Name______________________________ SID____________________________ EE147/247A Midterm Fall 2017

NO CALCULATORS, CELL PHONES, or other electronics allowed. Show your work, and put final answers in the boxes provided. ***Use proper units in all answers.***

1. [5] You have made a single comb drive with 10 gaps, each 1 micron wide, in a film that is 16 um thick. You apply V_{AC} = 15V sin(ωt) to one side of the comb, and -15V to the other. What is total force generated?

F(t)=

2. [4] Four resistors are in a Wheatstone bridge with a 1V excitation. The resistors all have a temperature coefficient of resistance of 1%, and a gauge factor of 100.
   a. If one resistor is stretched by 10 parts per million, what is the magnitude of the change in the bridge output.

V_{out}=

   b. If the electronics can detect signals down to 100nV, what is the minimum detectable strain?

ε_{min}=

   c. What is the temperature change in a single resistor which will give a 100nV bridge output?

ΔT=

3. [4] In the polyMUMPs process, list the thin film layers that will be present on the substrate (starting at the substrate and working up, in order) before the release etch, in regions with the following masking layers
   a. POLY0, ANCHOR1, POLY1, METAL
   b. Nothing (no geometry drawn at all)

4. [4] You have made a Tang-style comb drive resonator. You apply a large bias voltage V_{DC} to the structure, and a sinusoidal voltage V_{AC} sin(ωt) to one of the combs, with V_{AC}= V_{DC}/100. You sweep the frequency of the sinusoid, and measure a sinusoidal deflection of 1 um at very low frequency, a peak deflection of 50 um, and a deflection of 10 nm at 100 kHz.
   a. What is the resonant frequency?

f_n=

   b. What is the quality factor Q?

Q=

   c. When driving the resonator at the resonant frequency, ω_n, estimate the amplitude of the motion at 2ω_n.

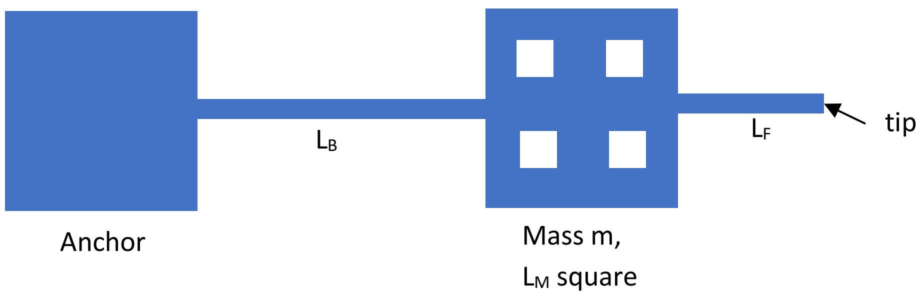
x(2ω_n)=

5. [3] True or False (circle one)

T / F The convention in layout is to draw conductors and draw holes in dielectrics.

T / F Etch holes are used in anchors to hold them to the substrate.

T / F In CoventorWare, simulated capacitances will be larger than simple hand calculations because CoventorWare takes into account fringing fields.



6. [5] The figure above shows our simple accelerometer from homework 1: a square proof mass of side length L_M, supported by a beam of length L_B, and a capacitor finger of length L_C. Now that we know more about beams, we can do a better job of estimating the deflection of the tip of the capacitor.
   a. Ignoring the mass of the spring and capacitor finger, what is the force and moment, F_0 and M_0, on the end of the beam due to an acceleration *a*?

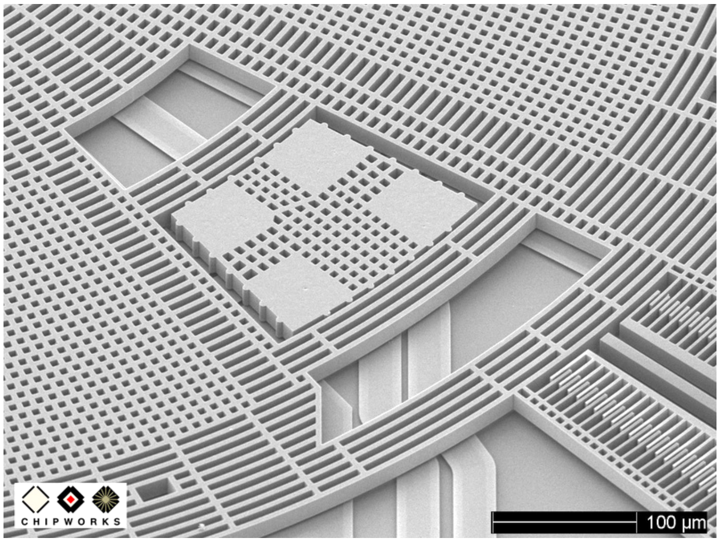
   b. In terms of F_0 and M_0, what is the y and θ deflection of the end of the *beam*?

   c. In terms of y and θ, what is the deflection of the tip of the capacitor?

7. [4] Assume that the anchor in the problem above is a 10um square of polysilicon which you have etched in RIE with vertical sidewalls. The poly is 2um thick sitting on a 2um thick oxide. You run two different variants of the oxide etch process on two different wafers:
   a. reactive ion etch (RIE) with vertical sidewalls
   b. 49% HF etch with 4 um etch distance

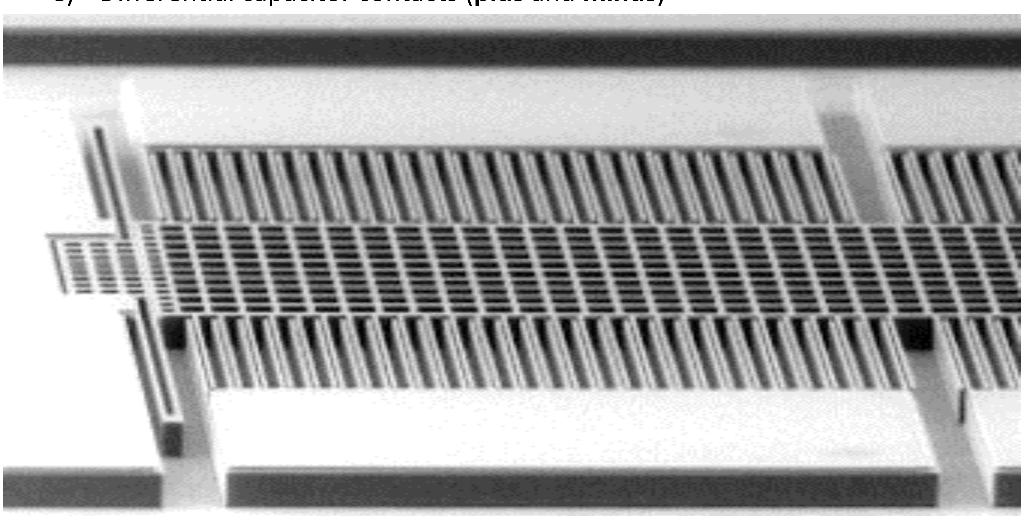
   Draw the cross sections of the resulting two wafers. Label materials.

8. [3] The image below shows a part of a gyroscope proof mass, designed to resonate in rotation on springs that are not shown. Label the **comb drives** that drive the resonance, the **resonant mass**, and the **over limit stops** that prevent the motion from getting too large.



(ST Micro LYPR540AH Tri-axis MEMS gyroscope)

9. [5] The image below shows about half of an SOI differential capacitive accelerometer. In the image, circle and label
   a) Proof **mass**
   b) Suspension **spring**
   c) Proof mass **anchor**
   d) A single variable **capacitor** (any one)
   e) Differential capacitor contacts (**plus** and **minus**)



From Dai et al., “Thermal drift analysis using a multiphysics model of bulk silicon MEMS capacitive accelerometer”, S&AV172N2 2011.