PROBLEM SET #6

Issued: Thursday, Nov. 4, 2010.

Due (at 7 p.m.): Tuesday, Nov. 23, 2010, in the EE C245 HW box in 240 Cory.

1. Suppose you would like to fabricate the folded-beam suspended comb-driven structure described by Figures 1-4 and the process flow in the pages that follow. The structure is constructed entirely of doped polysilicon, i.e., the red and green layers are both doped polysilicon, and this particular device features a shuttle mass held 2 μm above the substrate by a folded-beam suspension. Dimensions for the structure are given in the figures. The device is symmetric in both the *x* and *y* dimensions. The structure itself (in green) is 2 μm thick and the interconnect layers beneath (in red) are meant to be in a thin doped polysilicon layer.

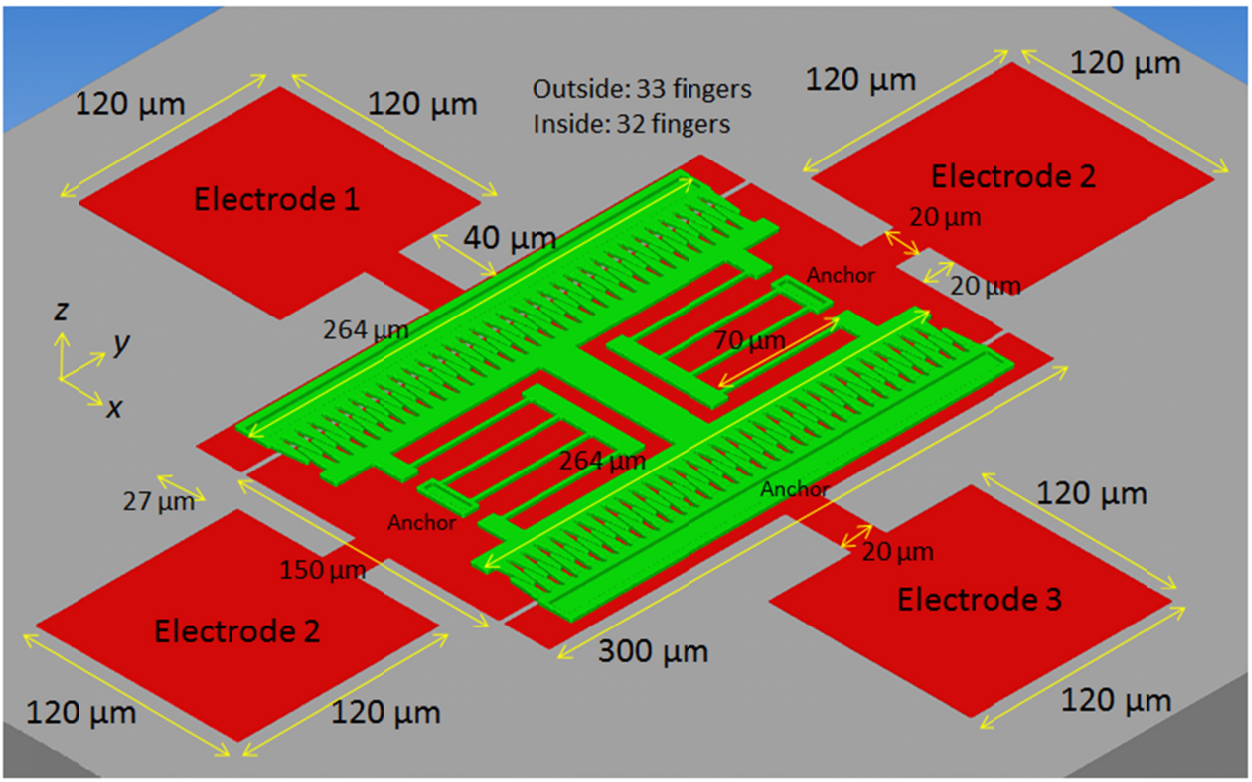

Figure 1. Overall view of the device to be fabricated.

(a) Calculate the *x*-directed fundamental resonant frequency of the structure assuming all electrodes are at 0 V. Assume the Young's modulus $E = 150$ GPa and density $\rho = 2300$ kg/m³ for polysilicon.

(b) Derive the capacitance $C(x) = \frac{\epsilon_0 A(x)}{g(x)}$ as a function of *x*-directed shuttle displacement between Electrode 1 and the shuttle mass. Note that you will need to find *A(x)* and *g(x)*.

(c) Find the static displacement of the shuttle when Electrodes 2 and 3 are at an electric potential of 10 V and Electrode 1 is at 0 V.

(d) Calculate the minimum voltage V_{PI} that when applied to Electrode 1 while maintaining Electrodes 2 and 3 at 0 V will cause the structure to pull-in to Electrode 1. Note that the gaps

between the shuttle and the anchors limit the shuttle's maximum displacement to 8 μm. Assume that these gaps are increased to above 10 μm for this problem.

(e) Calculate the *x*-directed fundamental resonant frequency of the structure assuming Electrodes 1 and 3 are biased at 0 V and Electrode 2 is biased at 10 V.

(f) Generate a three-mask layout for the device using Cadence. You should use the technology file *HW6_tech.txt* and display file *display.drf* to specify the names and colors of the masks. Output your layout as a *.gds file titled "*EE245HW6_<Your last name>.gds*". Recall that POLY1 and POLY2 are clear-field masks and ANCHOR is a dark-field mask. A Cadence tutorial will be given during the 11/8/10 discussion section. Notes describing how to start Cadence and set up the technology library (i.e. import the tech file) will be posted on the website.

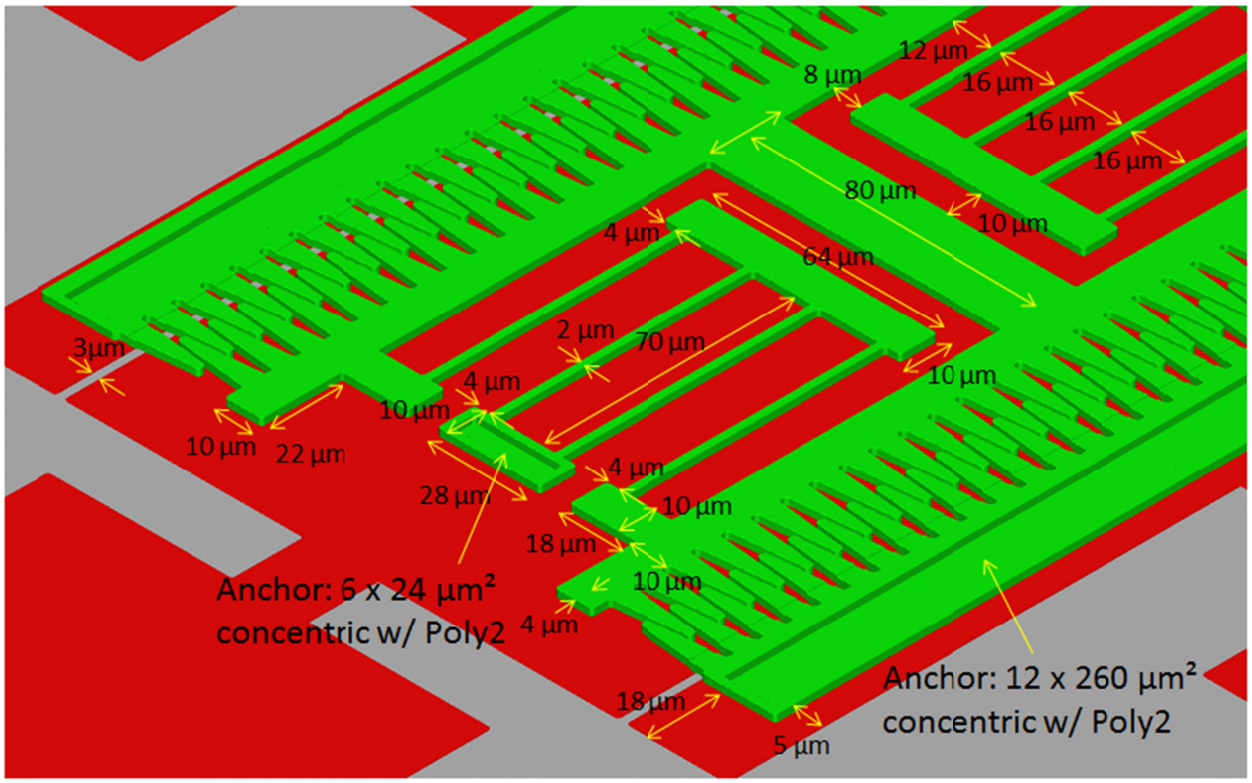

Figure 2. Dimensions of folded flexure system.

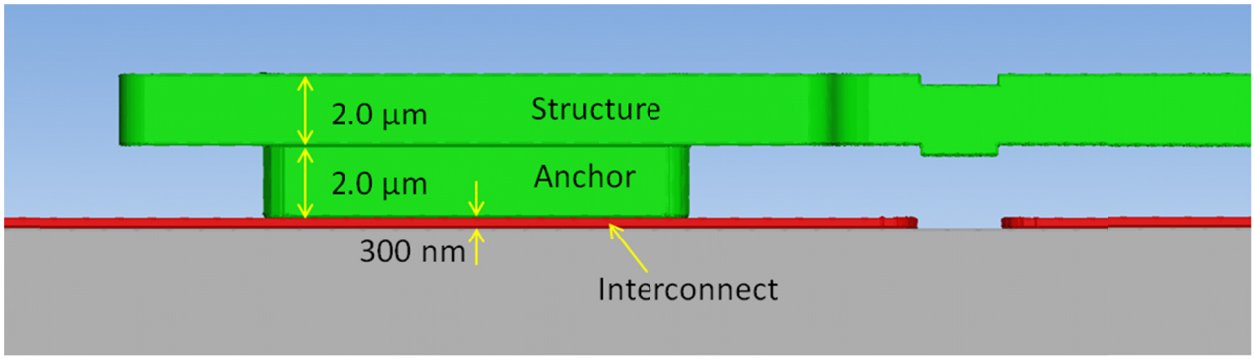

Figure 3. Device cross section.

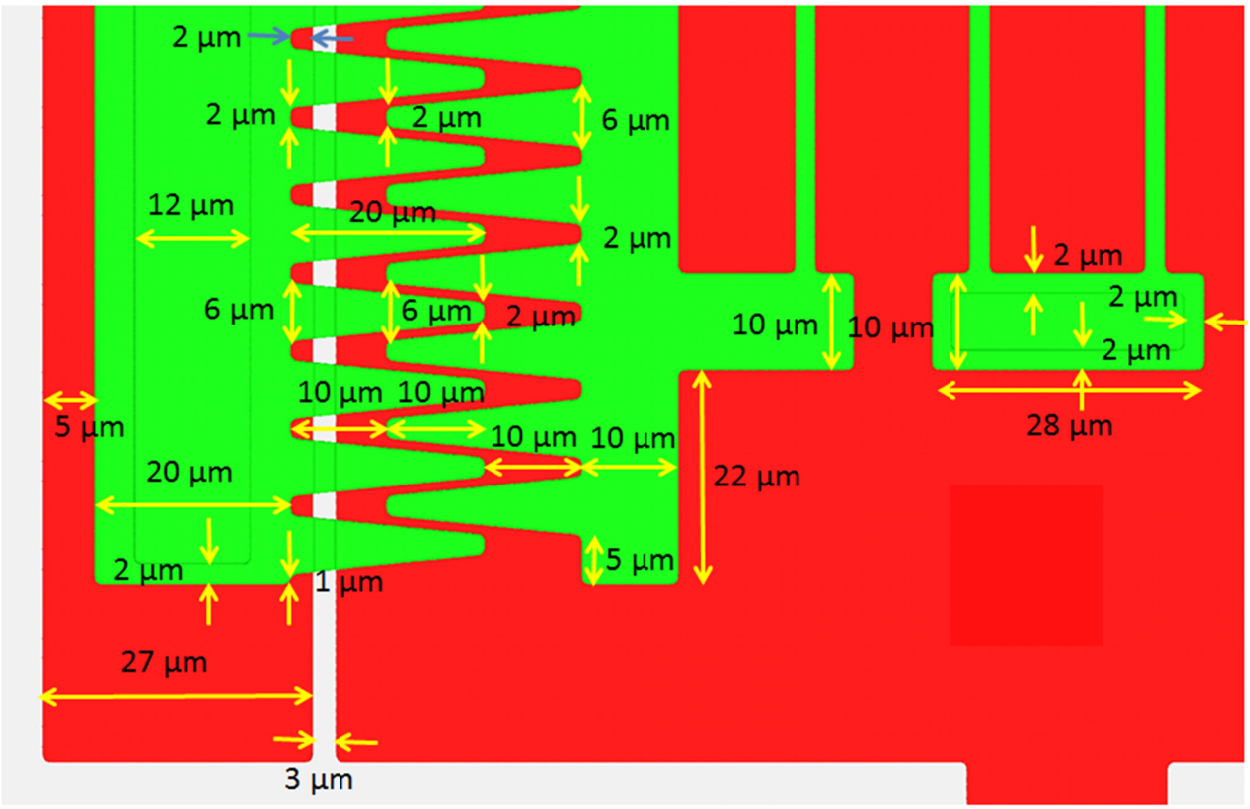

Figure 4. Top view of trapezoidal fingers. Note the rounded corners are an artifact of Coventor SEMulator ® and should not appear in your layout.

Folded-Beam Comb-Driven μMechanical Resonator Process

0.0 Starting Wafers: 8-12 ohm-cm, n-type, (100) prime or just n-type test wafers.
Control Wafers: PSGlF, PSGlB (Si)
NITlF, NITlB (Si)
POLYlF, POLYlB (tylanll ctrl.)
PSG2F, PSG2B (Si)
POLY2F, POLY2B (Si)
PSG3F, PSG33 (81)

1.0 $POCl_3$ doping
Tystar13, recipe 13POCL3A
Flows (slm): N_2: 5, $POCl_3$ (in N_2): 1
Time = 1 hour

1.1 Strip oxide
Sink8 BHF, 1 minute

2.0 PSGl Deposition: target = 2 μm
(immediately after n+ diffusion)
Tystar12, recipe 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
time (2μm) = 1 hour 40 minutes (-1000 A per 5 min.)
Include etching controls: PSGlF and PSGlB

3.0 Nitride Deposition: target = 300 nm
Deposit stoichiometric nitride:
Tystar17, STDNITA.017
temp. = 800 °C, Flows (sccm): SiH2C12 = 25, NH3 = 75
time = 1 hr. 22 min., (-220 nm per hour)
Include etching controls: NITlF and NITlB

4.0 Substrate Contact Mask: SNC (chrome-df) (Optional)

4.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 1.6 μm

4.2 Etch nitride in Lam1.
SF_6 = 175 sccm, He = 50 sccm

4.3. Etch in Lam2:
For 2 μm oxide: [press = 2.8 Torr, power = 350 W,
gap = 0.38 cm, CHF_3 = 30 sccrn, CF_4 = 90 sccrn,
He = 120 sccrn, time = 1 min.],[power = 0, same
gases, time = 1 min.] 3X
4.4. Wet dip in 10:1 BHF for 20 s to remove native oxide.
4.5 Remove resist, piranha clean wafers.

5.0 μStructure Polyl Deposition: target = 300 nm
Phosphorus-doped polysilicon deposition: Tystar16, 16VDPLYA
time = 2 hour 30 minutes, temp. = 650 C (~120 nm per hour)
Include etching controls: POLYlF, POLYlB

6.0 μStructure Polyl Definition Mask: SP1 (emulsion-cf)

6.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 1.1 μm

6.2 Plasma etch poly-Si in Lam5 etcher, inspect
(Cl_2/HBr at 300 Watts, 12 mTorr)

6.3 Remove PR, piranha clean wafers along with PSG2F and PSG2B.

7.0 Sacrificial PSG Deposition: target = 2 μm
Tystar12, 12VDLTOA
Flows (sccm) : SiH_4 = 60, PH_3 = 10.3 (entered) , O_2 = 90
time (2μm) = 1 hour 40 minutes (~100 nm per 5 min.)
Include etching controls: PSG2F and PSG2B

8.0 Sacrificial PSG Densification
RTA in Heatpulsel: 30 secs @ 950 C
(also do PSG2 ctrls)

9.0 (optional) Dimple Photo Mask: CD1 (chrome-df)

9.1 spin, expose, develop, descum, hard bake.

9.2 timed wet etch in 5:l BHF. (E.R. ~ 300 nm per min.)

9.3 Remove resist, piranha clean wafers.

10.0 μStructure Anchor Photo Mask: SG1 (chrome-df)

10.1 Spin, expose, develop, descum, hard bake.
PR thickness: 1.1 μm

10.2 Etch in lam2:
For 1 μm oxide: etch as usual.
For 2 μm oxide: [press = 2.8 Torr, power = 350 W,
gap = 0.38 cm, CHF_3 = 30 sccrn, CF_4 = 90 sccrn,
He = 120 sccrn, time = 1 min.], [power = 0, same
gases, time = 1 min.] 3X
For both cases, overetch with 700 W recipe.

10.3 Check contact using IV probe station.

10.4 Wet dip in 5:l BHF for 10 secs.

10.5 Remove resist, piranha clean wafers.

11.0 μStructure Poly2 Deposition: target = 2 μm
Phosphorous-doped polysilicon deposition: Tystar16, 16SDPLYA
time = 16 hours, temp. = 650 C
Include etching controls POLY2F and POLY2B (tylanll cntrls).

12.0 Oxide Mask Deposition: target = 500 nm
Tystar12, 12VDLTOA
Flows (sccrn): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
time = 25 minutes (~1000 A per 5 rnin.)
Include etching controls: PSG3F and PSG3B

13.0 RTA Anneal
Heatpulsel: 1 min. @ 1100 C in 50 l/sec N2

14.0 μStructure Poly2 Definition Mask: SP2 (emulsion-cf)
Align to μStructure polyl.

14.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 1.6 μm

14.2 Etch oxide mask in lam2.

14.3 (optional) Remove resist:
technics-c, 10 min. 02 plasma B 300 W

14.4 Etch 2nd poly in lam5: [press = 280 mTorr, power = 300 W, gap = 1.5 cm, $CC1_4$ = 130 sccrn, O_2 = 15 sccm, He = 130 sccm, time = 1 rnin.] then [power = 0, same gases, time = 1 rnin.] 5 or 6X, depending upon etch rate (E.R. usually - 4000 A per min.)

14.5 If haven't already removed resist, remove resist.
Technics-c, 10 min. 02 plasma B 300 W

15.0 μStructure Release

15.1 Piranha clean in sink8.

15.2 Wet etch in 5:l BHF (~600 nm per rnin.) in sink8.
(Etch for whatever time is needed to remove all exposed oxide, including oxide underneath structures)
Slowly agitate, rinse.
Spin dry or N2 gun dry.

15.3 Piranha clean in sink8 for 10 min. Follow with standard DI rinses. No HF dip. Spin dry or N2 gun dry.
