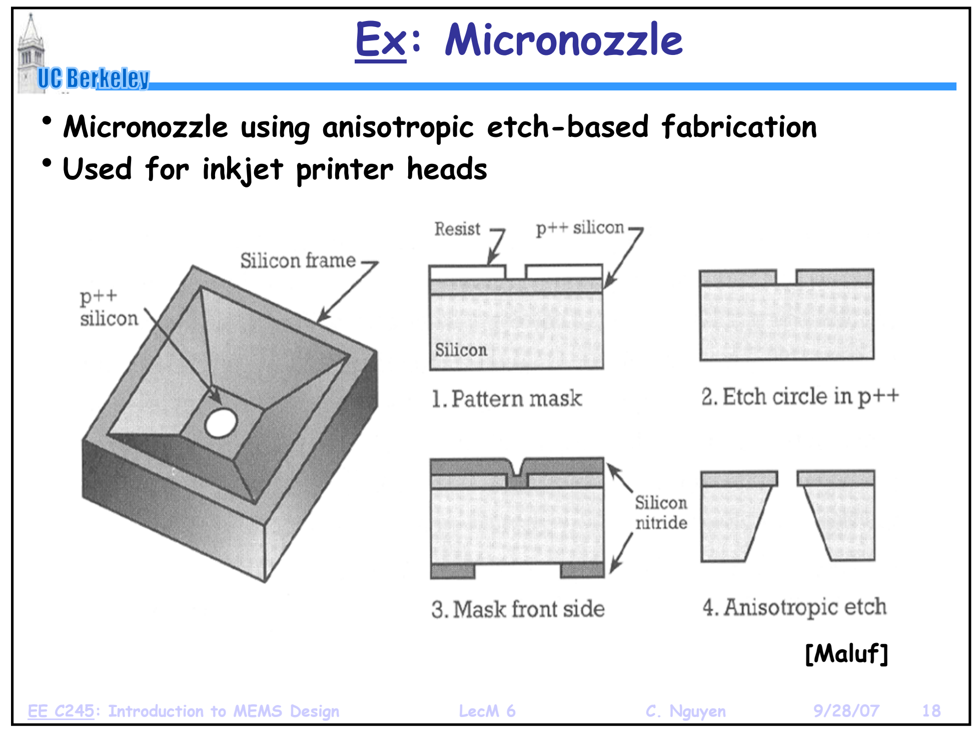

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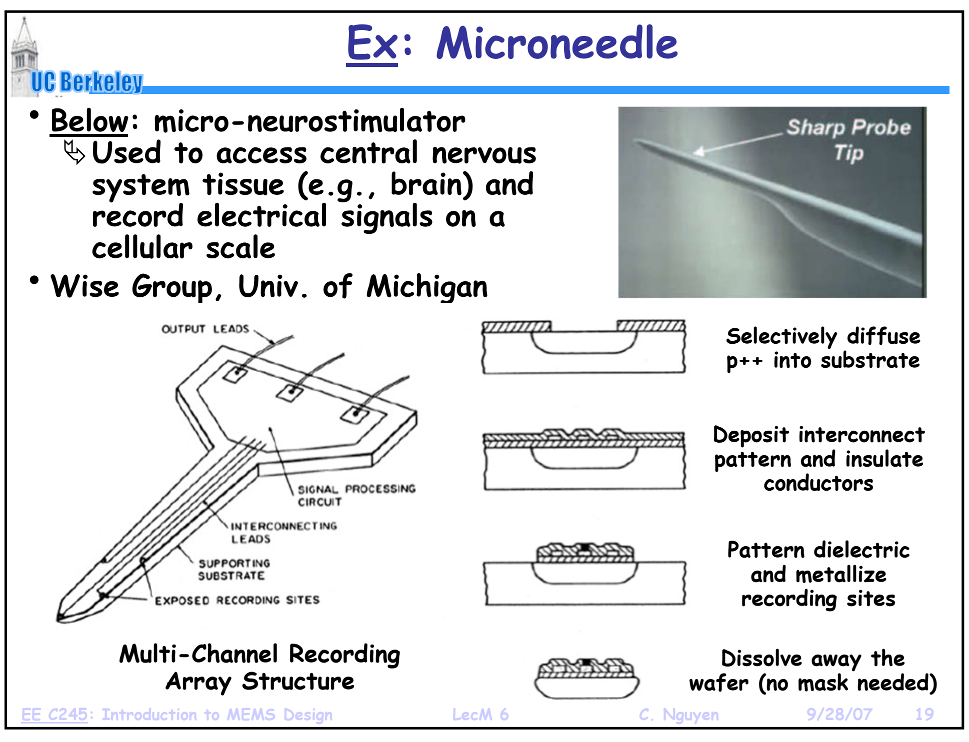

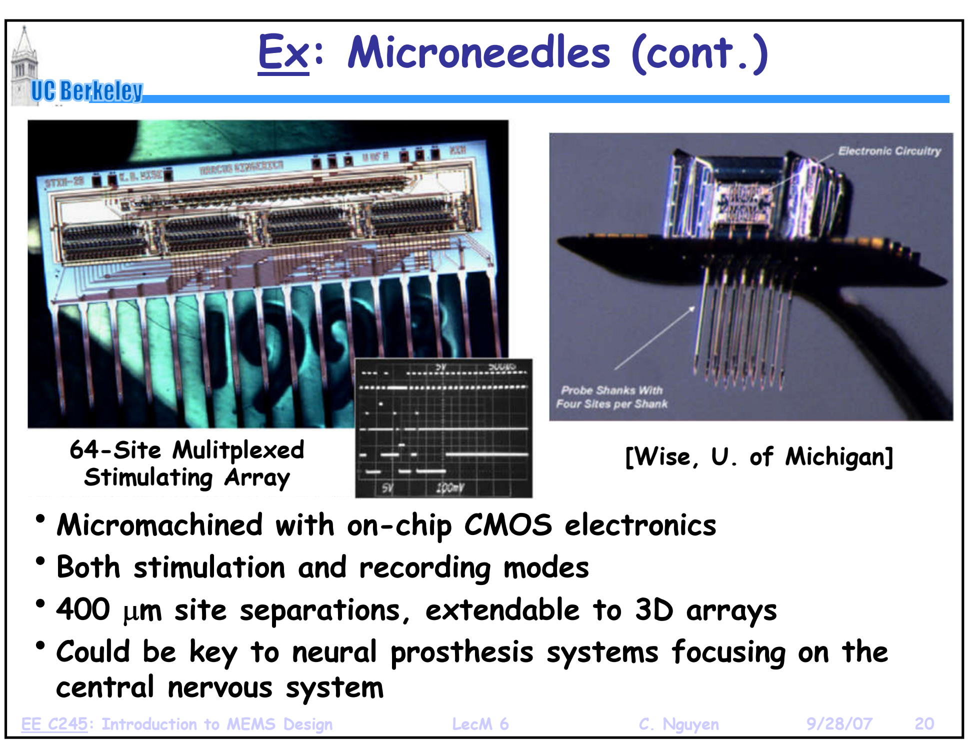

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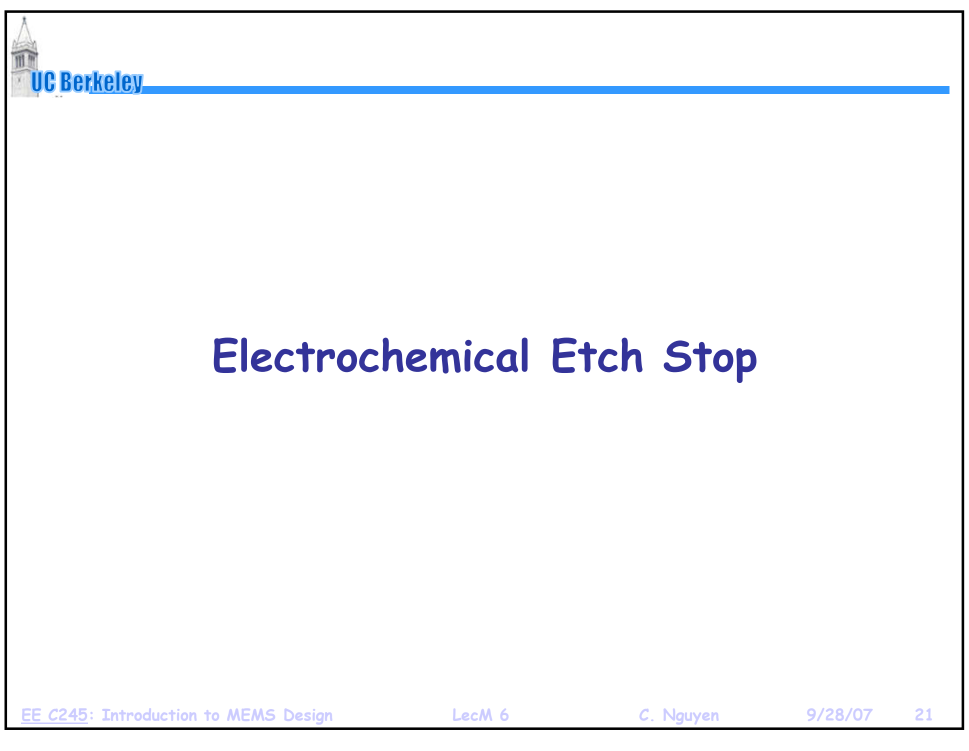

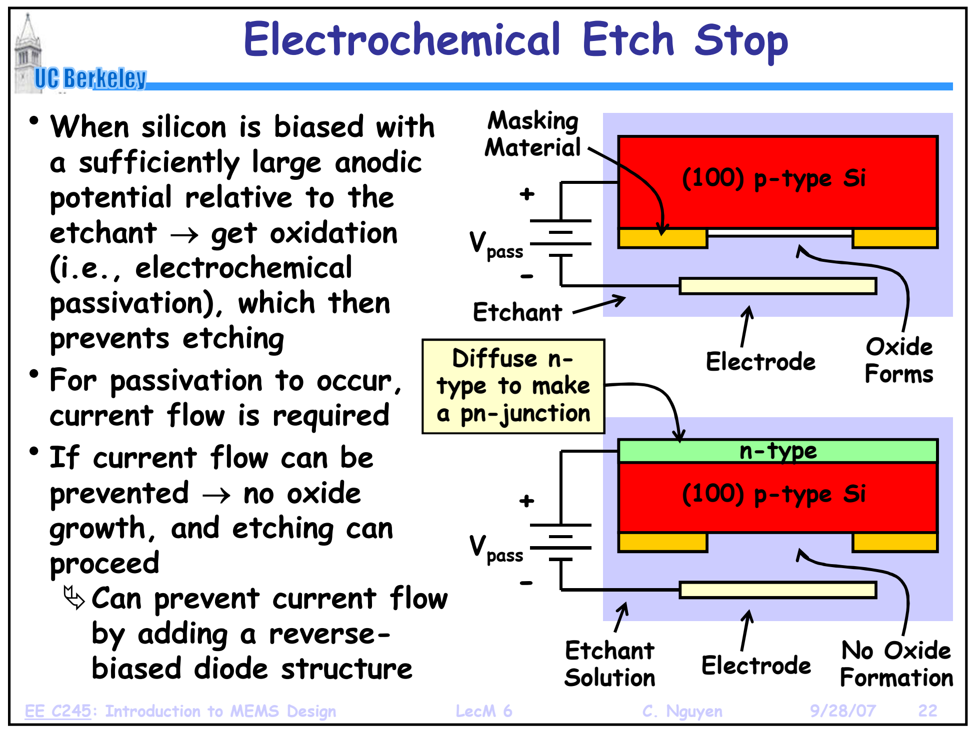

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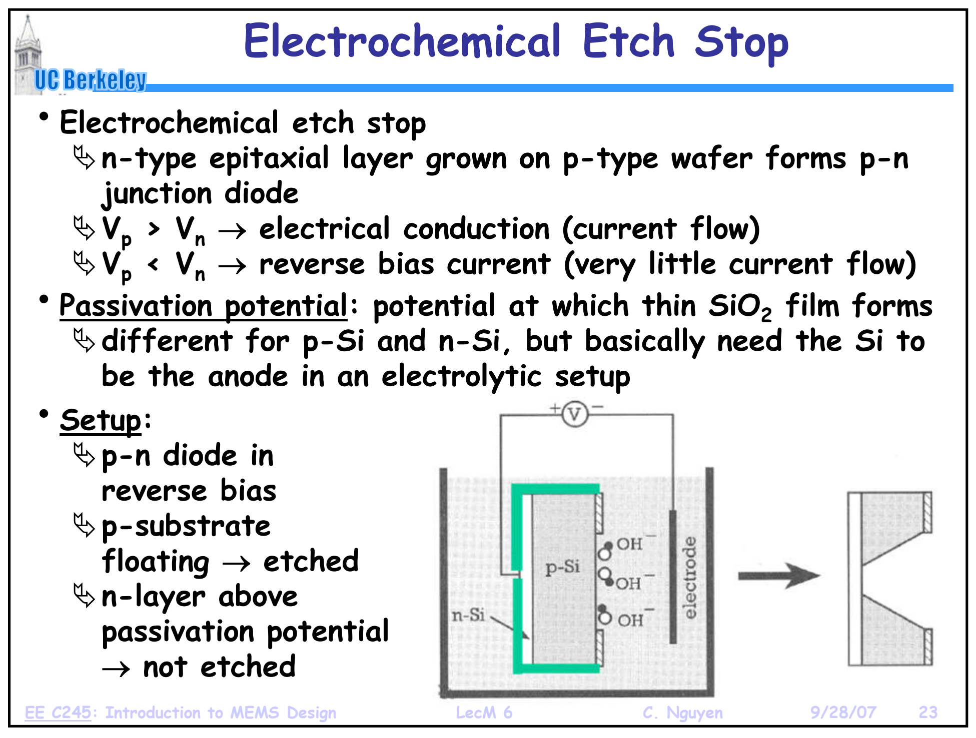

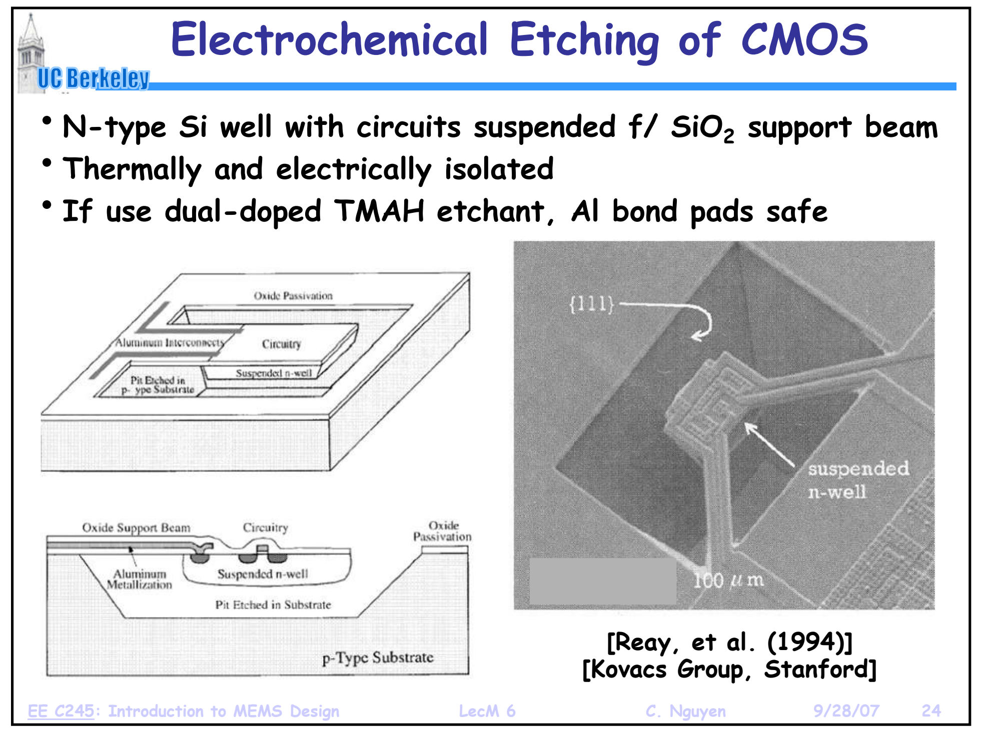

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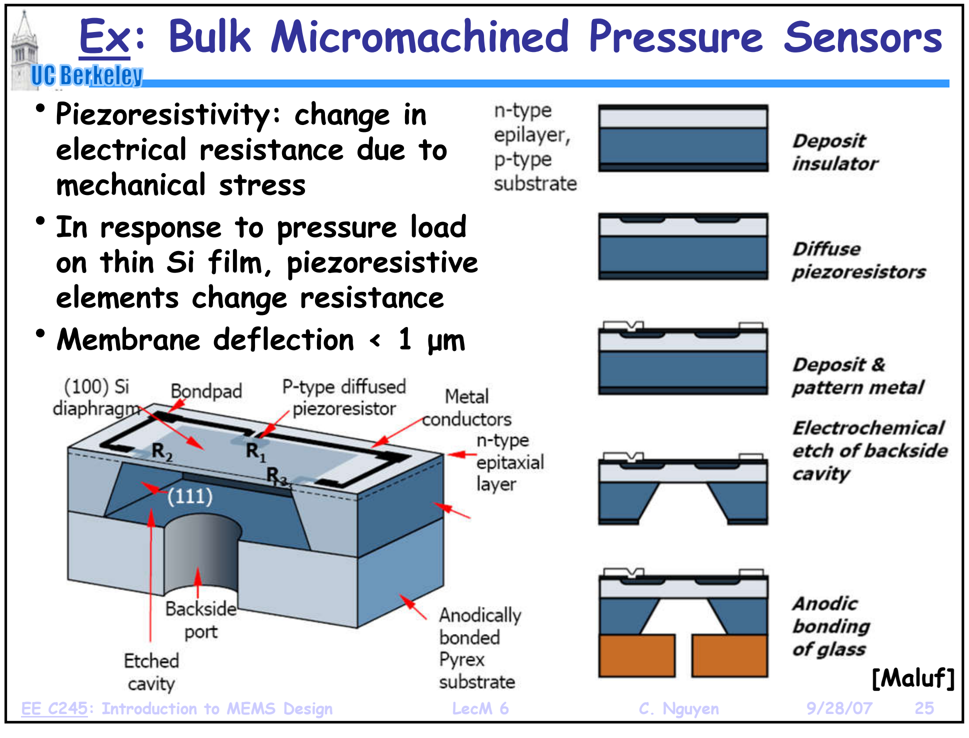

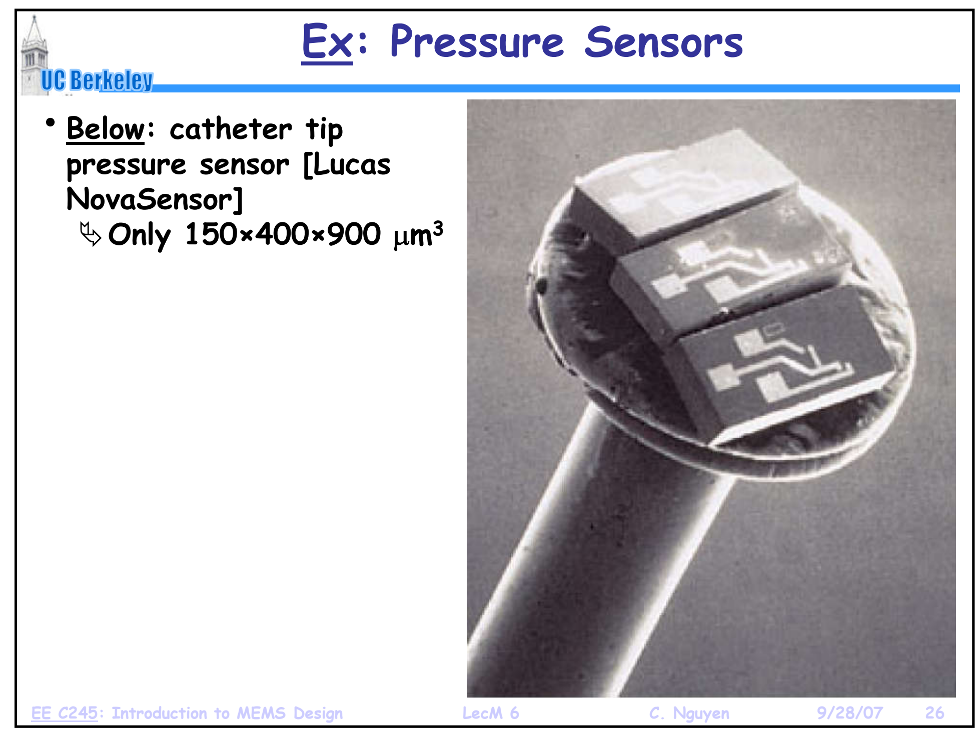

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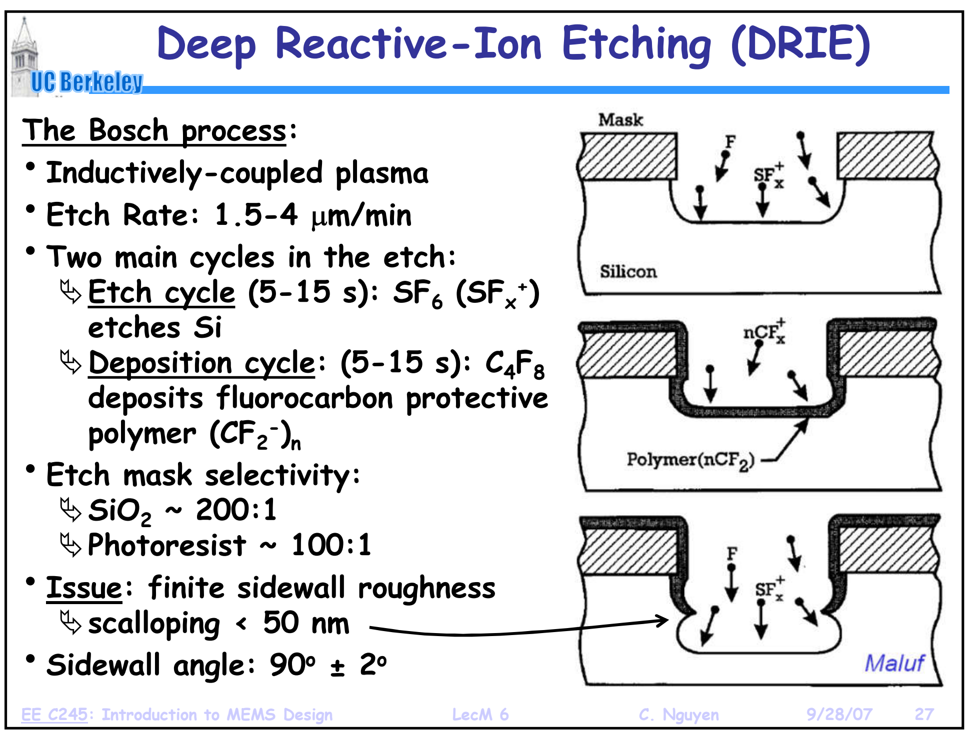

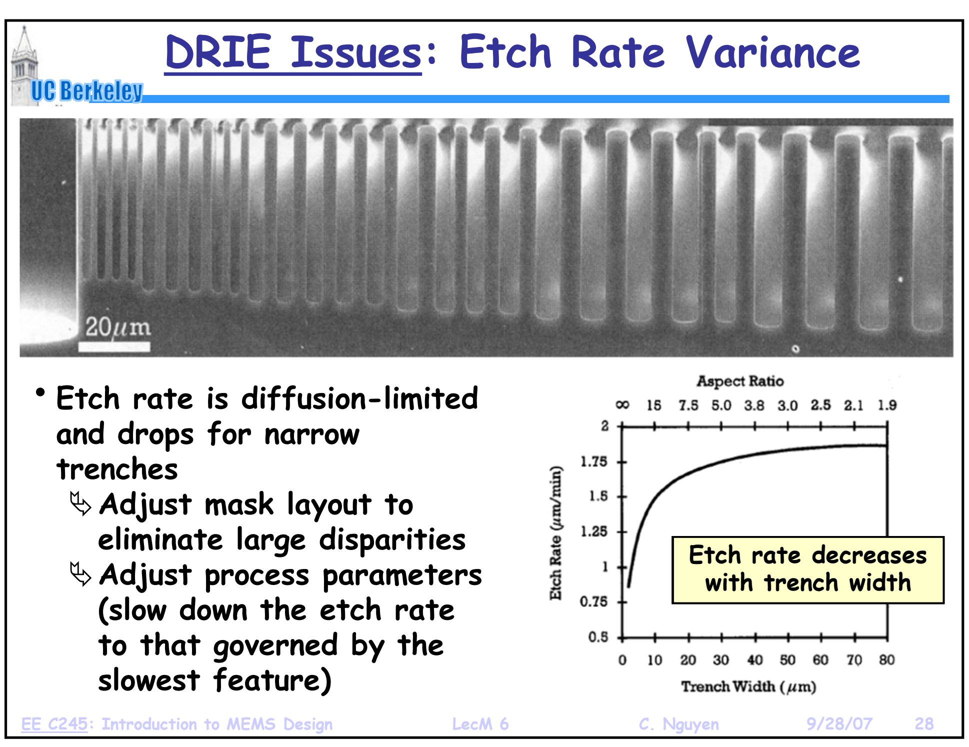

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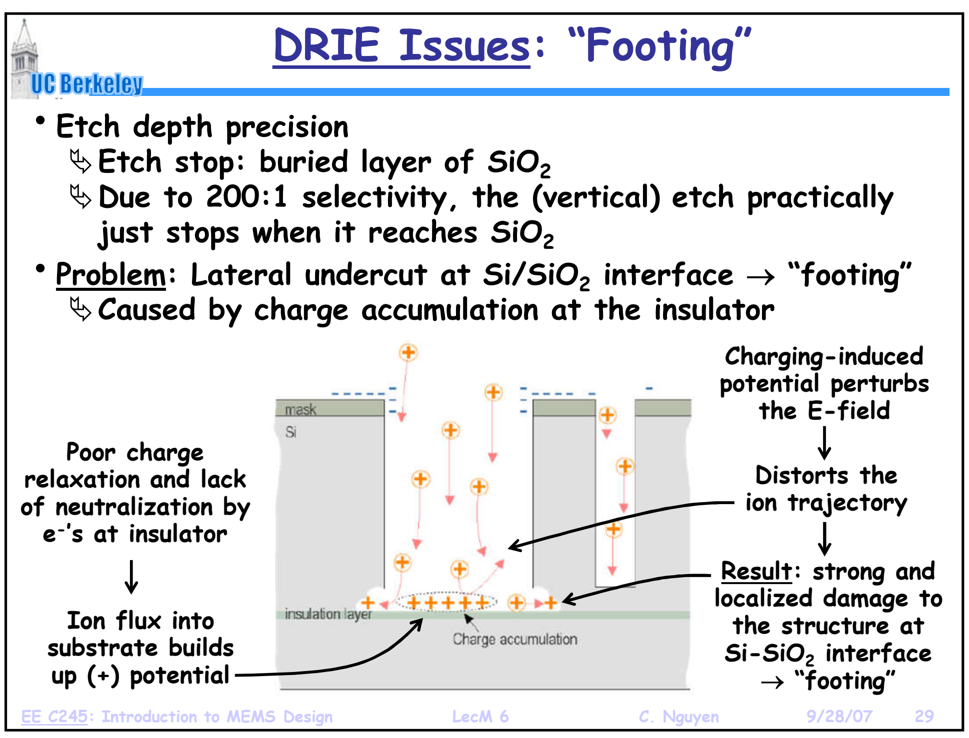

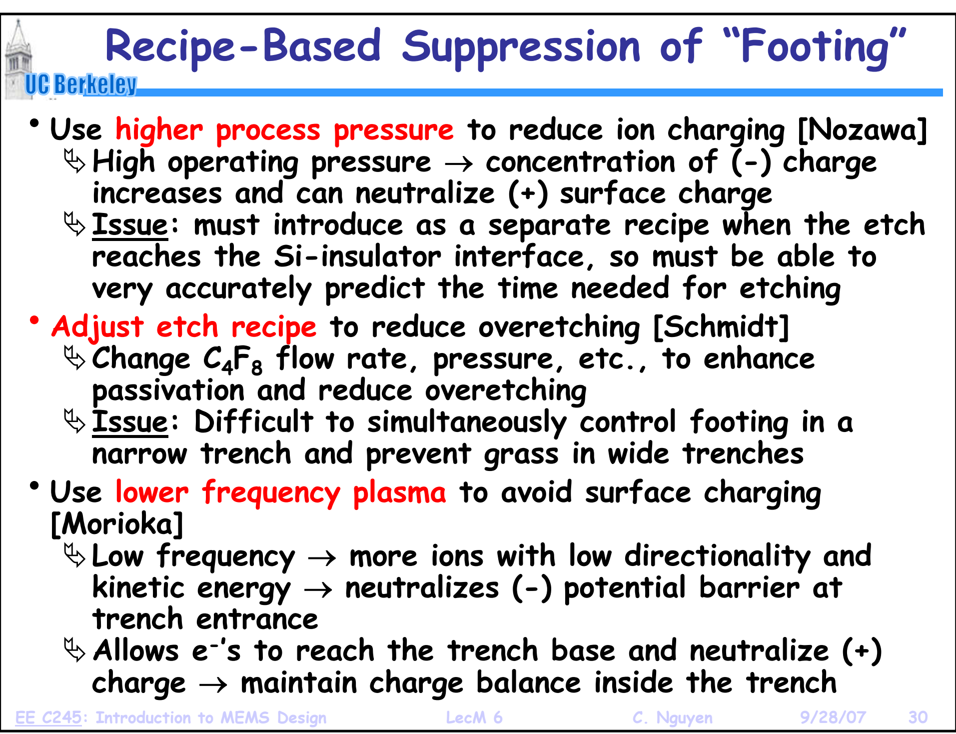

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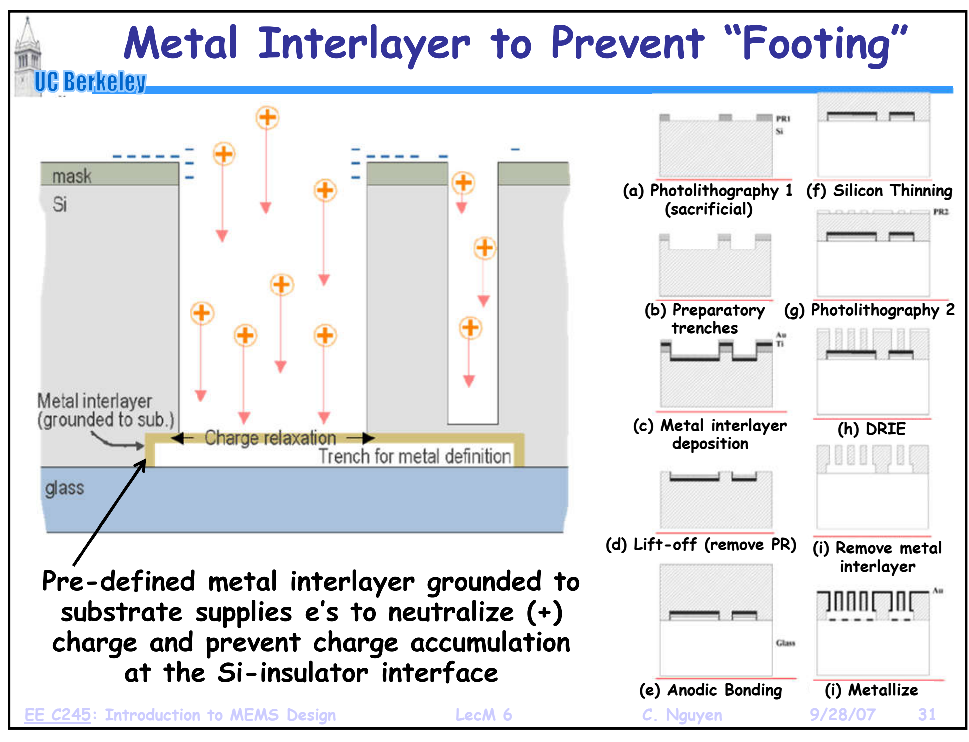

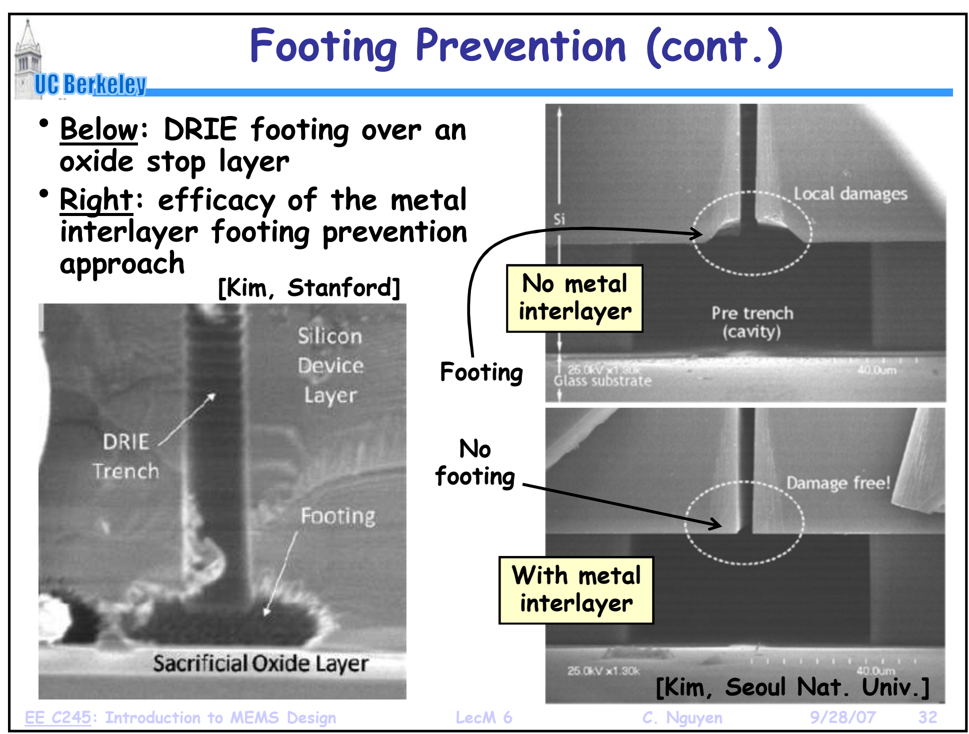

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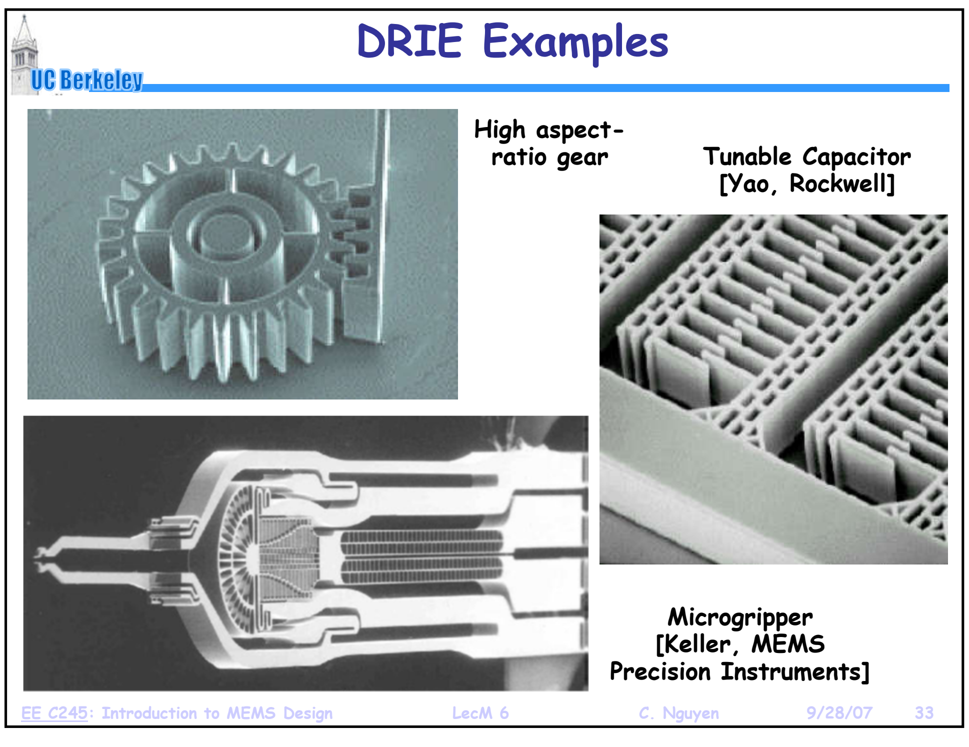

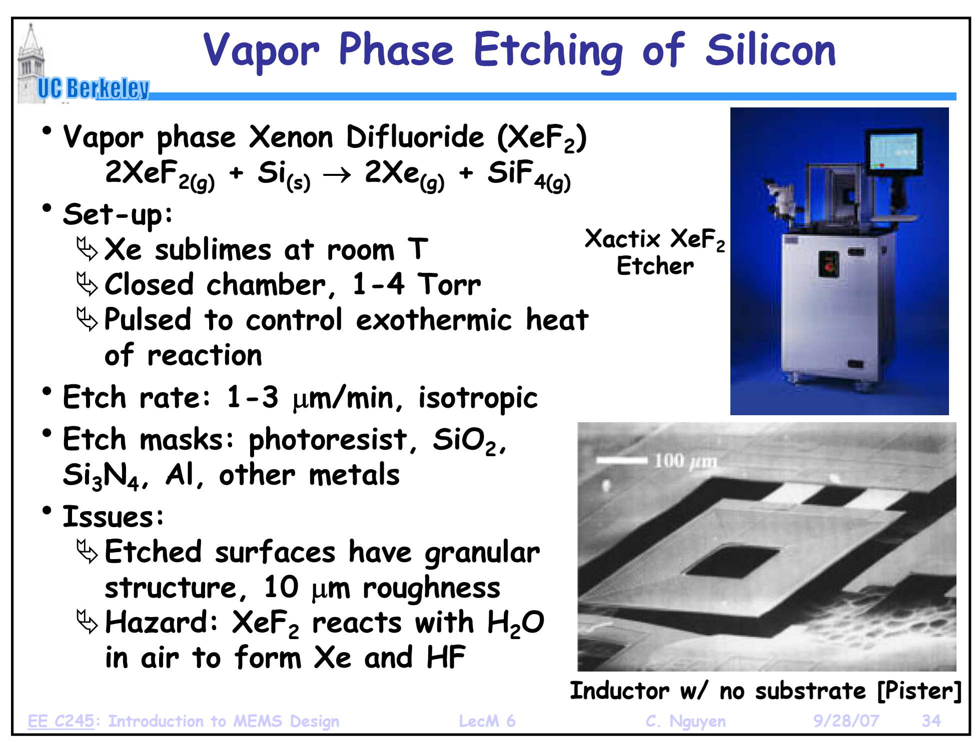

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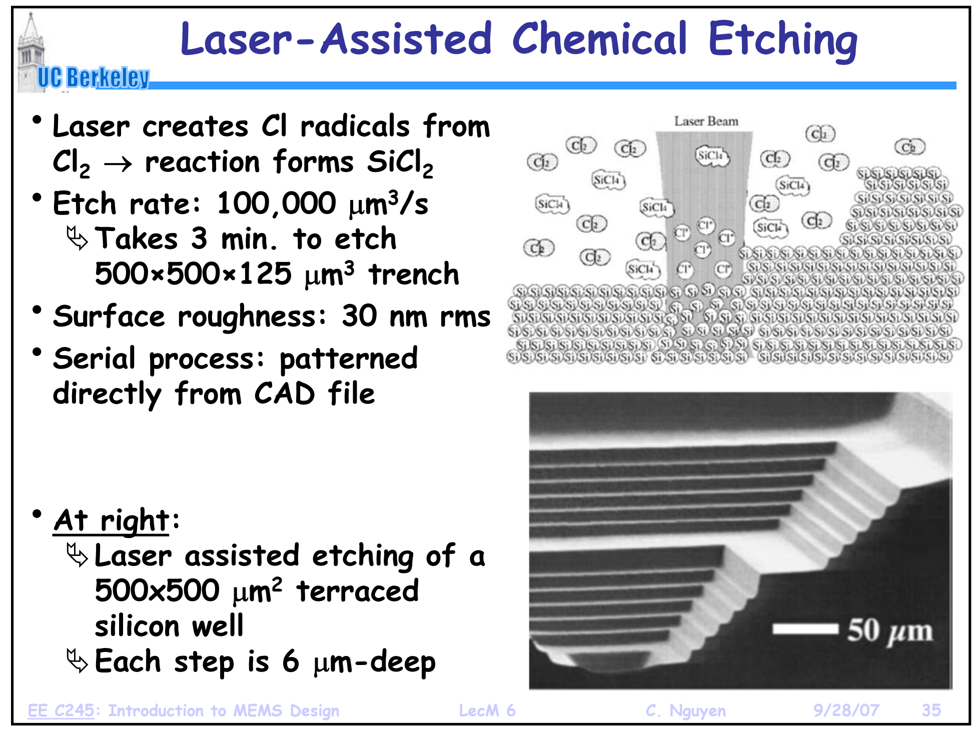

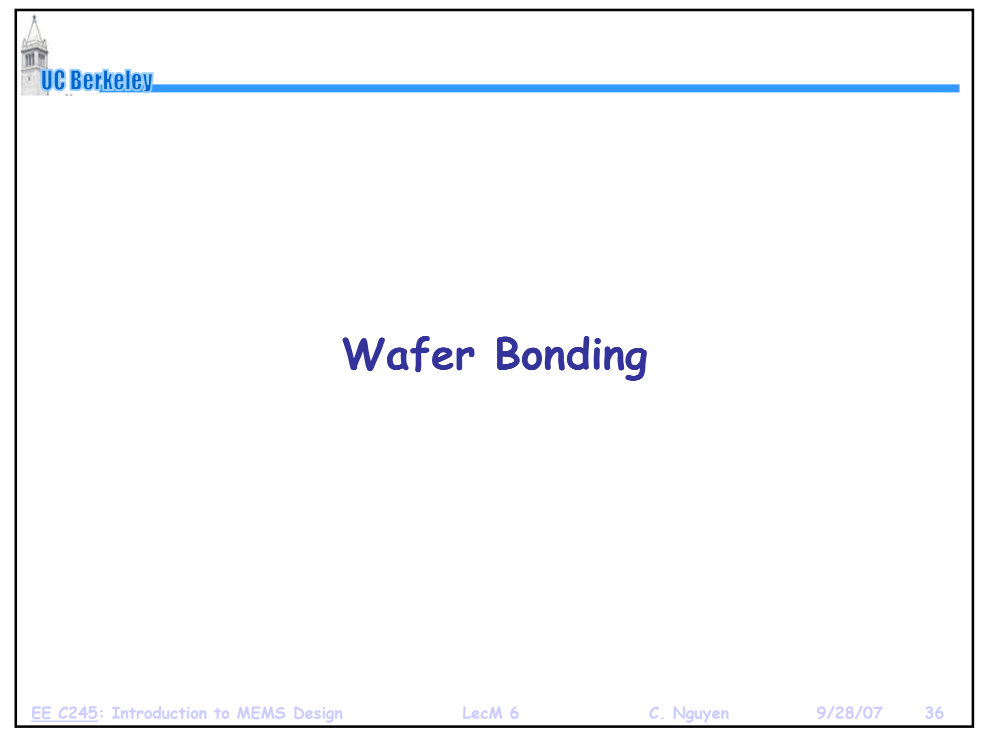

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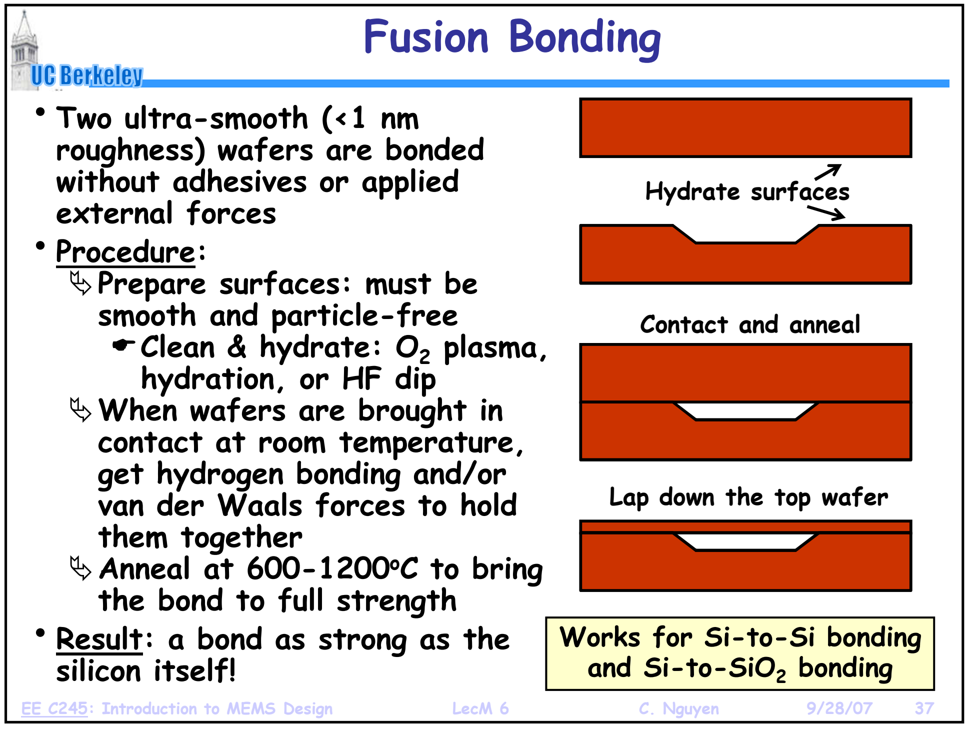

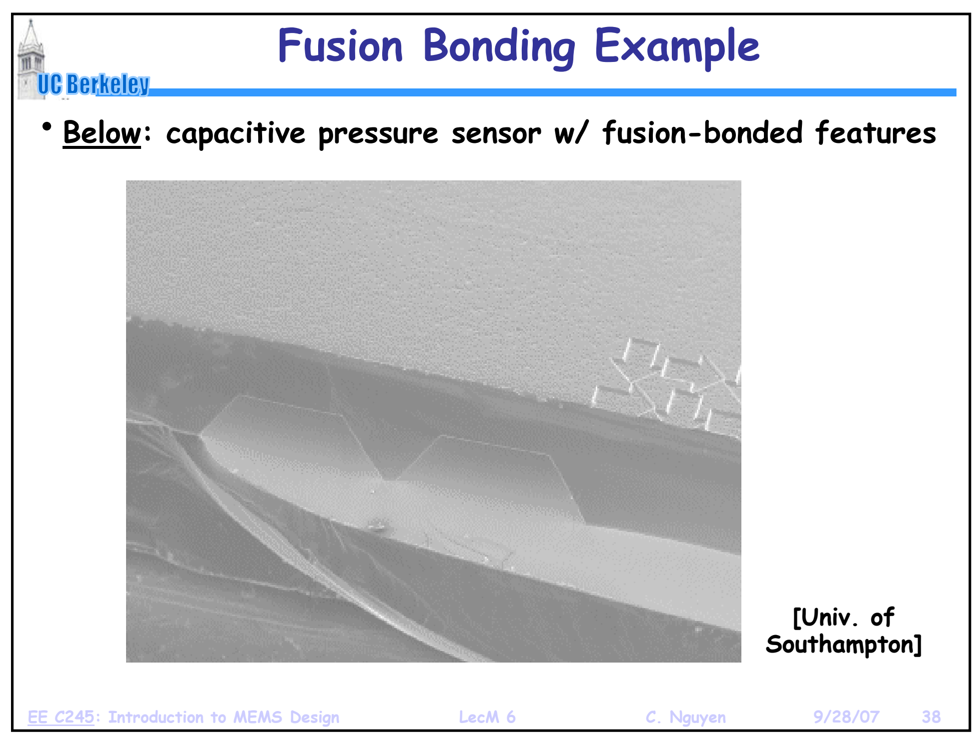

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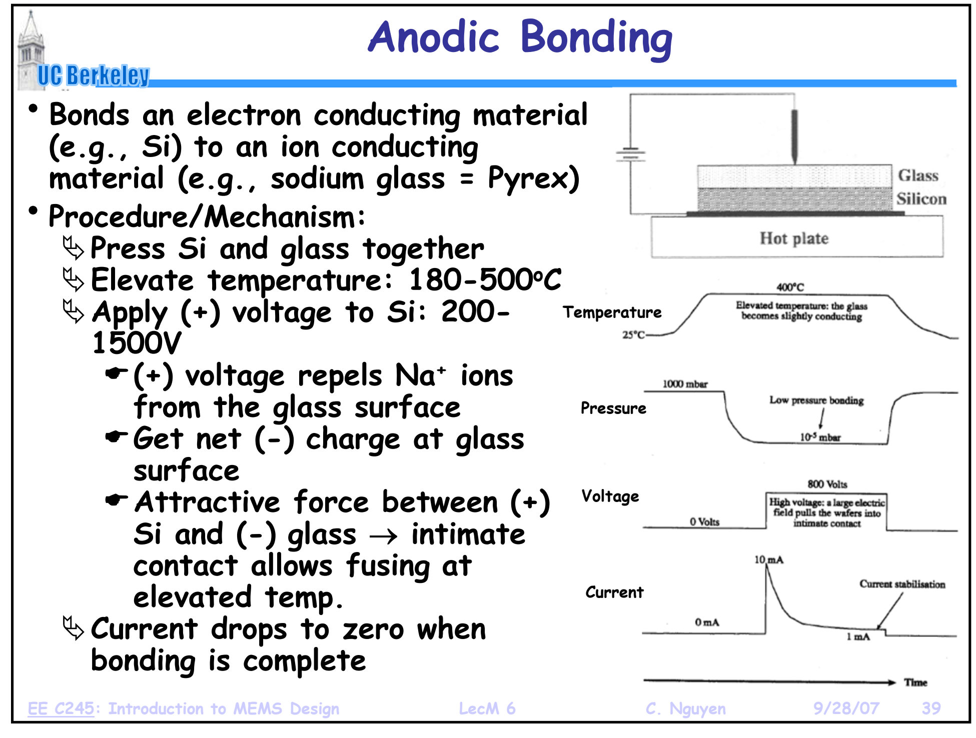

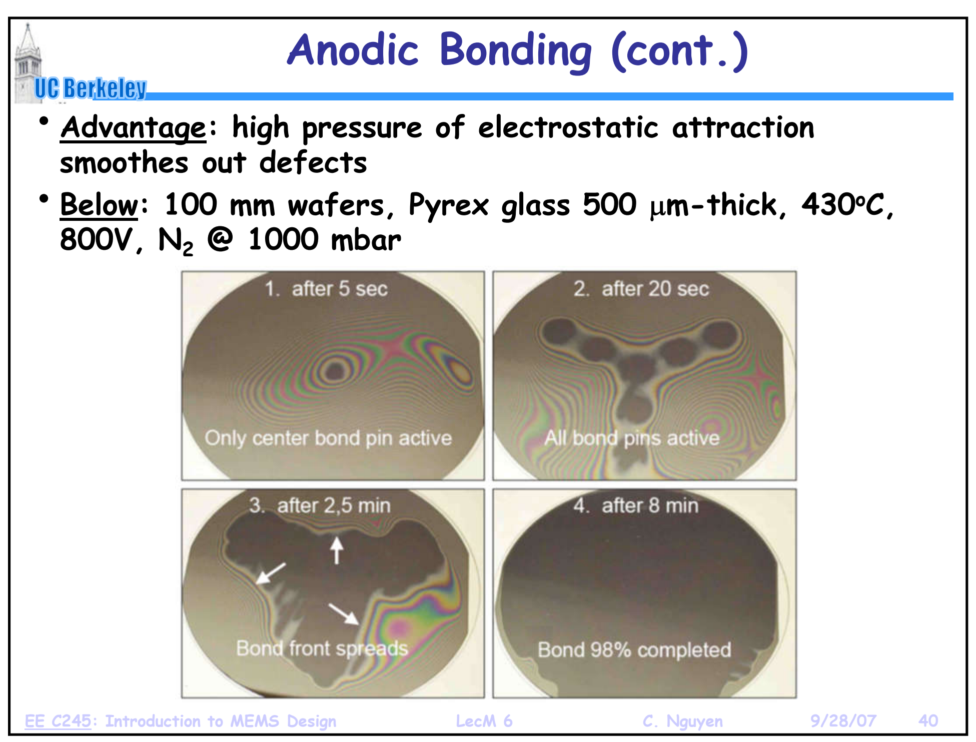

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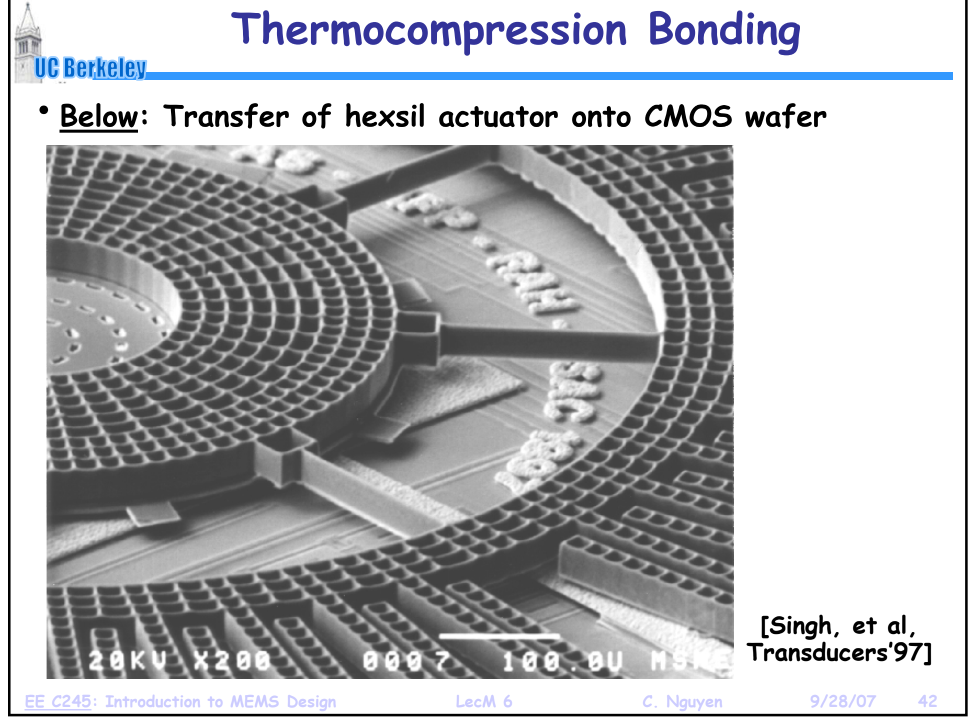
Metal Layer Bonding

- 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]

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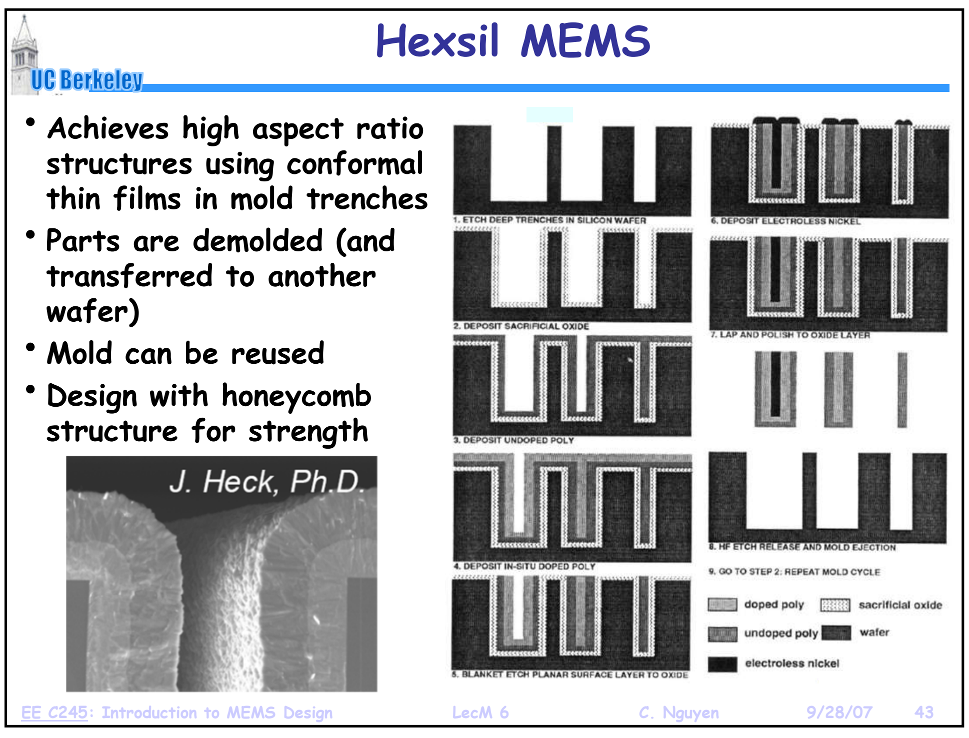

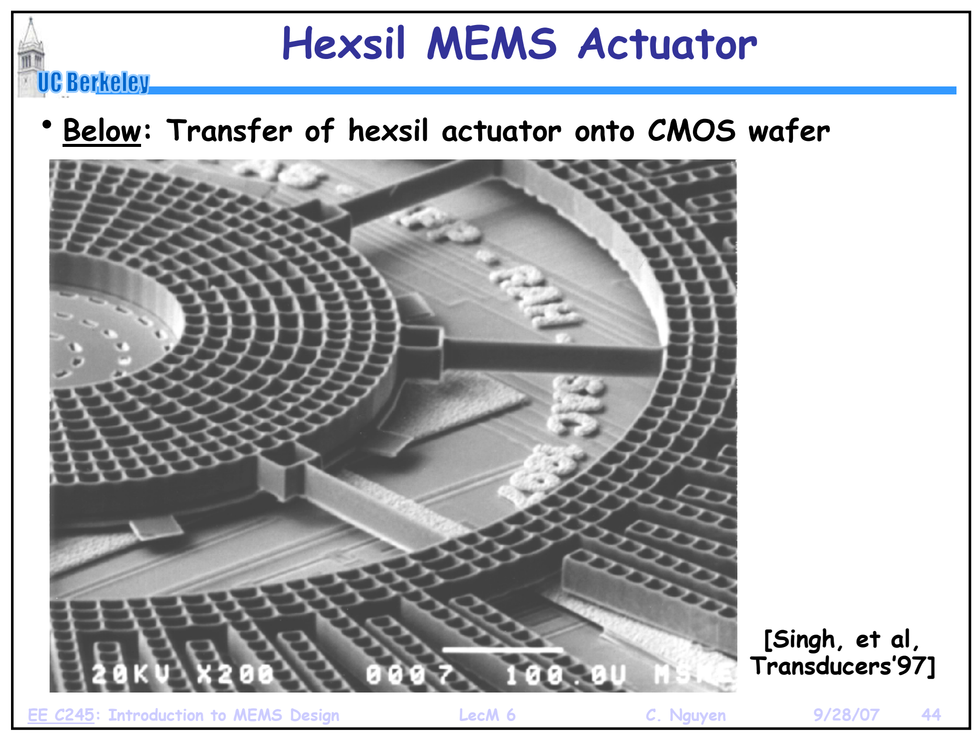

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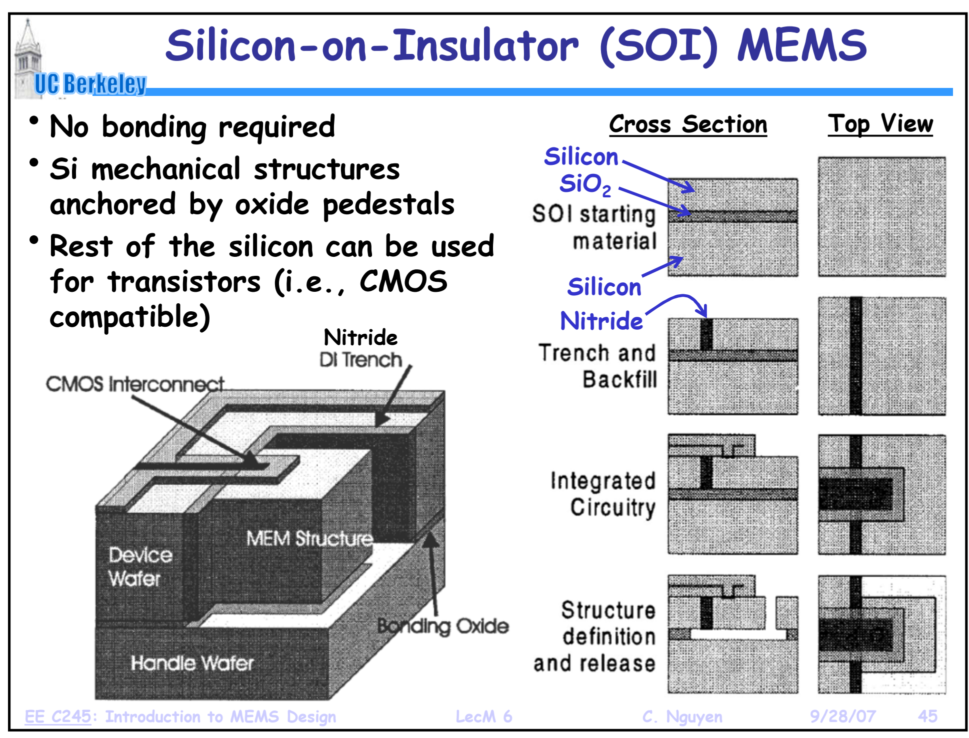

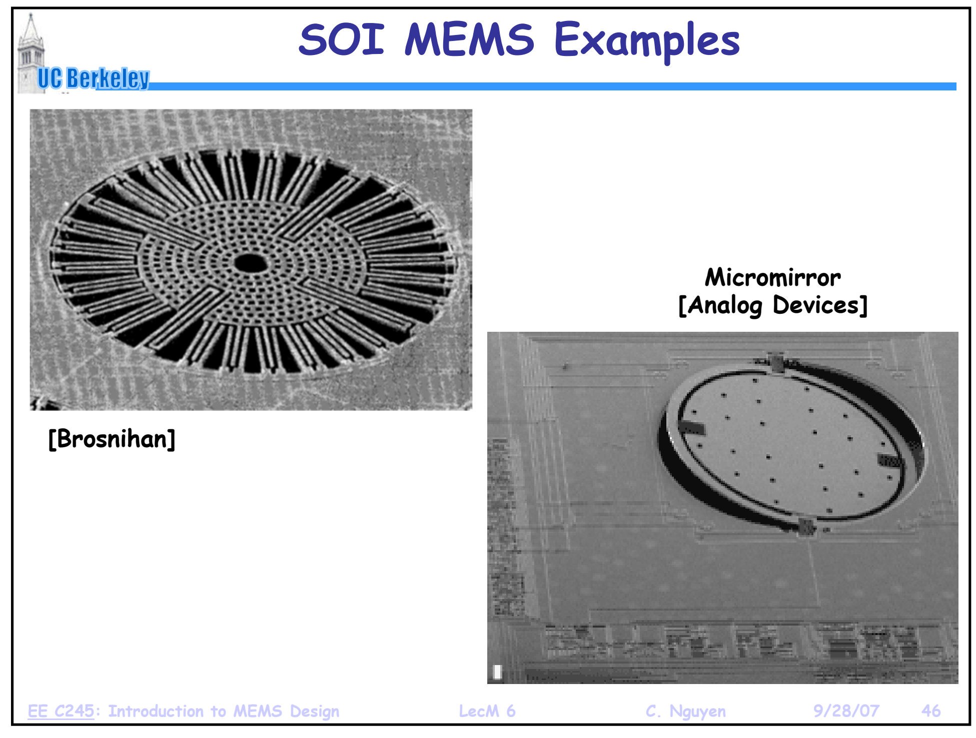

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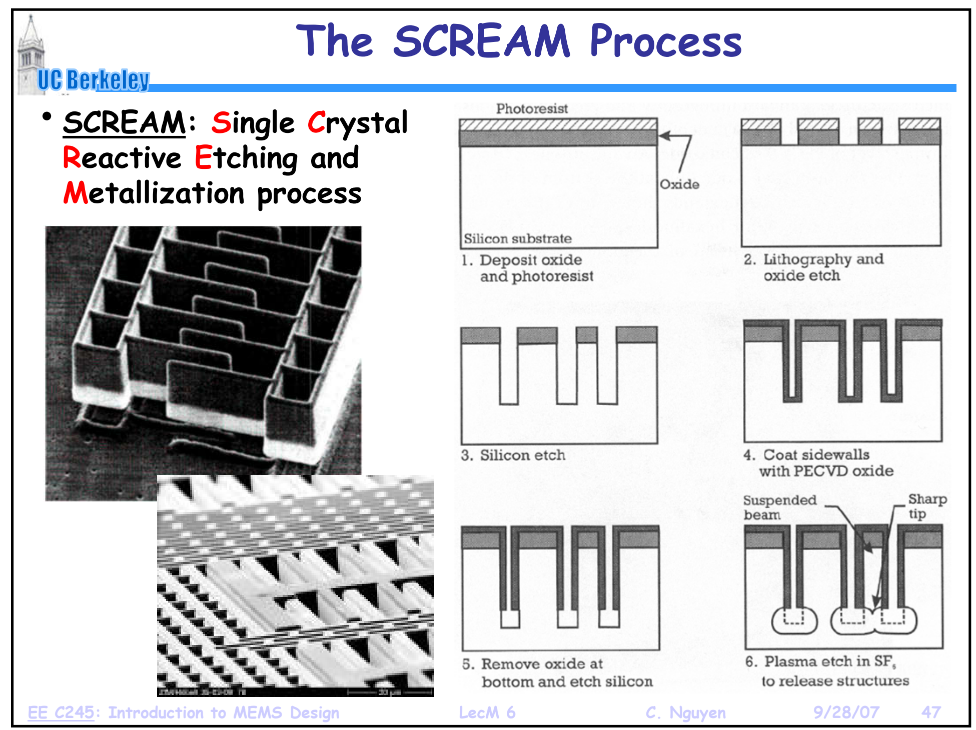
The SCREAM Process
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• SCREAM: Single Crystal Reactive Etching and Metallization process
Photoresist
Oxide
Silicon substrate
1. Deposit oxide and photoresist
2. Lithography and oxide etch
3. Silicon etch
4. Coat sidewalls with PECVD oxide
Suspended beam
Sharp tip
5. Remove oxide at bottom and etch silicon
6. Plasma etch in SF₆ to release structures
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