ME 517: Micro- and Nanoscale Processes

Lecture 15: Electrostatics III

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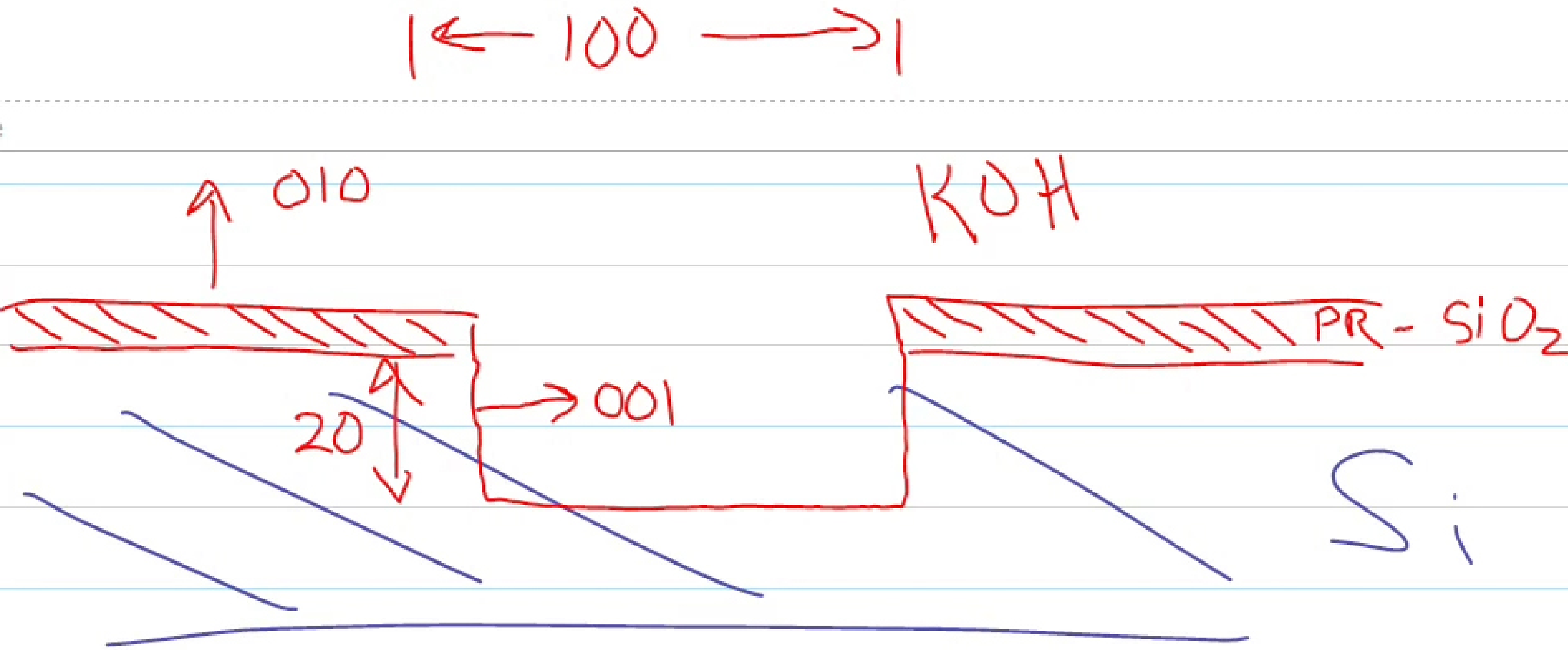
Title



Electrostatic Cantilever

Mechanical Transducers 279 ←Kovacs

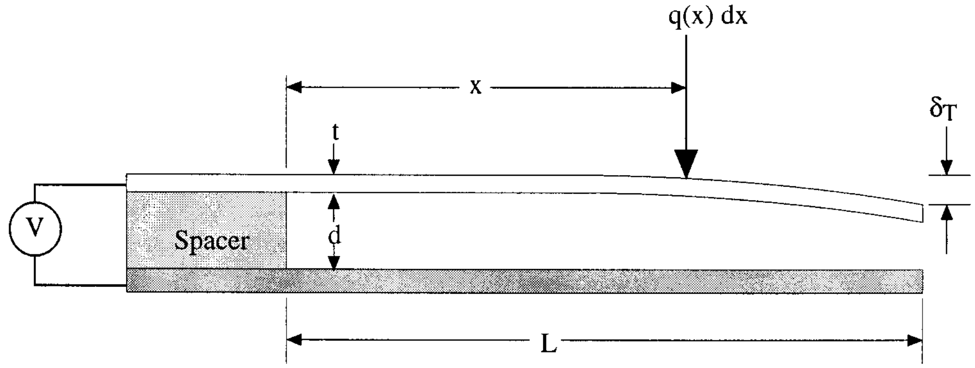
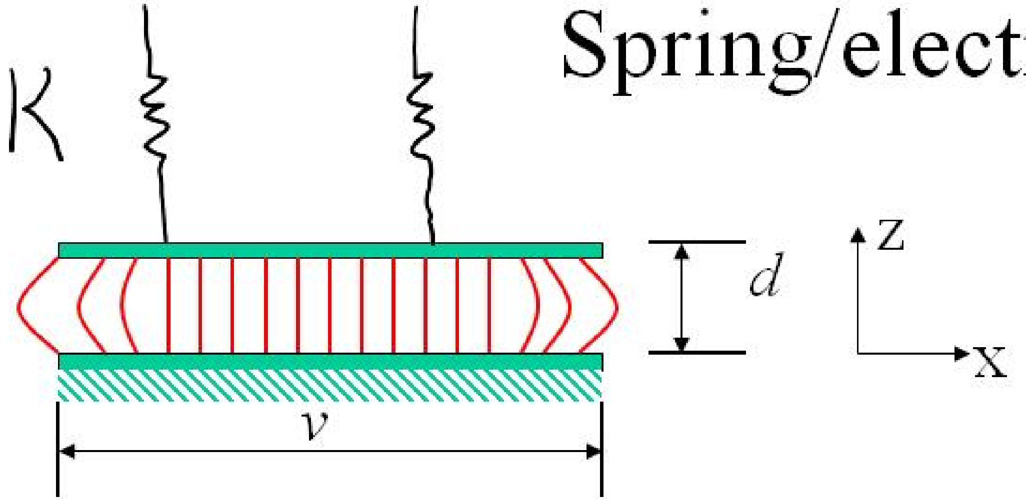


Illustration of an electrostatically deflected cantilever structure showing variable definitions for analysis. After Petersen (1978a).

- cantilever suspended above substrate forming parallel plate capacitor *in a vacuum*
- Analysis requires Euler-Bernoulli Beam Flexure Formula and electrostatics

Petersen, K.E., "Dynamic Micromechanics on Silicon: Techniques and Devices," IEEE Trans. On Electron Devices, vol. ED-25, no. 10, Oct. 1978, p. 1241-1250.

Spring/electrode model

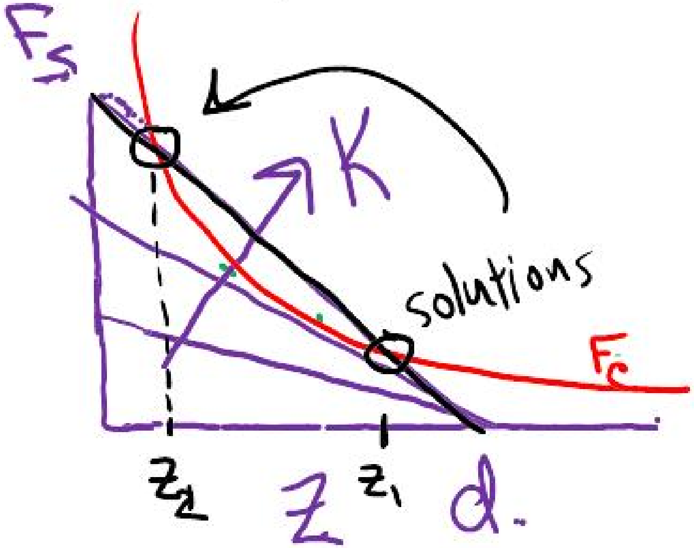


$$F_s = K(d - z)$$

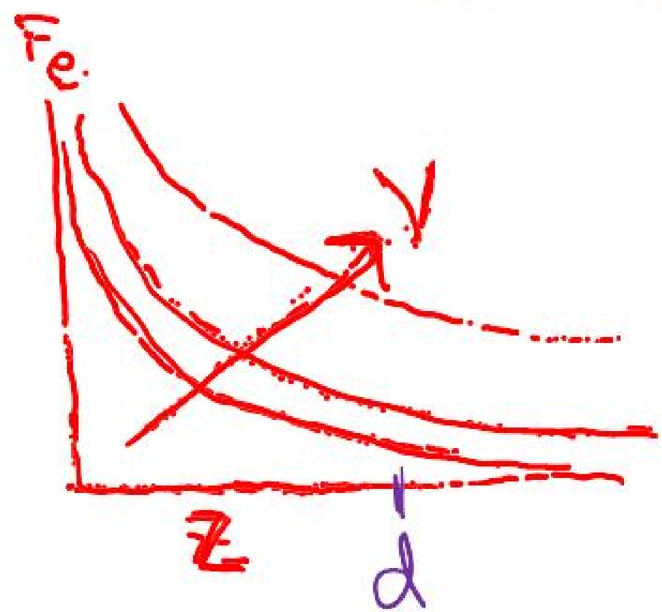
$$F_e = \frac{1}{2}\varepsilon_0\varepsilon_r \frac{vw}{z^2} V^2$$

$$F_s = F_e$$

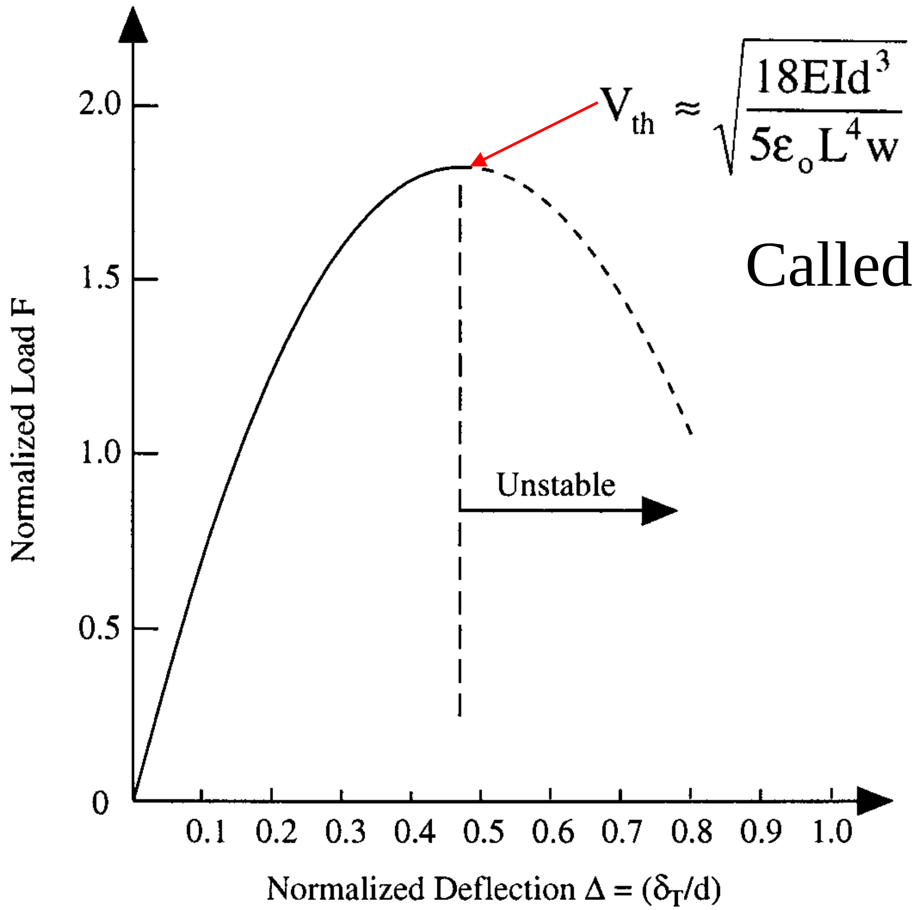
$$K(d - z) = \frac{1}{2}\varepsilon_0\varepsilon_r \frac{vw}{z^2} V^2$$



"Snap in"
"pull in"



Electrostatic Cantilever



$$V_{th} \approx \sqrt{\frac{18EId^3}{5\varepsilon_o L^4 w}}$$

Called ‘pull in’ point

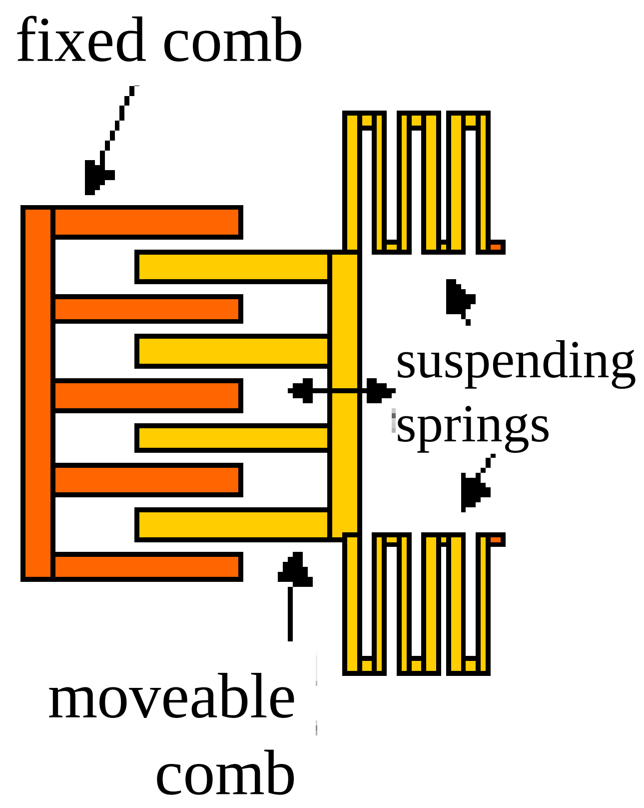
Plot showing the normalized load, F, versus the normalized deflection, Δ, for an electrostatically deflected cantilever. Adapted from Petersen (1978a). Beyond a certain threshold deflection, spontaneous collapse of the cantilever occurs.

Electrostatic Comb Drives

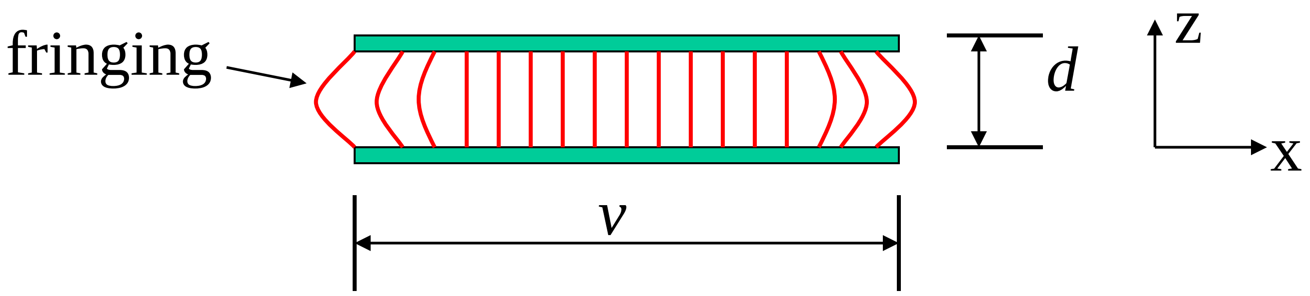
- Interlacing comb fingers create large effective capacitor area (Tang, Nguyen, Howe, 1989)

•Salient features:

- –linear relationship between capacitance and displacement
- –interlacing fingers provide much larger surface area than parallel plate capacitor
- –electrostatic actuation—low power consumption because no current



Capacitor



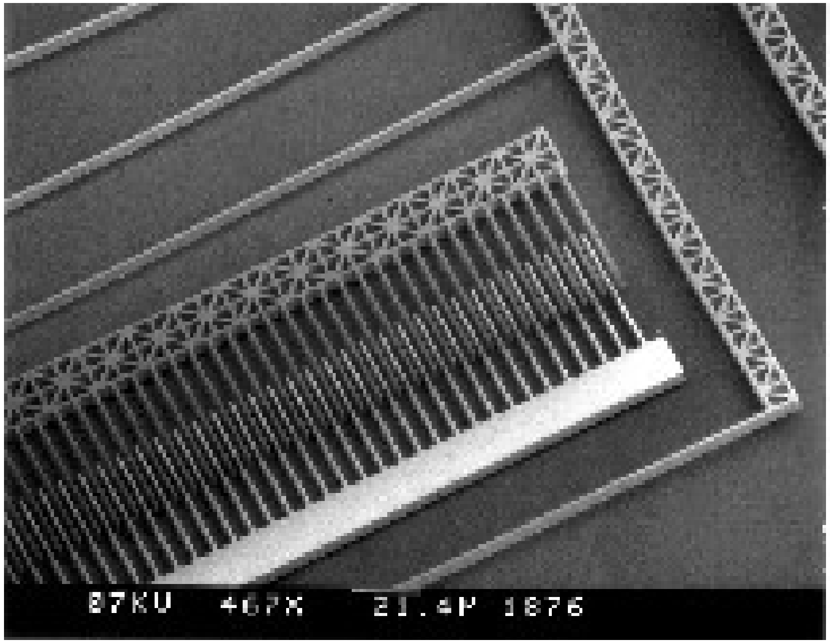
- Simplest geometry—parallel plate above
- Assuming that *d* is much smaller than *v* or *w*, fringing will not play a major role—assume that the field is uniform.

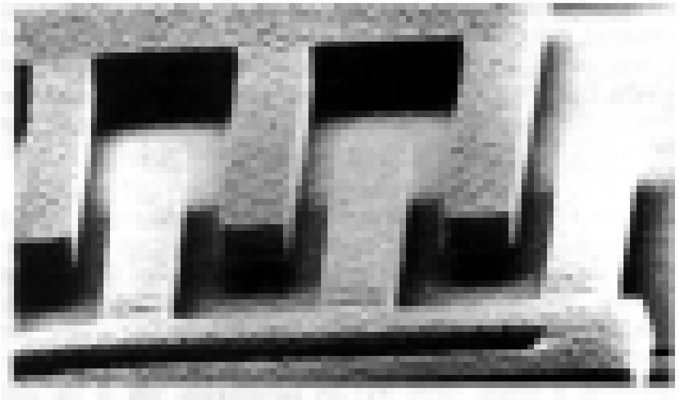
$$W_e = \frac{1}{2}\int_V \rho V dv = \frac{1}{2}\int_V \varepsilon_0 \varepsilon_r \left(\frac{V}{d}\right)^2 dv$$

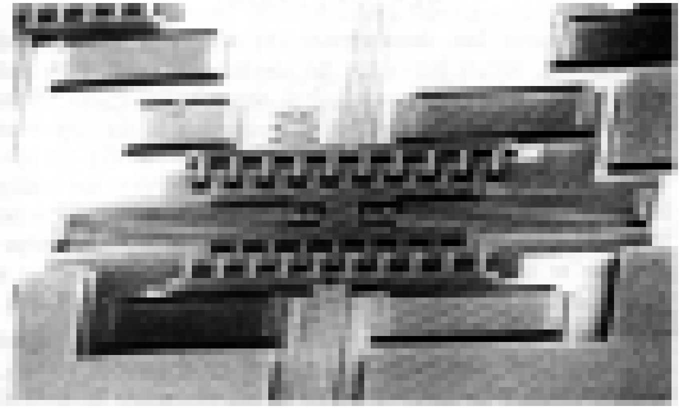
$$= \frac{1}{2}\varepsilon_0\varepsilon_r\left(\frac{V}{d}\right)^2 vwd = \frac{1}{2}\varepsilon_0\varepsilon_r\frac{vw}{d}V^2$$

Comb Drive

- How are these structures produced?







Comb Drive

Capacitance approximately

$C = \varepsilon_0 \, \varepsilon_r \, A/d$

$= 2n \, \varepsilon_0 \, \varepsilon_r \, lh/d$

Change in capacitance when moving by Δx:

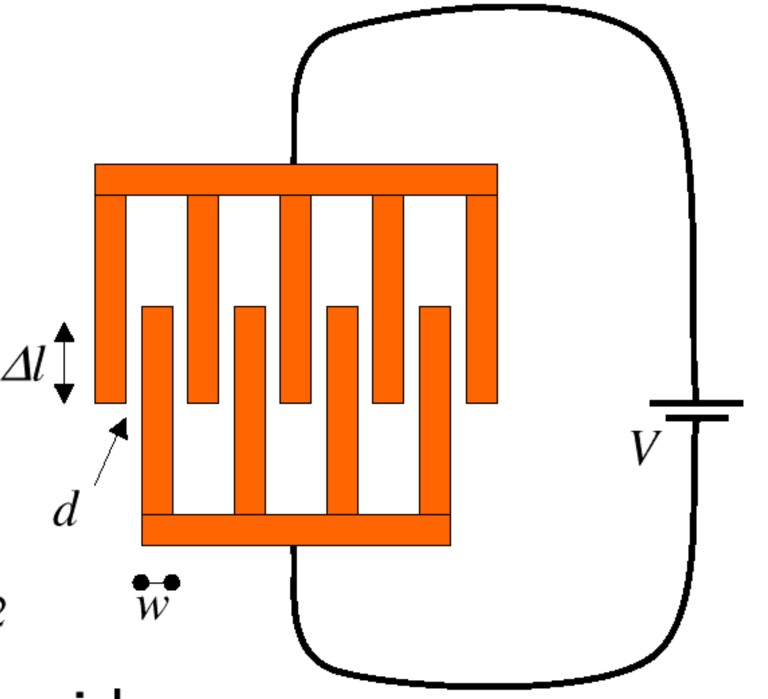
$\Delta C = \varepsilon_0 \, \varepsilon_r \, \Delta A \, / \, d$

$= 2n \, \varepsilon_0 \, \varepsilon_r \, \Delta l \, h/d$

Electrostatic force:

$F_{el} = \frac{1}{2} V^2 \, dC/dx = n \, \varepsilon_0 \, \varepsilon_r \, h/d \, V^2$

Note: F_{el} independent of Δl over wide range (fringing field), and quadratic in V.

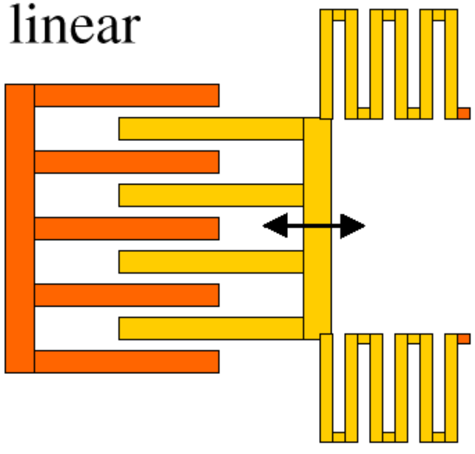


http://www.ee.washington.edu/class/502/aut00/

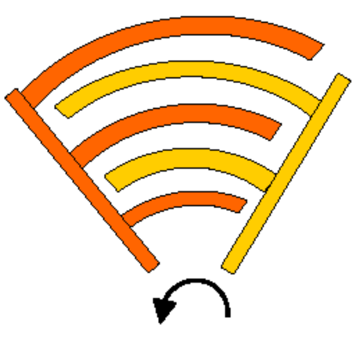
Comb Drive Design

Combs

linear

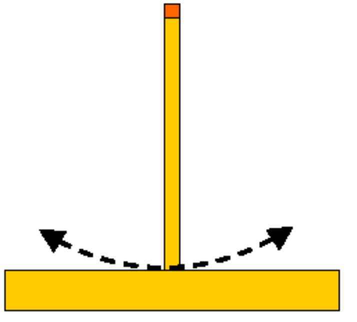


rotational

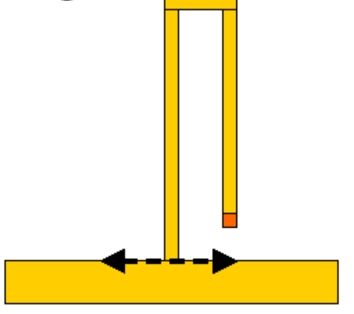


Suspensions

cantilever / bridge



crab leg

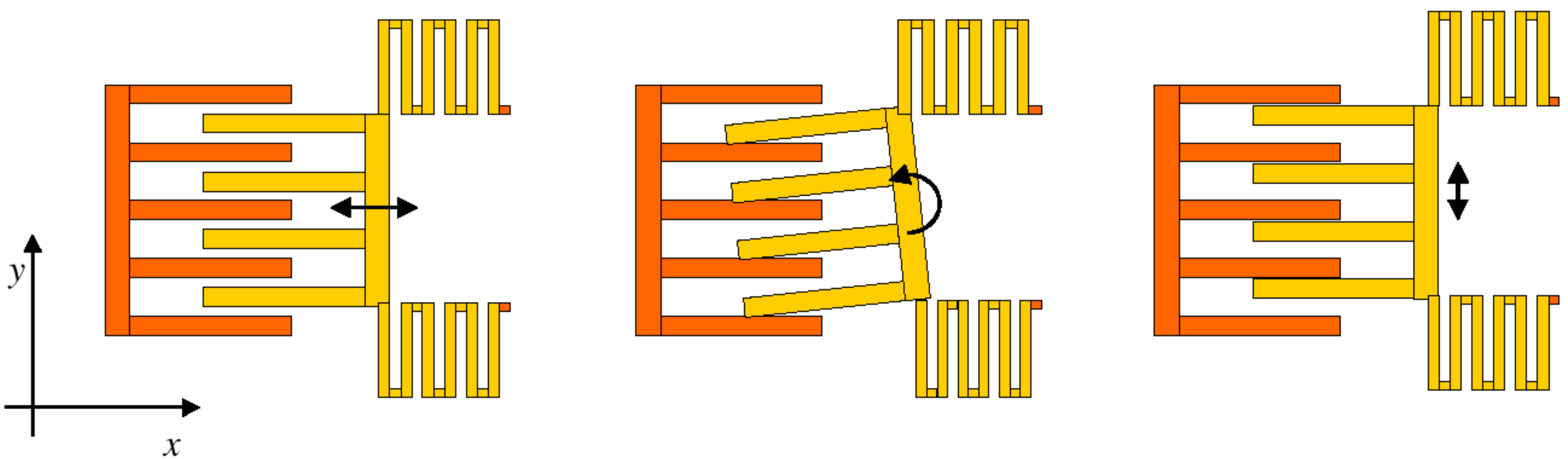


Comb Drive Failure Modes

Comb drives require low stiffness in x direction but high stiffness in y, z direction as well as rotations.

Note: comb fingers are in unstable equilibrium w.r.t. y direction.

good bad bad



The RF-MEMS Switch:

- If you apply a DC voltage so that both ends of the switch are charged differently you create an electrostatic force. This force causes an attraction between the two areas.