EE 147/247A Prof. Pister

Fall 2021

Homework Assignment #7

Due by online submission Friday 12/10/2021 (late Saturday at 9am)

1) You have developed a new MEMS process using a new material which you name Oskium after the Cal mascot. The process is a simple three mask process:
   a) 0.5um silicon nitride dielectric
   b) 0.5 um conductive poly/POLY0
   c) 2um sacrificial/CONT
   d) 1um Oskium/STRUCT
   e) complete sacrificial etch

- You have designed a test structure that consists of a collection of clamped-clamped beams which you are using to characterize the residual stress in the Oskium thin film. Looking in the microscope, you find that all of the beams longer than 200um are buckled, and all of the ones shorter than 200um are flat (see Figure 1 for an example).
- You have designed a test structure that consists of an array of cantilevers (clamped-free beams). The beams curl up slightly off of the wafer surface. 300 um long beams curl up about 1um, and 600 um long beams curl up 4 um. (see figure 2 for an example)

A. Estimate the average residual stress in the film. Is it compressive or tensile?

B. Estimate the residual stress gradient in the film.

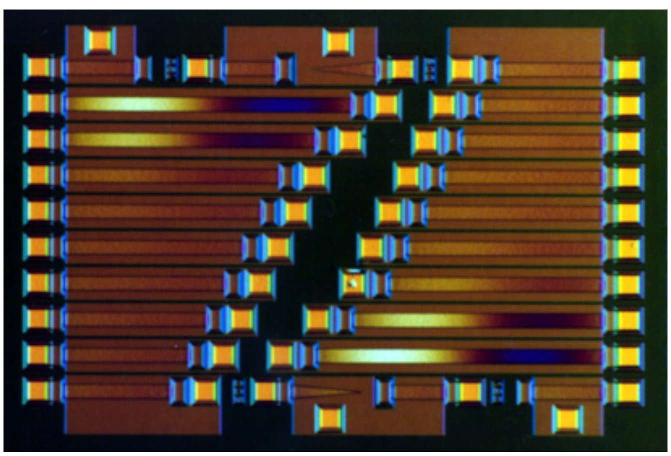

Figure 1 An image of an array of clamped-clamped beams as seen under a microscope. Most look about the same color along their length which indicates that they are flat. The longest have a clear color change along the length, indicating that they are buckled. This picture is taken with a Nomarski interference microscope which makes it easier to see, but the effect is also obvious in a normal visible light microscope at high magnification. [from http://terahz.org/_html/18SampledStudies.html]

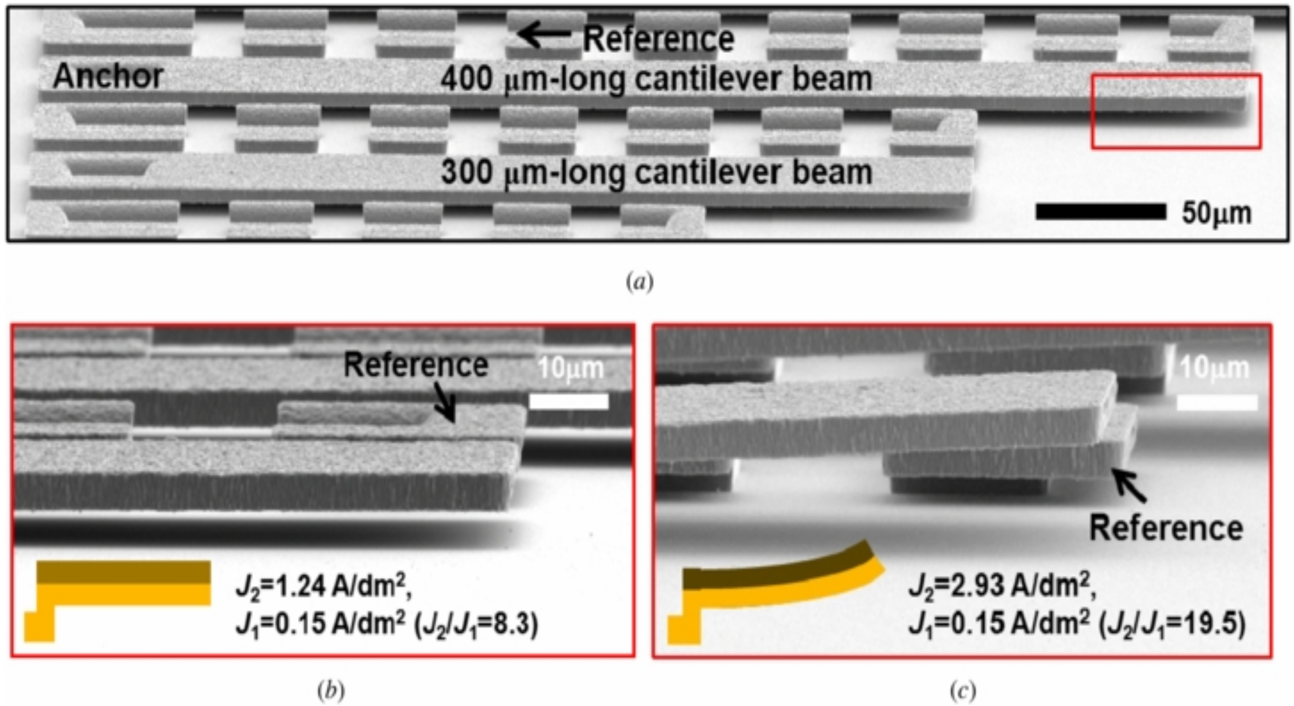

Figure 2 Residual stress gradient test structure. These pictures are taken with an electron microscope. Looking under an optical microscope at high magnification your depth of field is very shallow, on the order of a micron. You can use that and the (typically) graduated focus knob on the microscope to estimate the difference in height between the reference and the tip of the beam. (note the current densities in this figure relate to how these particular structures were electroplated, and are not relevant to the problem) [Hyun-Ho Yang et al, A new approach to control a deflection of an electroplated microstructure: dual current electroplating methods, 2013 J. Micromech. Microeng. 23]

2) In Joey Greenspun's DRIE presentation
   a. On slide 61, label the SEM cross-section with: substrate, buried oxide, device layer, etch hole, footing. Label the remaining silicon at the bottom of the etch hole, and estimate how much more silicon needed to be etched.
   b. On slide 62, why did the springs in the yellow box disappear during the etch?
3) Take a look at (BSAC grad) Kirt Williams' etch table [2]
   a) What wet etch would you use for silicon nitride? How long would it take to etch through a 0.2um film? What could you use as a mask?
   b) How many different answers are there to the question "What is the etch rate of silicon dioxide in HF"? I don't want to know the etch rates, I want you to see how many different HF etches you can find, and how many different silicon dioxides.
   c) If you wanted to use parylene-C as a mask for a KOH etch all of the way through a 550 um thick wafer, how thick would the parylene need to be?
   d) If you wanted to use parylene-C as a mask for a 5:1 BHF (buffered HF) release etch of an SOI wafer, how thick would the parylene need to be to last through a 10um lateral etch?
4) Take a look at Milanovic2004 [1]
   a) List the steps in the wafer bonding process.
   b) In figures 3 and 4 describing the first process
      i. List the four mask names, and the material that forms the mask on the wafer (PR, thermal oxide, or LTO), and on which surface it lives (front or back)
      ii. Draw the four different masks (1 dimensional cross-section pattern on each mask) that will give the cross-section shown in 4c
      iii. Assume that the minimum feature size on any backside etch is 30 um, and that the sidewall slope can vary such that the end of a backside etch where it touches the buried

oxide can be 10 microns bigger or smaller than the lithographically defined feature on the backside. Why does that place limits on how close an upper beam can be to a lower beam or a high beam? What is the constraint exactly?

iv. Can I make a decent upper/lower beam vertical comb drive in this process? Why or why not?

c) In Figures 8 and 9 describing the second process
   i) List the four mask names, and the material that forms the mask on the wafer (PR, thermal oxide, or LTO), and on which surface it lives (front or back)
   ii) Draw the four different masks (1 dimensional cross-section pattern on each mask) that will give the cross-section shown in Figure 9c
   iii) Why is it that this process can produce upper and lower beams that are right next to each other? Are the upper and lower beam planar locations defined with separate masks, or the same mask? To answer these questions be specific about what mask and etch defines where a lower beam will be, and its thickness, and what mask or masks define where in the layout view the three different beams will be.
   iv) Can I make a decent upper/lower beam vertical comb drive in this process? Why or why not?
   v) Figure 9c shows a middle beam. Could such a beam have been made in the first process? Why or why not?
d) In Figure 11, what combination of voltages move the mirror up and down. What combinations rotate it? Why do they have these different effects?

5) Given two perfectly flat square plates of side S separated by a nanometer-scale layer of water,
   a) what is the energy change associated with pulling the plates apart completely and exposing both sides to air (creating two new air/water interfaces)?
   b) If the distance that you need to pull the plates to separate them (and form the two air/water surfaces) is αS, where α is a small constant on the order of 0.001, what is the average force that must be exerted to separate the plates to that distance?
   c) Based on this model, what is the weight that can be supported by surface tension between plates that are 1mm square? 1um square?
   d) Using this model, what is the largest silicon cube that can be suspended by surface tension?
6) Given two perfectly flat square plates of side S with a micron-scale layer of water between them,
   a) Assuming a contact angle of 90 degrees, and considering only the air/water interface at the perimeter of the plates, what is the surface tension force pulling the plates together?
   b) If we ignore gravity and the surface tension force is balanced only by the Laplace pressure, what is the approximate radius of curvature of the resulting air/water interface? You may ignore the fact that the contact angle will change.
   c) For S=10um
      i) Sketch a cross-section assuming the water-filled gap between the plates is 1 um
      ii) Sketch a cross-section assuming the water-filled gap between the plates is 0.1 um (just show detail of the edge, not the whole 10 um width of the plate
      iii) Sketch a cross-section assuming the water-filled gap between the plates is 10 um
   d) For S=100um, compare the magnitude of the surface tension force to the weight of the plate, if it is made on POLY1 in the polyMUMPS process.
7) What would happen in an LPCVD tube being fed with silane and oxygen if the process were run at atmospheric pressure instead of low pressure?

[1] Milanovic, "Multilevel Beam SOI-MEMS Fabrication and Applications", JMEMS 2004.
https://people.eecs.berkeley.edu/~pister/147fa20/MilanovicMultilevelDRIE2004.pdf

[2] Williams, Gupta, Wasilik, "Etch rates for micromachining processes – part II", JMEMS 2003.
https://people.eecs.berkeley.edu/~pister/147fa20/WilliamsEtch2003.pdf