PROBLEM SET #5

Issued: Thursday, March 21, 2019

Due: Tuesday, April 9, 2019 at 9:00 a.m. on Gradescope.

1. Suppose a cantilever beam of length, L is subjected to a quadratically distributed load of intensity as shown in Fig. PS5.1.

(a) Derive an expression for the deflection, *w* as a function of location, x by integrating the moment.

(b) Derive an expression for the deflection, *w* as a function of location, x by using the principle of virtual work.

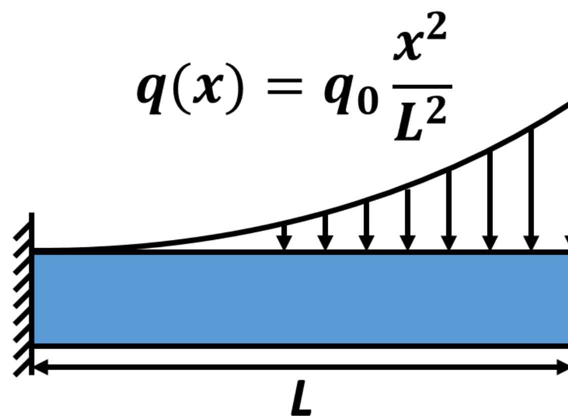

Fig 5.1

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

(a) Use Cadence to generate a 3-mask layout that achieves the structure of Figs. PS5.2-(1-4) using the process flow outlined in the pages that follow. Note that the poly1 and poly2 masks (SP1 and SP2) are clear-field, while the anchor mask (SG1) is dark-field. Export your layout as a gds file titled "EEC247B_MEC218_HW6_firstnamelastname.gds", replacing "firstnamelastname" with your own first and last names. Email this file to your GSI when you submit your homework.

(b) Calculate the effective dynamic mass on a shuttle location when the structure vibrates at its fundamental resonance frequency.

(c) Calculate the structure's resonance frequency.

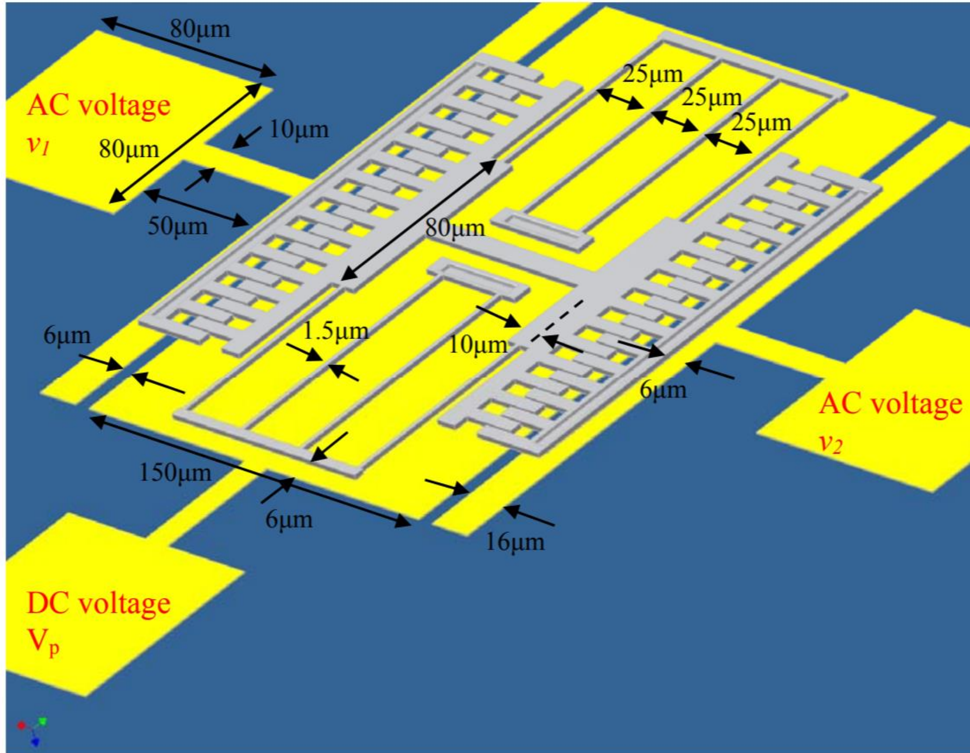

Fig PS5.2-1

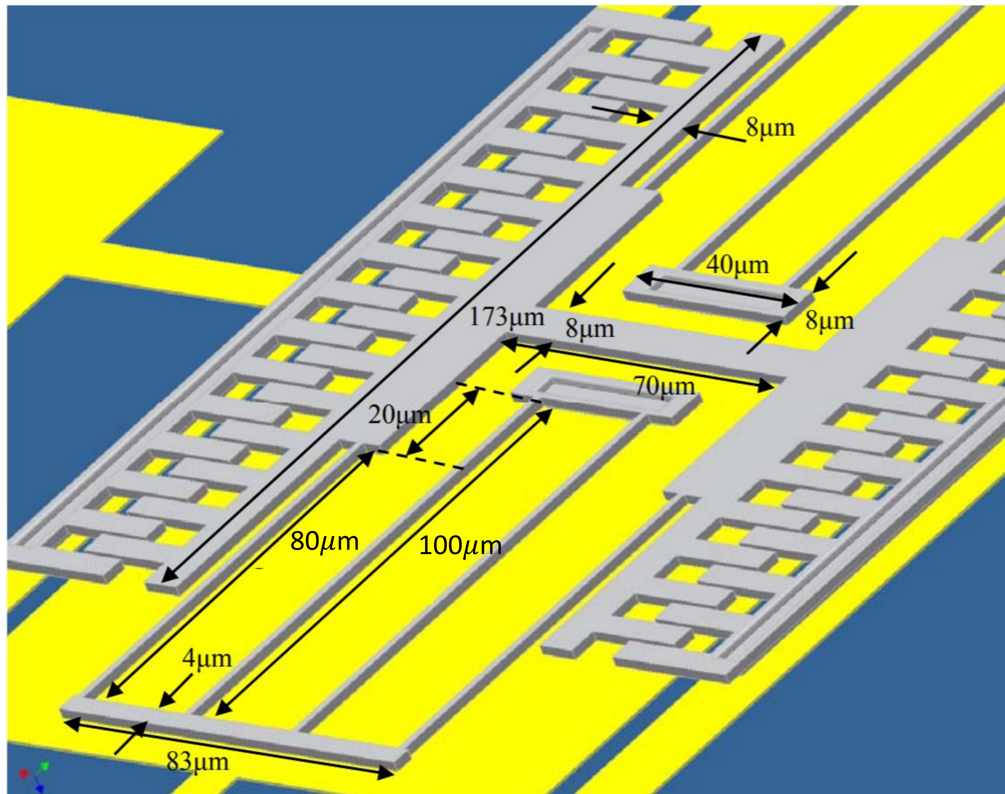

Fig 5.2-2

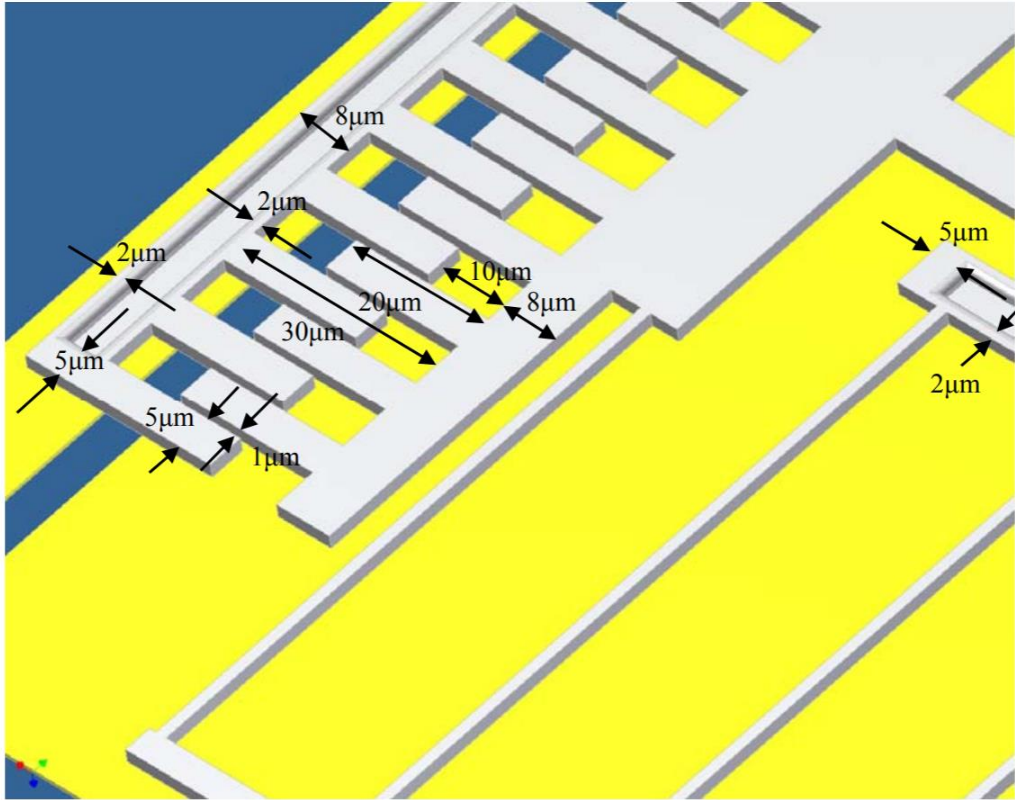

Fig 5.2-3

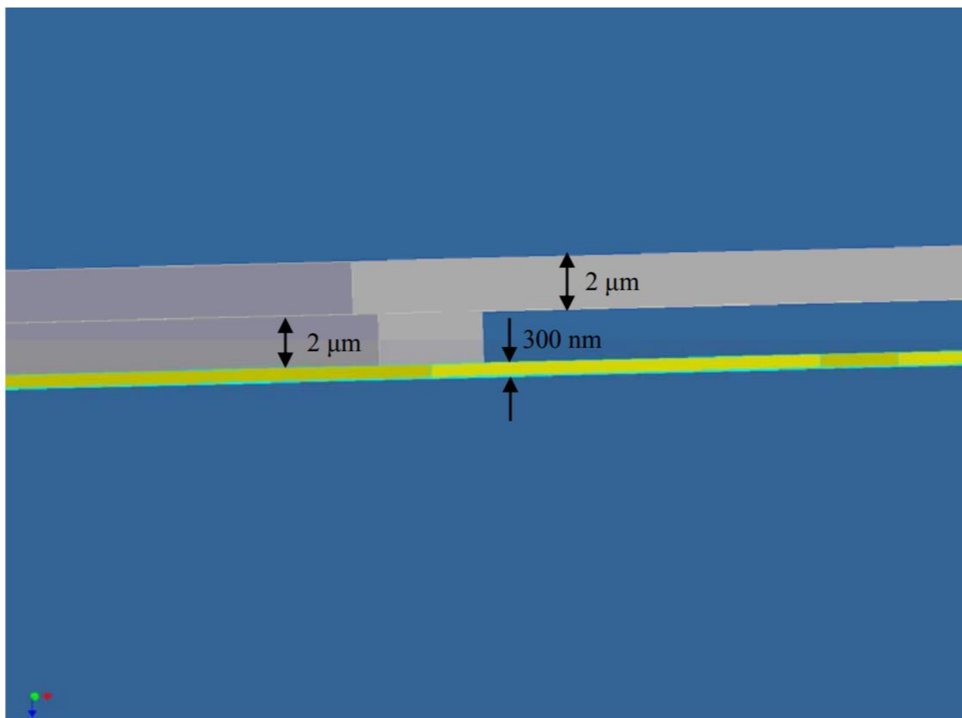

Fig 5.2-4

Folded-Beam Comb-Driven µMechanical Resonator Process Flow

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, recipe STDNITA.017
Temp. = 800 °C, Flows (sccm): SiH_2Cl_2 = 25, NH_3 = 75
Time = 1 hr. 22 min., (220 nm per hour)
Include etching controls: NITlF and NITlB

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

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 oxide in Lam2:
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 W, same gases, time = 1 min.] 3×

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, recipe 16VDPLYA
Time = 2 hrs. 30 min., Temp. = 650 °C (~120 nm/hr.)
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, recipe 12VDLTOA
Flows (sccm) : SiH_4 = 60, PH_3 = 10.3 (entered) , O_2 = 90
Time (2µm) = 1 hr. 40 min. (~100 nm per 5 min.)
Include etching controls: PSG2F and PSG2B

8.0 Sacrificial PSG Densification
RTA in Heatpulsel: 30 sec. @ 950 °C
(also do PSG2 controls)

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/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 oxide 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 sccm, CF_4 = 90 sccm, He = 120 sccm, time = 1 min.], [power = 0 W, same gases, time = 1 min.] 3×
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 sec.

10.5 Remove resist, piranha clean wafers.

11.0 µStructure Poly2 Deposition: target = 2 µm
Phosphorous-doped polysilicon deposition:
Tystar16, 16SDPLYA
Time = 16 hrs. 0 min., Temp. = 650 °C

Include etching controls POLY2F and POLY2B (tylan11 controls).

12.0 Oxide Mask Deposition: target = 500 nm
Tystar12, 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
Time = 25 min. (~1000 Å per 5 min.)
Include etching controls: PSG3F and PSG3B

13.0 RTA Anneal
Heatpulsel: 1 min. @ 1100 °C in 50 l/sec N_2

14.0 µStructure Poly2 Definition Mask: SP2 (emulsion-cf)
Align to µStructure poly1.

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. O_2 plasma B 300 W

14.4 Etch Poly2 in Lam5: [press. = 280 mTorr, power = 300 W, gap = 1.5 cm, CCl_4 = 130 sccm, O_2 = 15 sccm, He = 130 sccm, time = 1 min.], then [power = 0, same gases, time = 1 min.] 5 or 6×, depending upon etch rate (E.R. usually ~4000 Å per min.)

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 sink8.

15.2 Wet etch in 5:1 BHF (~600 nm per min.) in sink8.
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 sink8 for 10 min. Follow with standard DI rinses. No HF dip. Spin dry or N_2 gun dry.