PROBLEM SET #5

Issued: Wednesday, April 1, 2020

Due: Tuesday, April 14, 2020, 8:00 am via Gradescope

1. Fig. PS5.1 shows the schematic of a system of parallel electrodes where the outer plates are fixed and the inner plate is movable. The inner plate is kept at ground potential and outer plates are biased with equal DC voltages V_p to generate equal potential across each electrode gap. The inner plate is also attached to a spring that provides restoring force via stiffness k to keep the plate stable. Note that although the inner plate experiences equal forces on both sides, in a real-world scenario it would snap into one of the electrodes without a spring attachment since even the slightest motion (e.g. due to thermal noise) would generate a force imbalance.

Assume that you fix the inner plate while ramping up the DC voltage applied to outer electrodes to a certain value and then release the inner electrode. Derive an expression for the DC voltage V_p that will cause pull-in of the inner plate once released. Again, keep in mind that force imbalance will always occur under real-world conditions (in the presence of noise, finite asymmetry etc.).

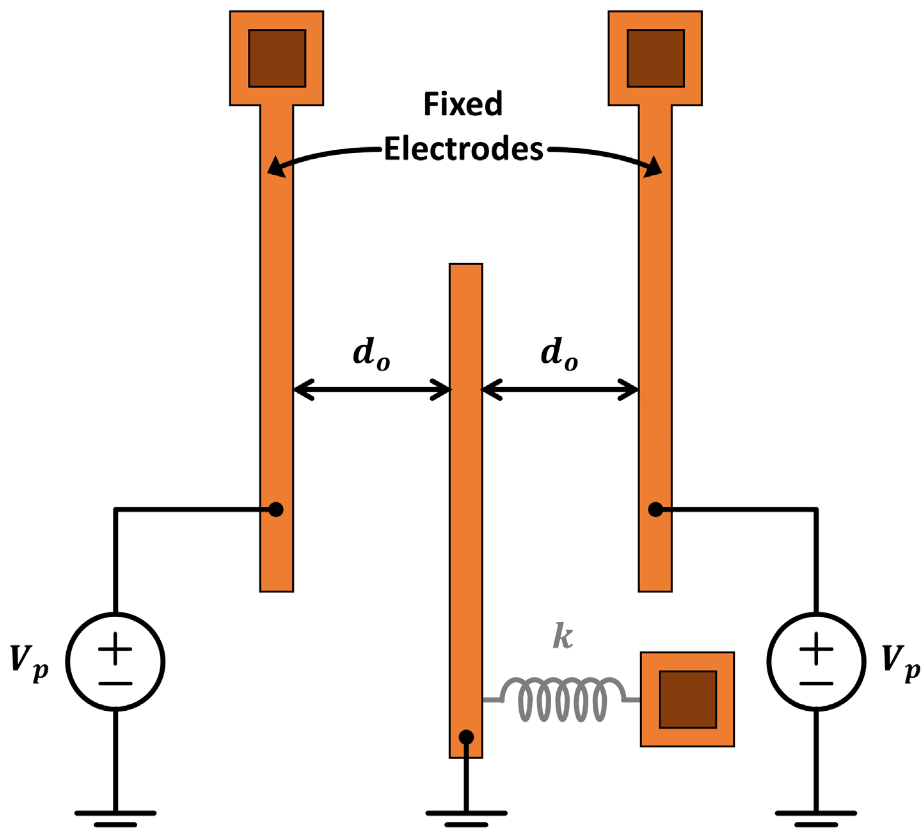

Figure PS5.1

2. Suppose you would like to fabricate the folded-beam suspended comb-driven structure described by Figures PS5.2 – 5.5 and the process flow in the pages that follow. The structure is constructed entirely of doped polysilicon, i.e., the green and orange layers are both doped polysilicon, and this particular device features a shuttle mass suspended 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 directions. The structure itself (green layer) is 2 μm thick and the interconnect features below (orange layer) are made of a thin doped polysilicon layer. Note that not all dimensions in the figures below are to exact scale.

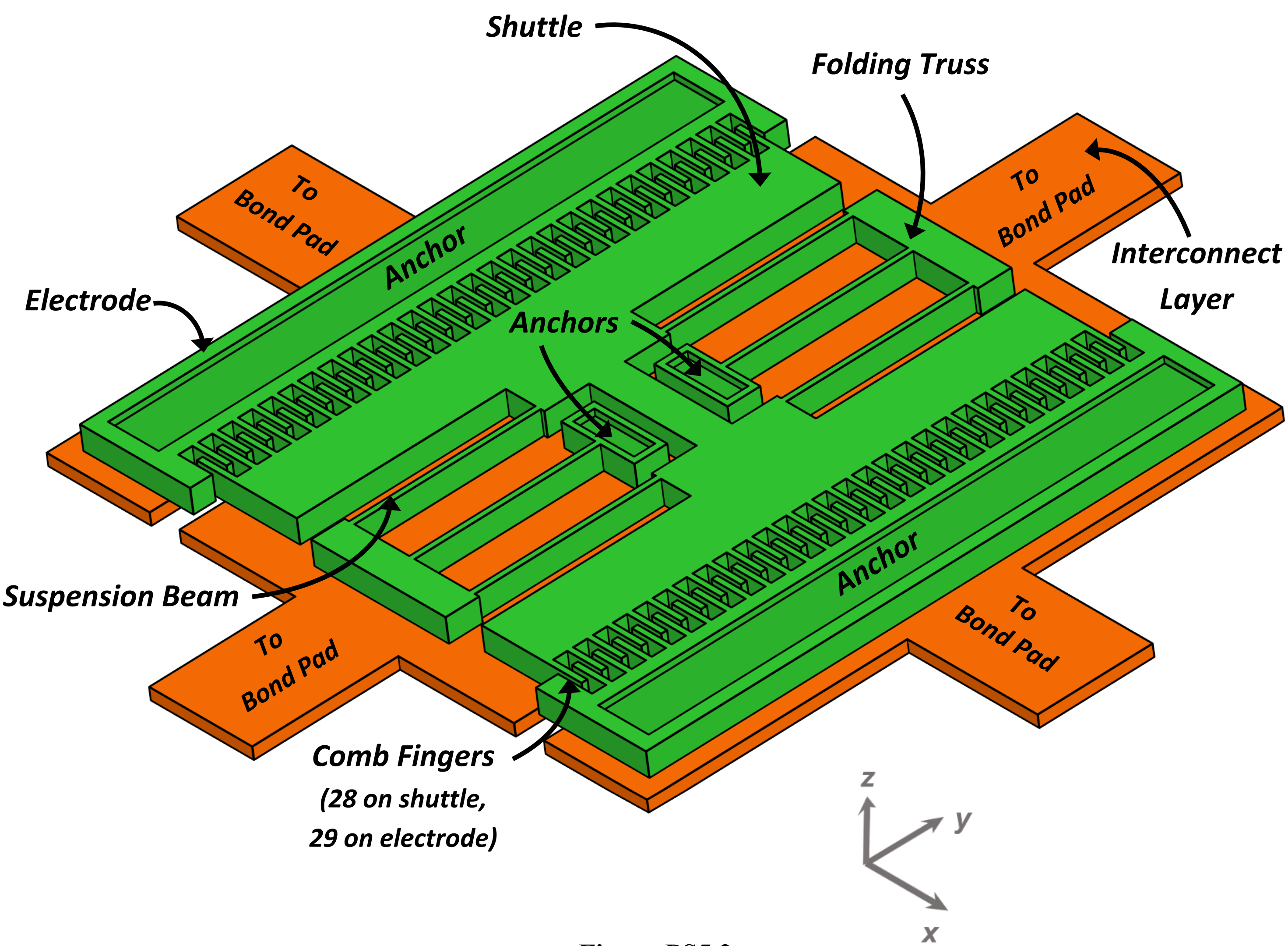

Figure PS5.2

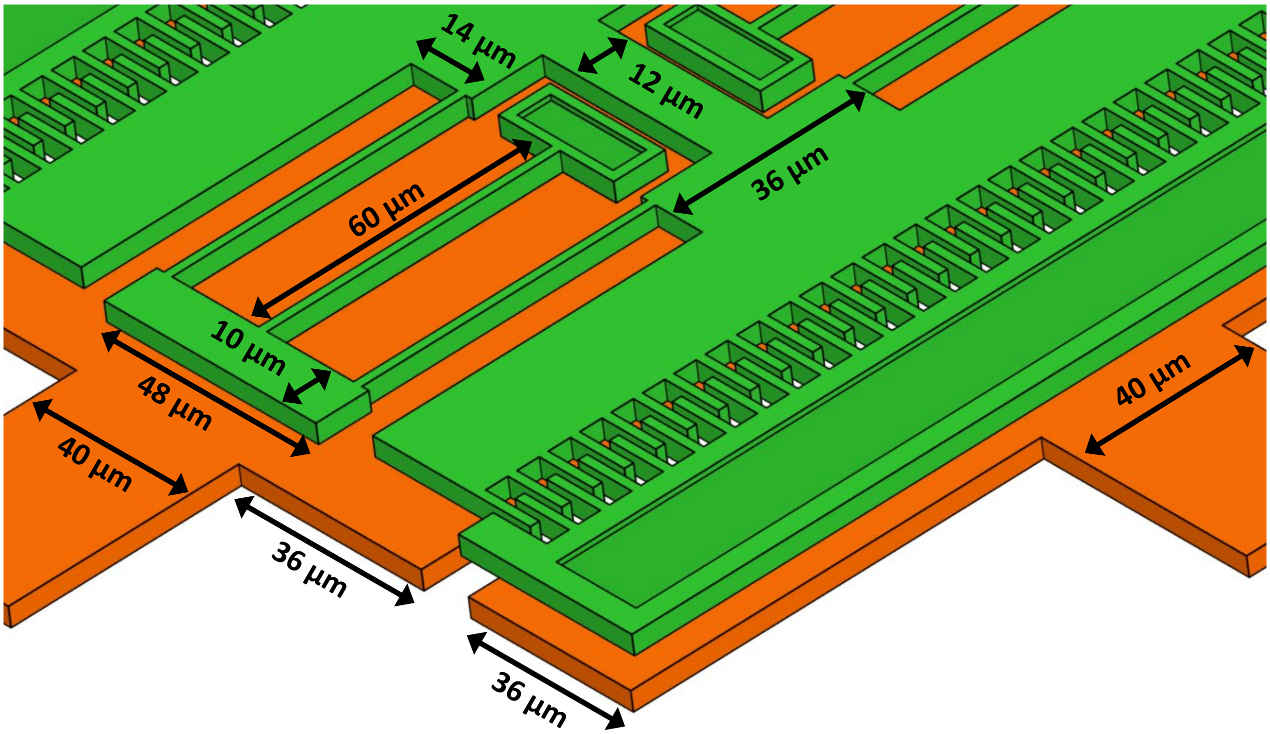

Figure PS5.3

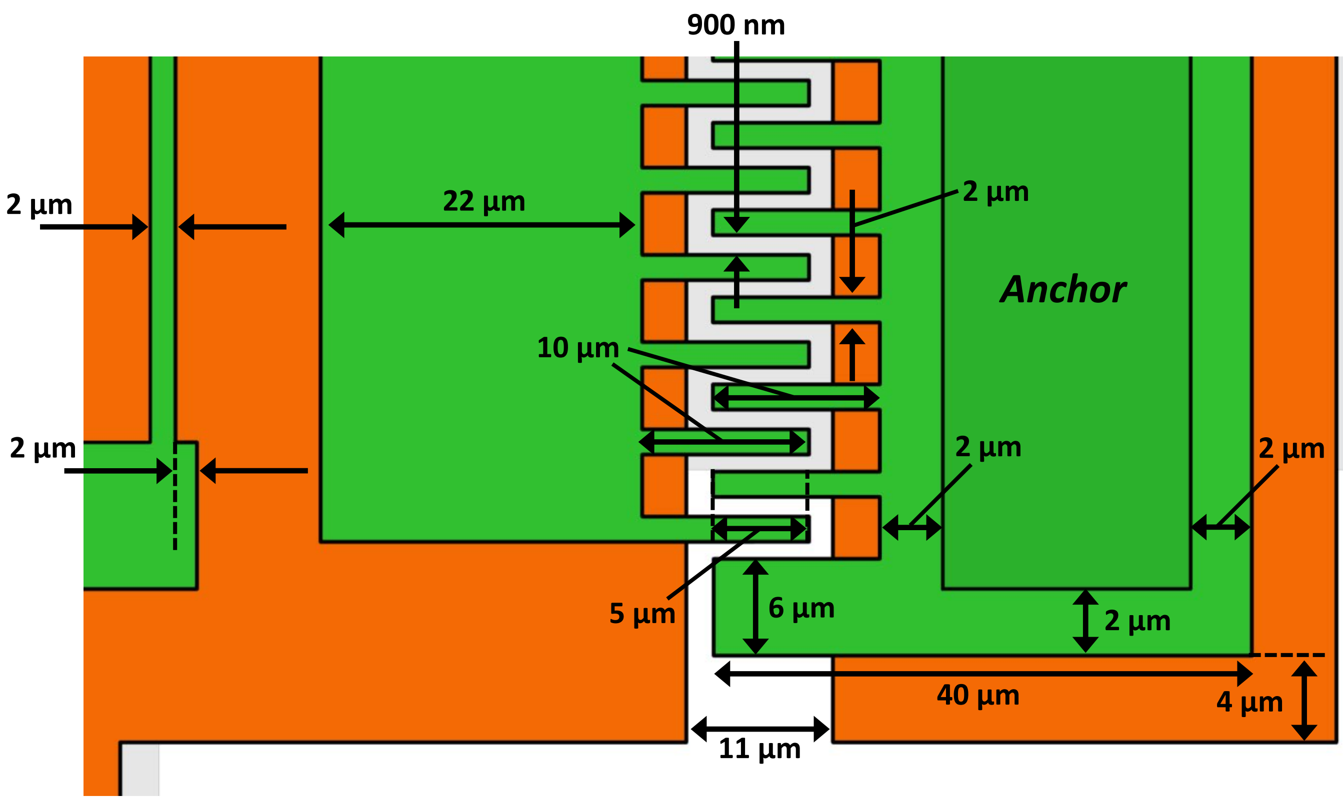

Figure PS5.4

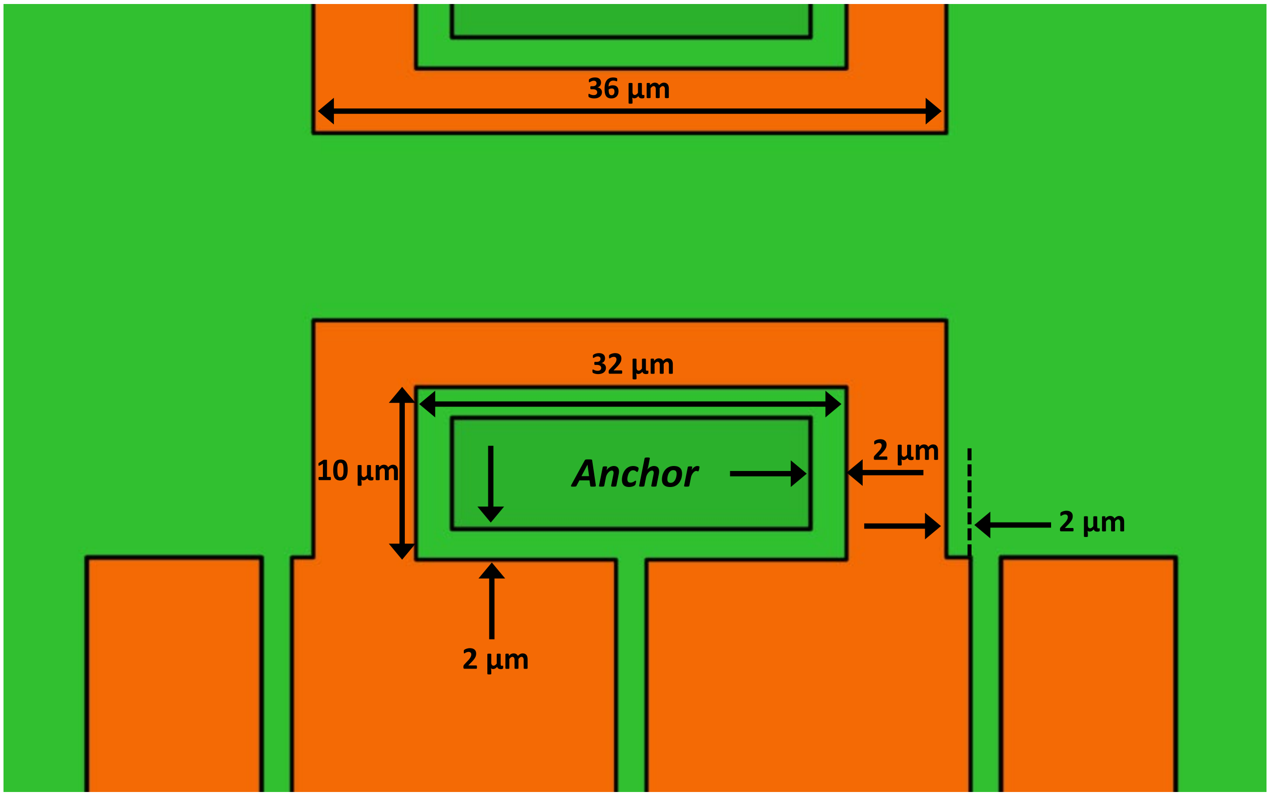

Figure PS5.5

(a) Calculate the x-directed resonance frequency of the structure, assuming that all electrodes (including the one connected to the shuttle) are biased at 0 V. Do not use a lumped mass-spring approximation, i.e., you will have to integrate along the lengths of the beams to find their kinetic energy. Assume that Young's modulus is $E = 150\,\text{GPa}$ and that density is $\rho = 2{,}300\ \text{kg/m}^3$ for the doped polysilicon.

(b) Use Cadence to generate a three-mask layout that achieves the structure above using the process flow outlined below. Note that the poly1 and poly2 masks (SP1 and SP2) are clear-field, while the anchor mask (SG1) is dark-field. You can leave the bond pads out of your design, but if you choose to include them, make sure that you make them large enough and space them far enough from each other and the structure to allow for wire-bonding. Export your layout as a gds file titled "*EEC247B_ME218_HW5_firstnamelastname.gds*", replacing "*firstnamelastname*" with your own first and last names. Email this file to your GSI when you submit the physical copy of your homework.

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_2C1_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 rnin.)
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 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. 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 rnin.], then [power = 0, same gases, time = 1 rnin.] 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:l 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.
