PROBLEM SET #3

Issued: Wednesday, February 26, 2020

Due: Tuesday, March 10, 2020, 8:00 am via Gradescope

1. The general equation for the deflection of a thin bar, such as the one shown in Fig. PS3.1, can be expressed as

$$\frac{\partial^4 u(x)}{\partial x^4} = \omega^2 \frac{\rho A}{EI} u(x)$$

where u is the vertical displacement as a function of x, the planar spatial coordinate. The general solution of this fourth-order differential equation then takes the form

$$u(x) = a_1 \cos(\alpha x) + a_2 \sin(\alpha x) + a_3 \cosh(\alpha x) + a_4 \sinh(\alpha x)$$

$$\alpha^2 = \omega \sqrt{\frac{\rho A}{EI}}$$

For the given fixed-fixed boundary conditions below, find the first three solutions of the differential equation and plot them on the same graph. Note that these solutions correspond to the mode shapes of the first three modes of vibration and should all be plotted with a normalized amplitude of vibration.

$$u(0) = 0, \;\; u(L) = 0$$

$$\frac{\partial u}{\partial x}(0) = 0, \;\; \frac{\partial u}{\partial x}(L) = 0$$

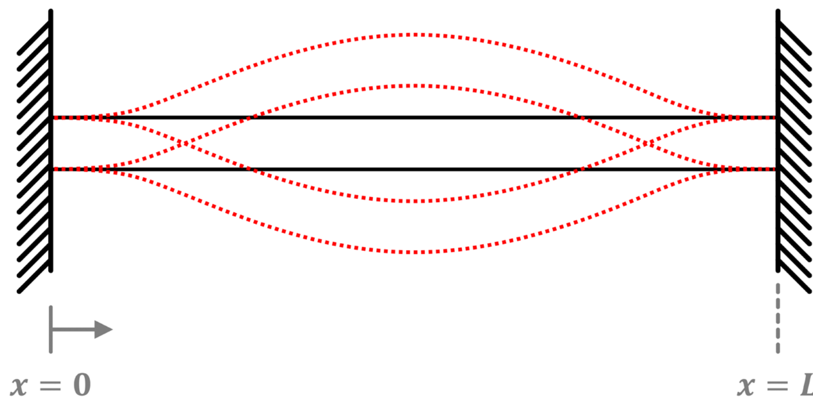

Figure PS3.1

2. The following pages comprise a surface micromachining process flow for a second-order clamped-clamped beam micromechanical filter, the layout for which is shown in Figs. PS3.2 – PS3.6. No details are spared in this flow; even equipment names are given, as are diagnostic steps used to verify select process steps. Furnace program names (for equipment in the UC Berkeley Nanolab) are also given. These de-tails are included to present a more realistic situation. In doing this problem, you must sift through the extraneous information and concentrate on the recipe information (i.e. film thicknesses, etch times, doses, temperatures, etc.).

Lateral Clamped-Clamped Beam Micromechanical Filter with Sub-Micron Capacitive Gaps Process Flow

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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 (tystar16 ctrl.)
PSG2F, PSG2B (Si) POLY2F, POLY2B (Si)
PSG3F, PSG33 (81)

1.0 Wafer $POCl_3$ 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 PSG 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 PSG Densification
RTA in Heatpulse1: 30 secs @ 950 °C
Also do PSG1 ctrls

4.0 Nitride Deposition: target = 400 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

5.0 Substrate Contact Mask: CONT (chrome-df)

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

5.2 Etch nitride in Centura-mxp.
SF_6 = 175 sccm, He = 50 sccm

5.3 Etch oxide in Lam6:
For 2 μm oxide: [press = 2.8 Torr, power = 350 W, gap = 0.38 cm, CHF_3 = 30 sccm, CF_4 = 90 sccm, He = 120 sccm, time = 1 min.],[power = 0, same gases, time = 1 min.] 3x

5.4 Wet dip in 10:1 BHF for 20 s to remove native oxide.

5.5 Remove resist, piranha clean wafers.

6.0 Interconnect Polyl Deposition: target = 500 nm
Phosphorus-doped polysilicon deposition:
Tystar16, 16VDPLYA
Time = 2 hour 30 minutes, temp. = 650°C (~120 nm per hour)
Include etching controls: POLYlF, POLYlB

7.0 Interconnect Polyl Definition Mask: POLY1 (emulsion-cf)

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

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

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

8.0 Sacrificial PSG Deposition: target = 200 nm
Tystar12, 12VDLTOA

Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
Time (200 nm) = 10 minutes (~100 nm per 5 min.)
Include etching controls: PSG2F and PSG2B

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

10.0 µStructure Anchor Photo Mask: ANCHOR (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 = 350W, gap = 0.38 cm, CHF_3 = 30 sccm, CF_4 = 90 sccm, He = 120 sccm, 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 5:1 BHF for 10 secs.

10.5 Remove resist, piranha clean wafers.

11.0 µStructure Poly2 Deposition: target = 2 µm
Undoped polysilicon deposition: Tystar16, 16SUPLYA
Time = 16 hours, temp. = 650°C
Include etching controls POLY2F and POLY2B (tystar16 cntrls).

12.0 PSG Mask Deposition: target = 500 nm
Tystar12, 12VDLTOA
Flows (sccm): 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 Thermal Anneal
Heatpulsel: 60 min. @ 1000°C in 50 l/sec N_2

14.0 µStructure Poly2 Definition Mask: POLY2 (emulsion-cf)
Align to Poly1 interconnect

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

14.2 Etch oxide hard mask in lam2.

14.3 (optional) Remove resist:
technics-c, 10 min. O_2 plasma B 300 W

14.4 Etch 2nd poly in lam5:
(Cl_2/HBr at 300 Watts, 12 mTorr)

14.5 If haven't already removed resist, remove resist.
Technics-c, 10 min. O_2 plasma B 300 W

15.0 µStructure Release

15.1 Piranha clean in msink8.

15.2 Wet etch in 5:1 BHF (~600 nm per min.) in msink8.
(Etch for whatever time is needed to remove all exposed oxide, including oxide underneath structures)
Slowly agitate, rinse.
Spin dry or N_2 gun dry.

15.3 Piranha clean in msink8 for 10 min. Follow with standard deionized water (DI) rinses. No HF dip. Spin dry or N_2 gun dry.

For etch steps, if the etch uses a plasma or RIE process, assume perfect anisotropy. Also, assume that any etch time is determined by first calculating the time needed to etch through the nominal film thickness based on the nominal etch rate, then adding a 30% over-etch to remove any small remaining spots of material. Assume that after you develop your photoresist, it has a sidewall angle of 90°. Also assume that the photoresist will have the given thickness in the field regions and have a perfectly flat upper surface.

When considering etches in this problem, assume the selectivities given in Table PS3.1 (estimated from Kirt Williams', "Etch Rates for Micromachining Processing"). As a reminder, the definition of selectivity is $S_{A/B} = ER_A/ER_B$.

Etchant	Layer A	Layer B	Selectivity $S_{A/B}$
SF_6 + He	Nitride ER = 50 nm/min	PR	1:1
		Oxide	2:1
		Silicon	1:3
CF_4 + CHF_3 + He	Oxide ER = 450 nm/min	PR	3:1
		Nitride	3:1
		Silicon	4:1
Cl_2 + HBr	Silicon/Polysilicon ER = 350 nm/min	PR	1:1
		Oxide	100:1
		Nitride	1:2
HF (release)	Oxide ER = 2 μm/min	Nitride	250:1

Table PS3.1

(a) Draw cross-sections for the structure along the **A-A′**, **B-B′** and **C-C′** lines in the layout

(i) After step 10.0 of the process

(ii) At the end of the process.

Here, you should get the thickness dimensions correct (to within 100 nm or 20%, whichever is finer) and calculate the etching times based on the nominal thickness of the layers and 30% over-etch. Draw the length (horizontal) dimensions using a compressed scale. If any structures completely detach from the wafer, please show this clearly in the final sketch.

(b) Conformal deposition on the wafer when there is topography on the surface can lead to stringers. Why should a process designer be aware of potential stringers and avoid them? Point out the possible stringers in this process and propose a solution to remove them with minimal impact to the intended structure.

(c) Assume the sheet resistance of the interconnect polysilicon (i.e., Poly1) is 20 Ω/□, and that of the polysilicon structural material (i.e., Poly2) is 5 Ω/□. Calculate the total resistance between the centers of bond pads **P1** and **P2** (where probe tips might be placed in contact).

(d) Suppose each beam structure has an effective restoring stiffness of 1,500 N/m at its midpoint, and for the purposes of this problem, suppose you can use this number to represent the total restoring stiffness of each beam. Suppose also that if a beam bends, the sacrificial gap varies according to the following shape function:

$$g(x, C) = g_o - Cu_1(x)$$
$$\text{for } 0 \le x \le L \text{ and } 0 \le C \le g_o$$

where C is the downward displacement of the beam towards the substrate at its midpoint, L is the length of the beam, g_o is the initial gap spacing of the unperturbed beam, and $u_1(x)$ is the first solution of displacement function you derived in problem 1.

If the contact angle of water between the underside of a beam and the substrate (and underlying electrode) is $\theta_c = 30°$, and the room-temperature surface tension of the water-air interface is $\gamma_{la} = 72.75 \times 10^{-3}$ N/m, will the device be stuck down after drying in air? Consider only stiction forces under the 41-μm section (what we'll call the active area) between the anchors of each beam, and lump all the stiction force over the active area into a single force at the midpoint of each beam.

(e) Now assume the structure is to be immersed in methanol, rather than water prior to drying. You know that methanol has a surface tension at the liquid-air interface of $\gamma_{la} = 22.5 \times 10^{-3}$ N/m, but you are unable to find a definitive answer for the contact angle between methanol and silicon. Will the device be stuck down after drying in air? How can you know this with an unknown contact angle for methanol?

(f) Assuming the same $g(x, C)$ function as in part (d) and that the device is immersed in water before drying, what is the minimum sacrificial oxide thickness that you can use and still end up with a structure that is not stuck to the substrate after release?

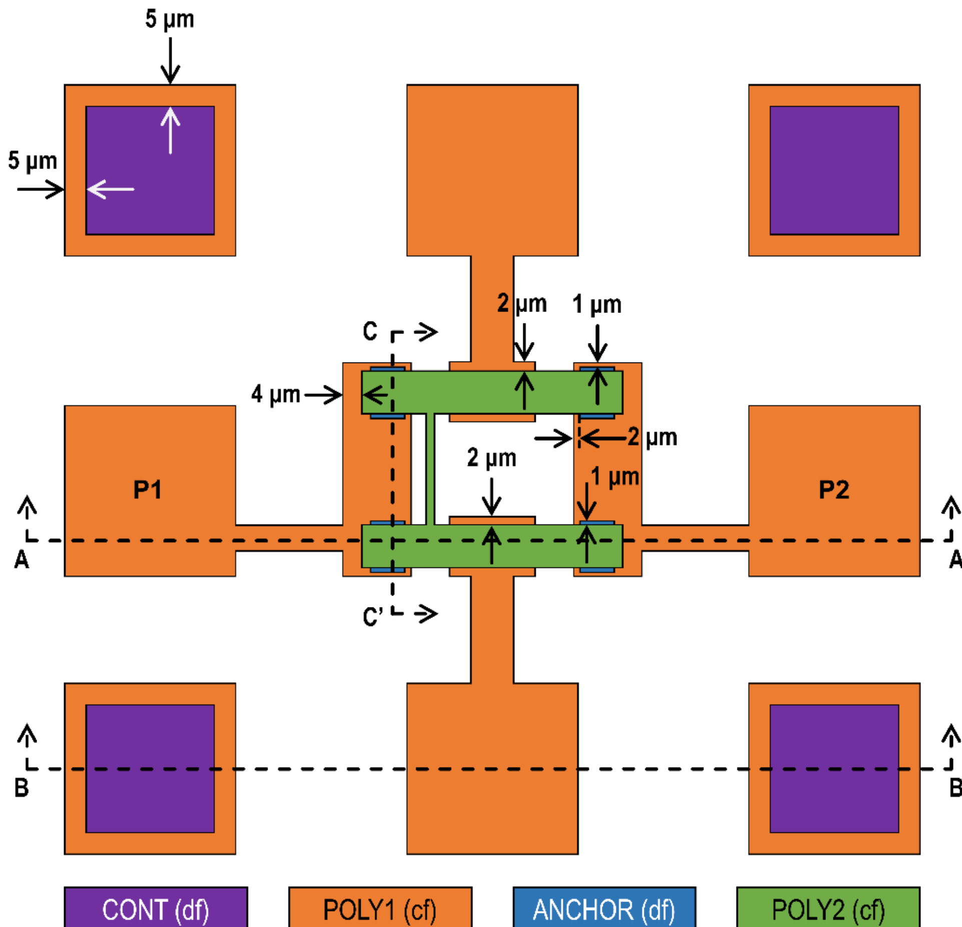

Figure PS3.2

The four masks used in this process flow are shown below with dimensions labeled.

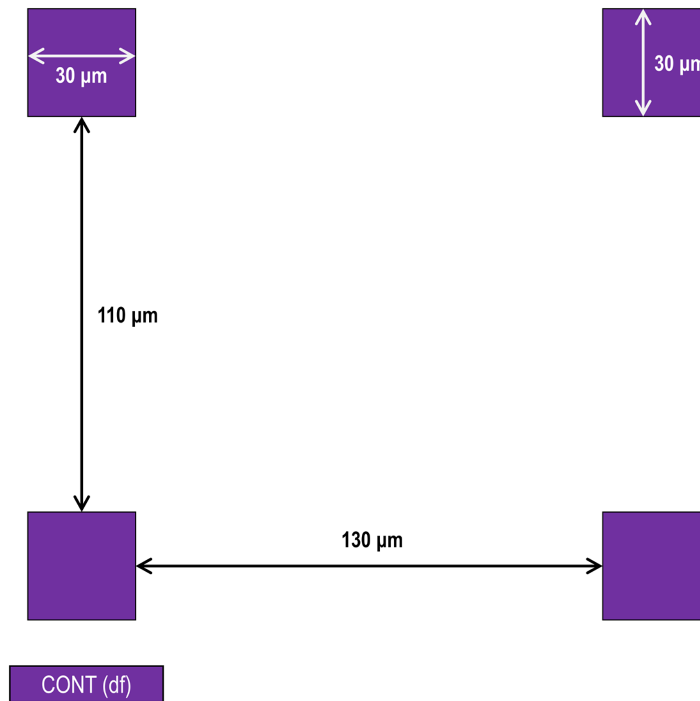

Figure PS3.3

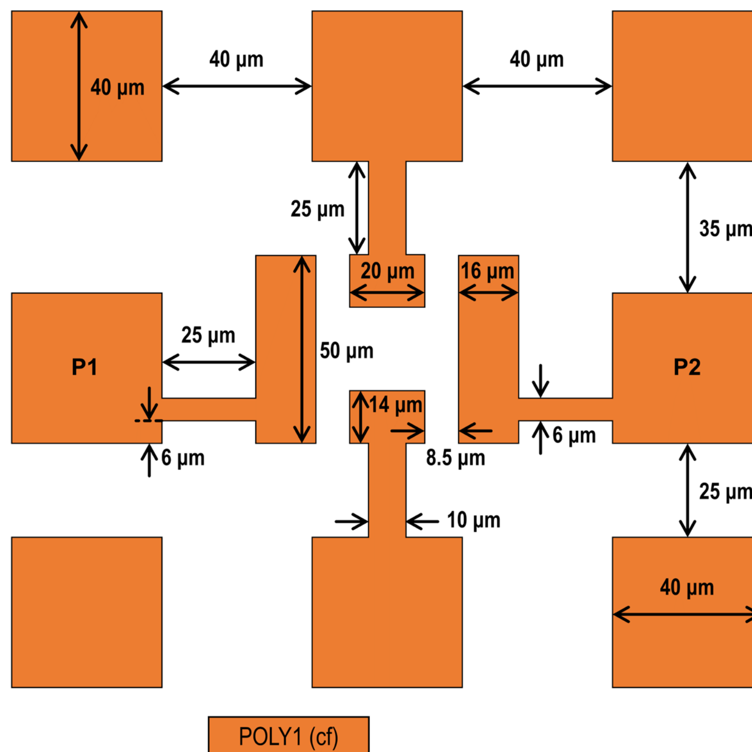

Figure PS3.4

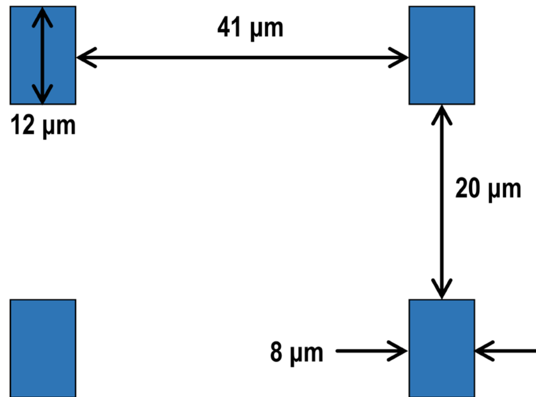

Figure PS3.5

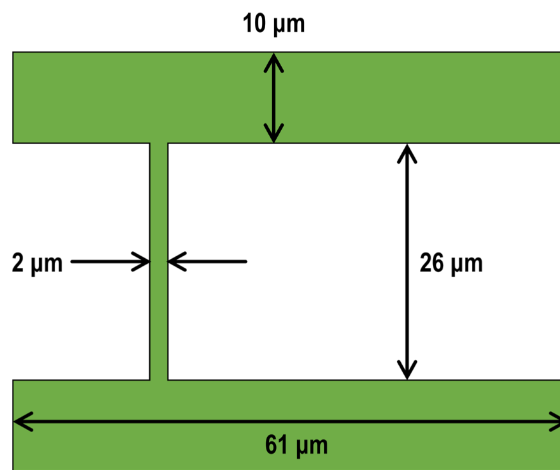

Figure PS3.6