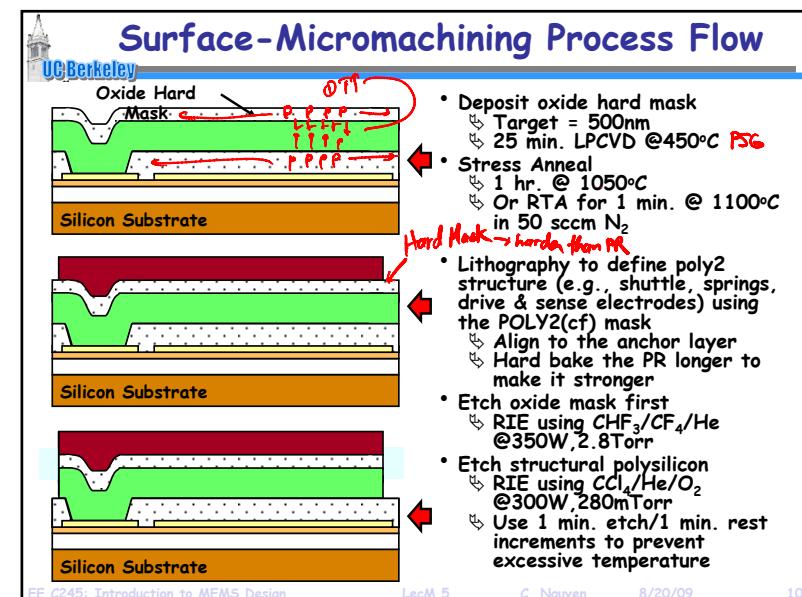
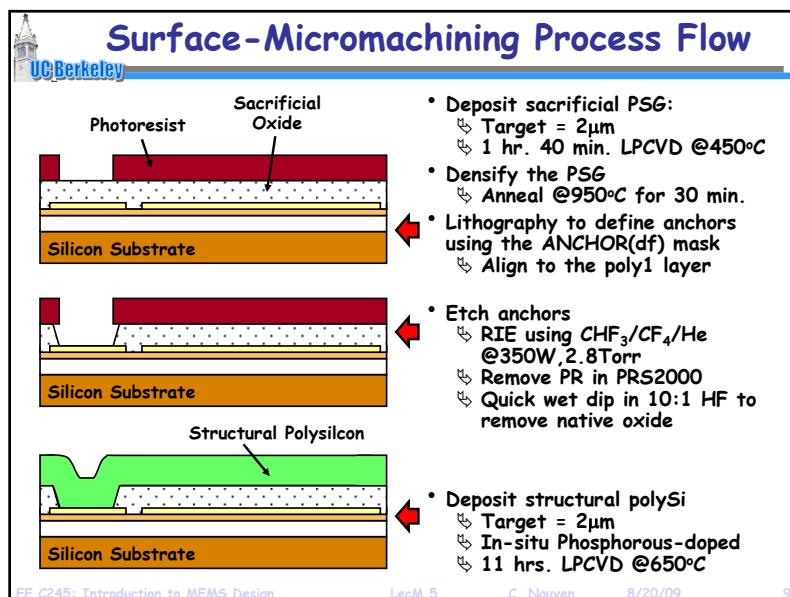
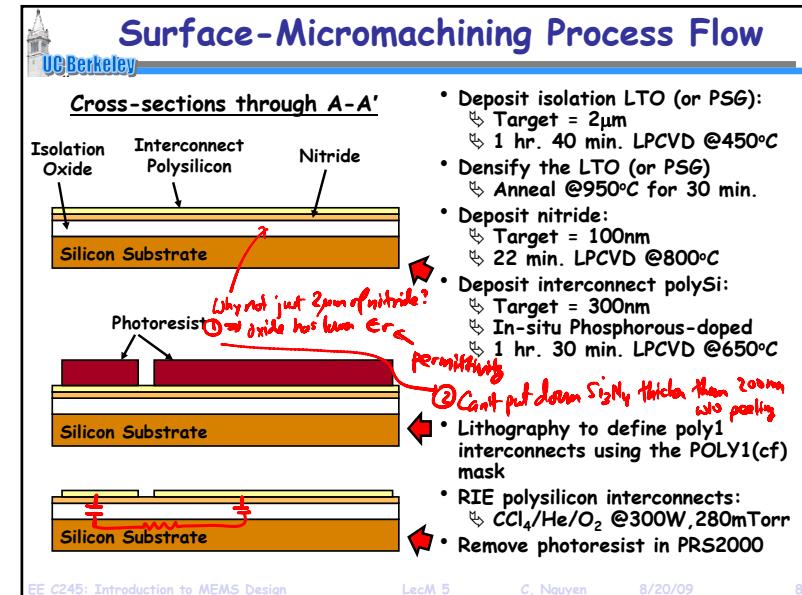
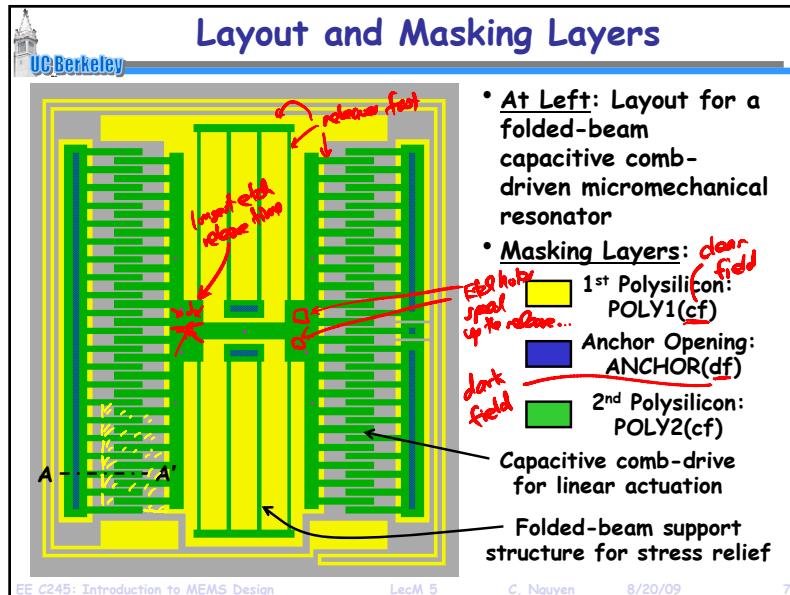
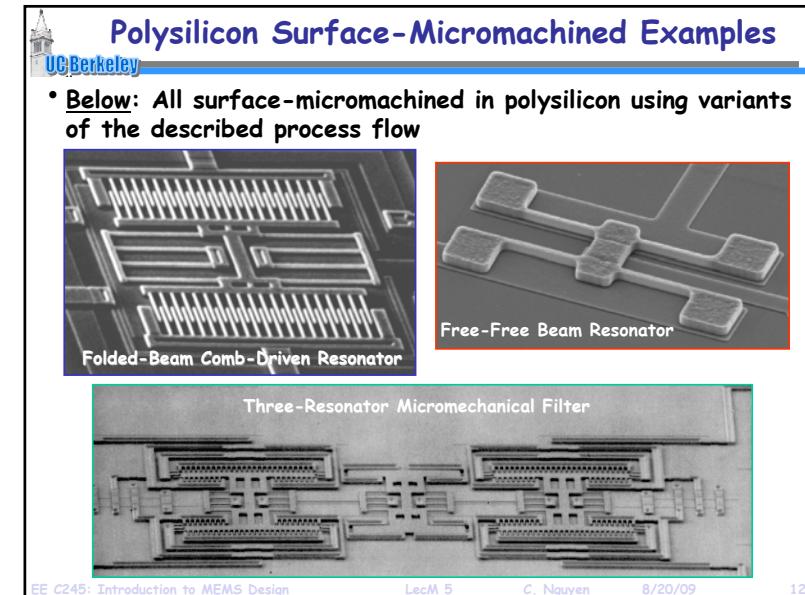
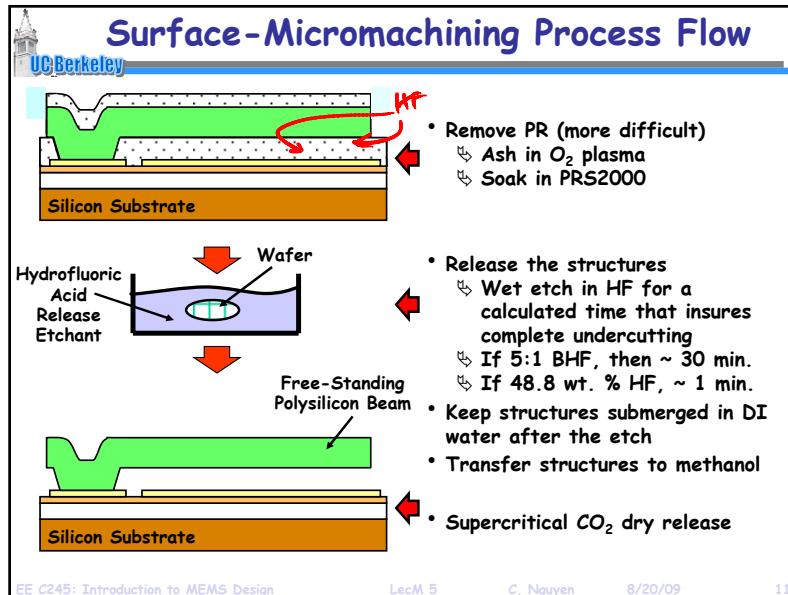


Lecture 9: Surface Micromachining II/Stiction



Lecture 9: Surface Micromachining II/Stiction



Structural/Sacrificial Material Combinations

Structural Material	Sacrificial Material	Etchant
Poly-Si	SiO_2 , PSG, LTO	HF, BHF
Al	Photoresist	O_2 plasma
SiO_2	Poly-Si	XeF_2
Al	Si	TMAH, XeF_2
Poly-SiGe	Poly-Ge	H_2O_2 , hot H_2O

- Must consider other layers, too, as release etchants generally have a finite E.R. on any material
- Ex: concentrated HF (48.8 wt. %)
 - Polysilicon E.R. ~ 0
 - Silicon nitride E.R. $\sim 1-14$ nm/min
 - Wet thermal SiO_2 $\sim 1.8-2.3$ mm/min
 - Annealed PSG ~ 3.6 mm/min
 - Aluminum (Si rich) ~ 4 nm/min (much faster in other Al)

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Wet Etch Rates (f/ K. Williams)

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Wet-Etch Rates for Micromachining and IC Processing (Å/min)

The wet-etch rate was measured by the authors with fresh solutions, etc. The center and bottom values are the low and high rates observed by the authors and others in our lab under less carefully controlled conditions.

ETCHANT EQUIPMENT CONDITIONS	TARGET MATERIAL	MATERIAL														
		SiC Si <100°	Poly Si	Poly Ox	Wet Ox	Dry Ox	LTO	PSG unrel	PSG anneal	SiO ₂ NIST	Low-d NIST	Al 2% Si	Spin Ti	Spin Ti/W	OCO	Other
Concentrated HF (98%) Wet Sink Room Temperature	Silicon oxides	-	0	230	230	>14k	F	35k	140	52	42	<50	F	-	0	0
10:1 HF Wet Sink Room Temperature	Silicon oxides	-	7	0	230	230	340	15k	4700	11	3	2500	0	11k	<20	0
25:1 HF Wet Sink Room Temperature	Silicon oxides	-	0	0	97	95	150	W	1500	5	1	W	0	-	-	0
5:1 HF Wet Sink Room Temperature	Silicon oxides	-	9	2	1000	1000	1200	6800	4400	9	4	1400	<20	F	1000	0
Phosphoric Acid (85%) Bath with Reflux (10°C)	Silicon nitrides	-	7	-	0.7	0.8	<1	37	24	28	19	9800	-	-	500	300
Silicon Etchant (10 HNO ₃ : 90 H ₂ O : 3 NH ₄ F) Wet Sink Room Temperature	Silicon	1500	1000	1000	97	W	110	4000	1700	2	3	4000	130	3000	-	0
KOH (1 KOH : 2 H ₂ O by weight) Hosed Stand Bath 80°C	c100+ Silicon	14k	>15k	F	77	-	94	W	380	0	0	F	0	-	-	F
Aqueous Etchant Type A (16 H ₃ PO ₄ : 1 HNO ₃ : 1 H ₂ O)	Aluminum	-	<10	<9	0	0	0	-	<20	0	2	4000	1000	6000	-	0
Ammonium Etchant Bath 20%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanium Etchant (20 H ₂ O : 1 H ₂ O ₂ : 1 HF) Wet Sink Room Temperature	Titanium	-	12	-	120	W	W	W	2100	8	4	W	0	8800	-	0
H ₂ O ₂ (30%) Wet Sink Room Temperature	Titanium	-	0	0	0	0	0	0	0	0	<20	190	0	40	<2	0
Perchloric (10 HClO ₄ : 1 H ₂ O) Bath with Reflux (10°C)	Cleaning of metal and organic	-	0	0	0	0	-	0	0	0	1800	-	2400	-	F	F
Acetone Wet Sink Room Temperature	Platinum	-	0	0	0	0	0	-	0	0	0	-	0	-	>4k	>3k

Note: - = not performed; W = wet performed, but known to work (> 100 Å/min); P = not performed, but known to be fast (> 10 kÅ/min); F = some of film peeled during etch or when dried; Avidine was visibly attacked and degraded. Each entry is a set of 4-6 etch rates for the transparent silicon and half of the wafer for single-crystal silicon and the metals. Each rate will vary with temperature and prior use of solutions, area of exposure of film, other materials present (e.g., photoresist), film properties and microstructure, etc. Some variation should be expected.

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Lecture 9: Surface Micromachining II/Stiction

Film Etch Chemistries

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- For some popular films:

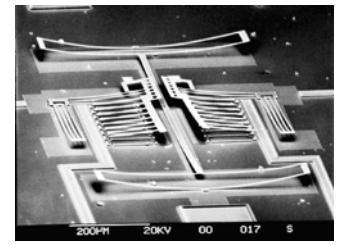
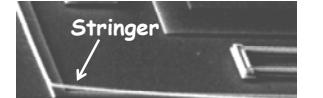
Material	Wet etchant	Etch rate [nm/min]	Dry etchant	Etch rate [nm/min]
Polysilicon	HNO ₃ :H ₂ O: NH ₄ F	120-600	SF ₆ + He	170-920
Silicon nitride	H ₃ PO ₄	5	SF ₆	150-250
Silicon dioxide	HF	20-2000	CHF ₃ + O ₂	50-150
Aluminum	H ₃ PO ₄ :HNO ₃ : CH ₃ COOH	660	Cl ₂ + SiCl ₄	100-150
Photoresist	Acetone	>4000	O ₂	35-3500
Gold	KI	40	n/a	n/a

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Issues in Surface Micromachining

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- Stiction:** sticking of released devices to the substrate or to other on-chip structures
 - Difficult to tell if a structure is stuck to substrate by just looking through a microscope
- Residual Stress in Thin Films**
 - Causes bending or warping of microstructures
 - Limits the sizes (and sometimes geometries) of structures
- Topography**
 - Stringers can limit the number of structural levels

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Microstructure Stiction

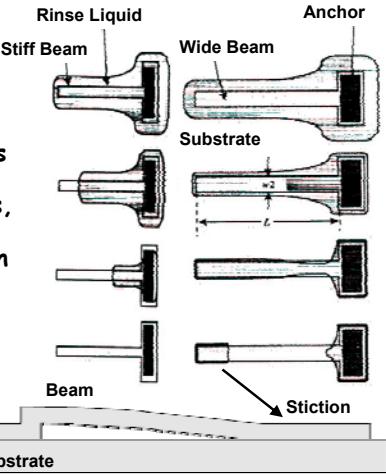
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Microstructure Stiction

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- Stiction:** the unintended sticking of MEMS surfaces
- Release stiction:**
 - Occurs during drying after a wet release etch
 - Capillary forces of droplets pull surfaces into contact
 - Very strong sticking forces, e.g., like two microscope slides w/ a droplet between
- In-use stiction:** when device surfaces adhere during use due to:
 - Capillary condensation
 - Electrostatic forces
 - Hydrogen bonding
 - Van der Waals forces



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Lecture 9: Surface Micromachining II/Stiction

Hydrophilic Versus Hydrophobic

Hydrophilic:

- A surface that invites wetting by water
- Get stiction
- Occurs when the contact angle $\theta_{\text{water}} < 90^\circ$

Hydrophobic:

- A surface that repels wetting by water
- Avoids stiction
- Occurs when the contact angle $\theta_{\text{water}} > 90^\circ$

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Hydrophilic case P_2 P_1

Hydrophobic case P_2 P_1

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Microstructure Stiction

- Thin liquid layer between two solid plates \Rightarrow adhesive
- If the contact angle between liquid and solid $\theta_c < 90^\circ$:
 - Pressure inside the liquid is lower than outside
 - Net attractive force between the plates
- The pressure difference (i.e., force) is given by the Laplace equation

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Wetted Area A

Microstructures

Contact Angle θ_c

Force Applied to Maintain Equilibrium F

Liquid Layer Thickness g

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Microstructure Stiction Modeling

Laplace Equation: Surface Tension @ the Liqu-Air Interface F

$$\Delta P_{\text{La}} = \frac{\gamma_{\text{La}}}{r} \quad r \leftarrow \text{Radius of Curvature of the Meniscus } (-\text{if concave})$$

Liquid-Air Interface

$$[r = -\frac{(g/2)}{\cos \theta_c}] \rightarrow F = -\Delta P_{\text{La}} A = \frac{2A\gamma_{\text{La}} \cos \theta_c}{g}$$

Force needed to keep the plates apart
 \Rightarrow (+) force means a (-) Laplace pressure

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Wetted Area A

Microstructures

Contact Angle θ_c

Force Applied to Maintain Equilibrium F

Liquid Layer Thickness g

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