

*Homework Assignment #7 (Due Nov. 29th)*

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**Problem 1: Actuator in DRIE process**

Assuming a DRIE aspect ratio  $S$ , a minimum feature size  $l$ , a material density  $r$ , and a maximum voltage  $V$ ,

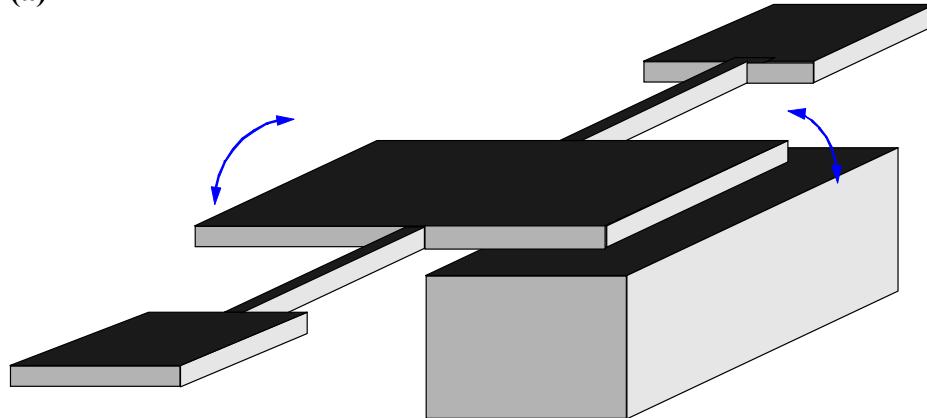
- a) calculate the force per unit area of an ideal gap-closing actuator array. (Use the zero-deflection force, not the force after pull-in; you may assume some magical sublithographic gap stop if you like).
- b) Calculate the force output per kilogram, assuming a film thickness  $t$ . Will micro robots with gap closing electrostatic actuators be able to lift themselves without massive gearing or levers?
- c) What is the optimum value for  $t$ , assuming we want to make minimum sized gaps and the maximum aspect ratio possible in our beams?
- d) Calculate the maximum work done per cycle of the actuator against a constant force load (what is the load?).
- e) Calculate the electrical energy input per cycle, assuming that some smart control circuit limits the total charge on the capacitor plates to twice the charge applied initially to the actuator (the zero-deflection charge).
- f) What is the energy efficiency of this actuator?
- g) Assuming that you choose the support spring for your gap closing actuator such that when the gap closer has pulled in completely that the spring force is equal to the zero-deflection force of the electrostatic actuator, calculate the resonant frequency of your actuator in terms of only  $V$ ,  $l$ , and  $r$ .
- h) Ignoring damping, estimate the maximum power output per kilogram of an electrostatic gap closing actuator.
- i) Insect flight muscle has a peak power density of 100W/kg, about as high as it gets for animals. Will micro robots based on gap closing electrostatic actuators ever fly? How is your accelerometer made? Provide sketches (with dimensions) of each part, and a sketch of the entire device.

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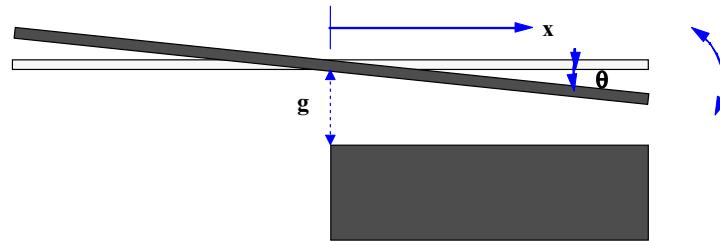
## Problem 2: Torsional Mirror

Torsional mirrors driven by gap-closing actuator are commonly used in designing scanning mirror. Assume that the mirror plate is rigid and is rotated around its central axis under electrostatic torque, balanced by two-spring mechanical torque,  $M_{\text{spring}} = k_{\text{spring}} * \theta$ .  $k_{\text{spring}}$  is spring constant, depending only on the dimension of springs, i.e., length, width and thickness of spring.

(a)



(b)



(a) Suspended mirror supported by two torsional beams.  
(b) Cross section of mirror, moving under electrostatic force.

- Find the pull-in position and pull-in voltage.
- How much power is consumed during one pull-in actuation in your design? Assume that there is a gap-close limit stop to prevent shorting after pull-in.