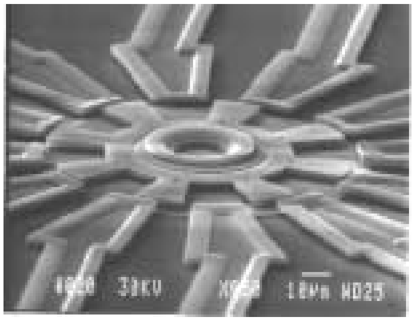
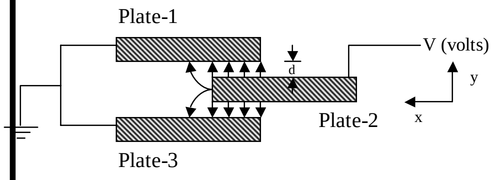
Overview

- Electrostatics
  - Basic equations
  - Early applications
  - Use in systems
  - Scratch drive



Electrostatic Actuators



Consider parallel plate 1 & 2

Force of attraction (along y direction)

$$F_p = (\tfrac{1}{2}\,\varepsilon\, V^2)(A/g^2)$$

1nN@15V

dimensionless

Consider plate 2 inserted between plate 1 and 3

(Popularly known as a COMB DRIVE)

Force of attraction (along x direction) $F_c = (\tfrac{1}{2}\,\varepsilon\, V^2)(2t/g)$

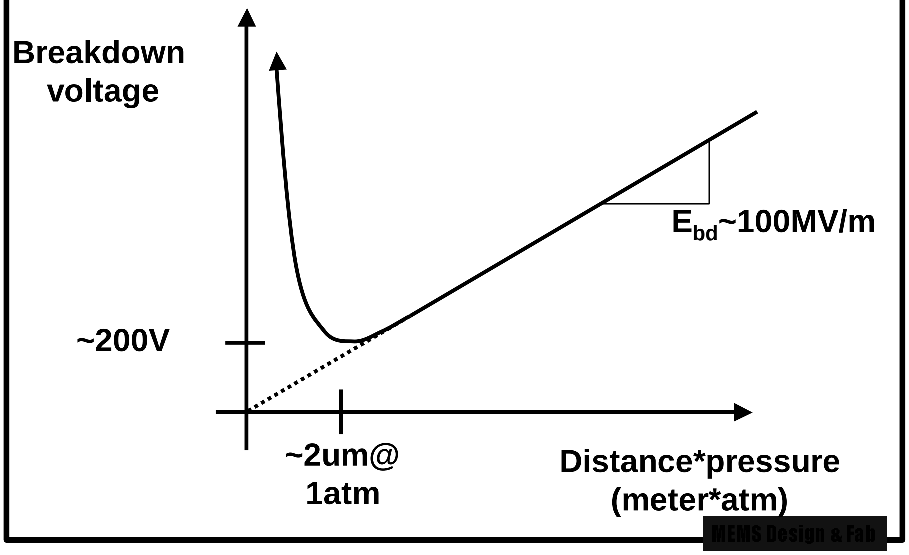
Constant with x-directional translation

Electrostatics work sheet

- Assume you have a gap-closing actuator with 1 meter square plates separated by 1 meter. At 15V, what is the force between them?
- What if the plates are 1 micron square separated by 1 micron?
- 1mm square, separated by 1 micron, at 150V?

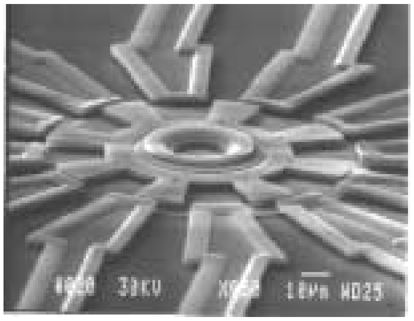
	1m^2x1m	1um^2x1um	1mm^2x1um 150V
Unit force = ½ ε V^2			
Area multiplier=A/g^2			
F_p = (½ ε V^2)(A/g^2)			

Paschen Curve

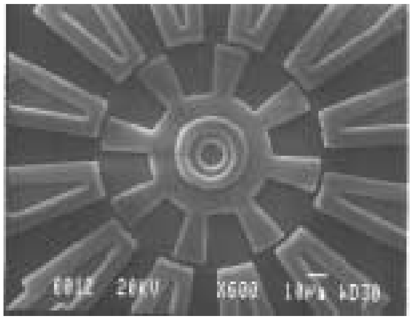


Side Drive Motors

Side view of SDM



Top view of SDM



First polysilicon motors were made at UCB (Fan, Tai, Muller), MIT, ATT
Typical starting voltages were >100V, operating >50V

High-Aspect-Ratio Rotary Polygon Micromotor Scanners

High-Aspect-Ratio Rotary Polygon Micromotor Scanners

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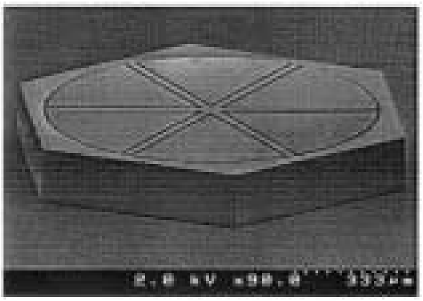


Figure 1. SEM photo of a typical DRIE fabricated polygon scanner using a hexagonal rotor. The rotor is 1.4mm in diameter, and the reflecting sidewalls are 200μm-tall.

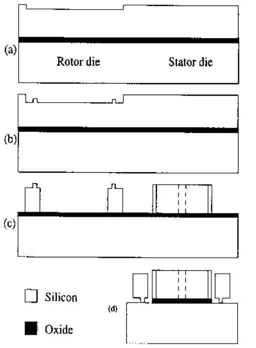
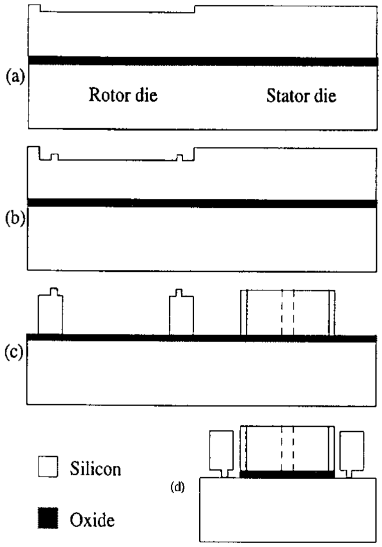


Figure 3. Cross-sectional schematics describing the micromotor fabrication process: (a) after recess definition and patterning to a depth of 8 μm; (b) after bushing definition and patterning to a depth of 2 μm; (c) after rotor/stator definition and DRIE patterning through the top wafer; and (d) after rotor release and assembly onto the corresponding stator.

High-Aspect-Ratio Rotary Polygon Micromotor Scanners



A Rotary Electrostatic Micromotor 1×8 Optical Switch

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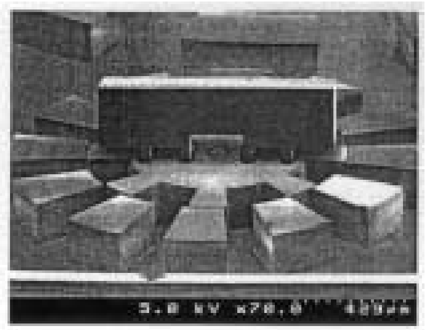

Fig. 3 SEM photo of an assembled microswitch with vertical 200 µm-tall reflective mirror plate.

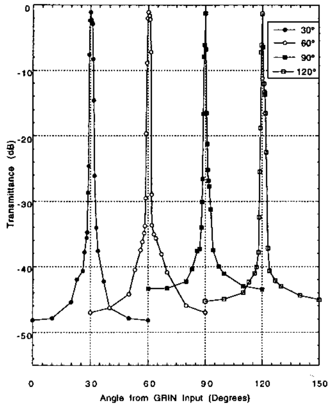

Fig. 4 Insertion loss and crosstalk measurements for multi-mode optics at 850 µm.

Micro Electro Mechanical Systems
Jan., 1998 Heidelberg, Germany

Fiber Attenuator

Low Insertion Loss Packaged and Fiber-Connectorized Si Surface-Micromachined Reflective Optical Switch

V. Aksyuk, B. Barber, C. R. Giles, R. Ruel, L. Stulz, and D. Bishop
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Murray Hill, NJ 07974

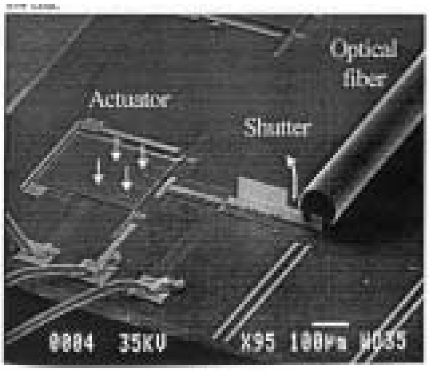

Figure 1. MEMS optical switch. For clarity the second optical fiber is not shown.

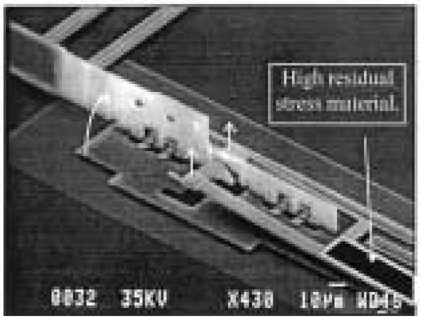

Figure 2. Self-Assembling optical shutter. High tensile residual stress metal is deposited on a polysilicon beam anchored at one end. Upon release the metal-poly sandwich structure deforms, moving the free end of the beam upward. The lifting structure engages the cut in the hinged-plate shutter causing it to rotate 90 degrees into tits operating position.

Solid-State Sensor and Actuator Workshop
Hilton Head 1998

Fiber Attenuator

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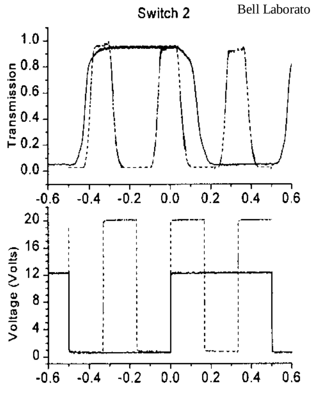

Figure 7. Second generation, fast switch operation. 10 times faster operation relative to Switch 1 is achieved with twofold increase in actuation voltage.

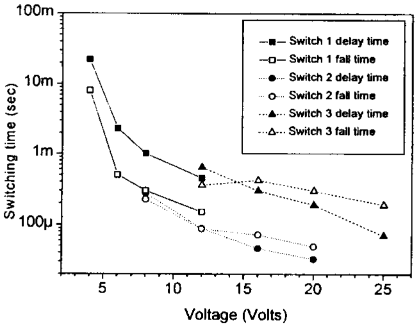

Figure 8. **Switch closing time as a function of actuator voltage. Solid symbols-switch delay time. Open symbols-fall time. Delay time results from the shutter having to accelerate and travel some distance before it starts blocking the beam.**

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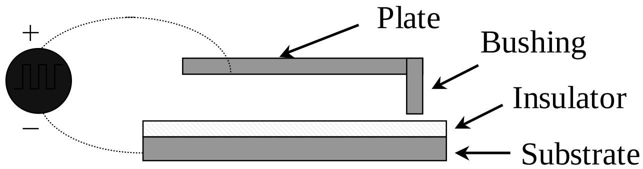
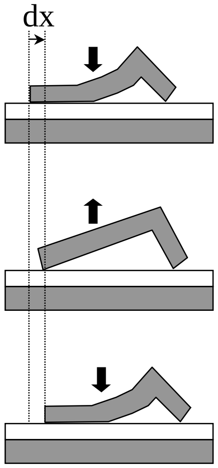
Scratch Drive Actuator (SDA)



- Micro XYZ positioning stages
  (L. Y. Lin, et. al., 1997; Li Fan, et. al., 1997)
- Self-assembly of MEMS devices
  (A. Terunobu, et. al., 1997; Y. Fukuta, et. al., 1997)
- Free-space fiber optic cross/bar switch
  (Shi-Sheng Lee, et. al., 1997)

SDA operation



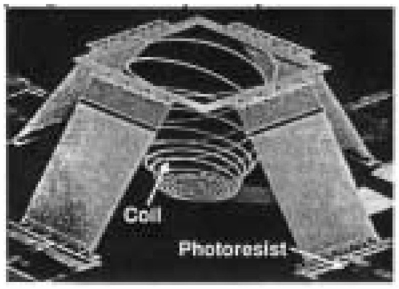
1) Applied voltage bends SDA downward
2) When released, SDA returns to original shape
3) Reapplying voltage causes SDA to move a distance ‘dx’

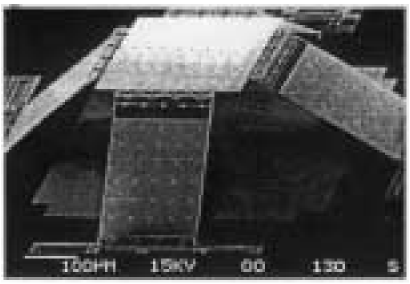
Caveat: sometimes they go backward!

Tuneable RF components
Inductors and Variable Capacitors

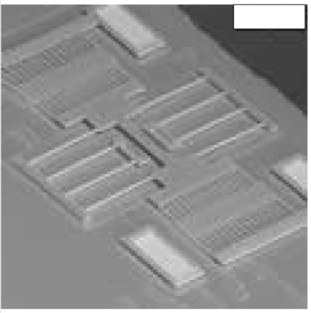
Ming Wu, UCLA

Assembled using scratch-drive actuators

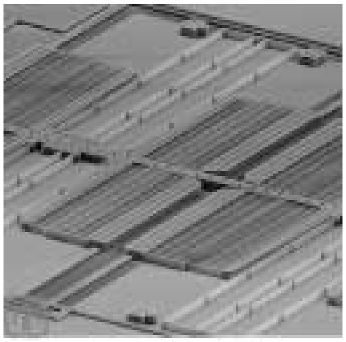




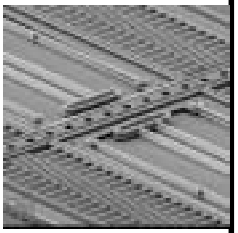
Comb Drives



Tang/Nguyen/Howe

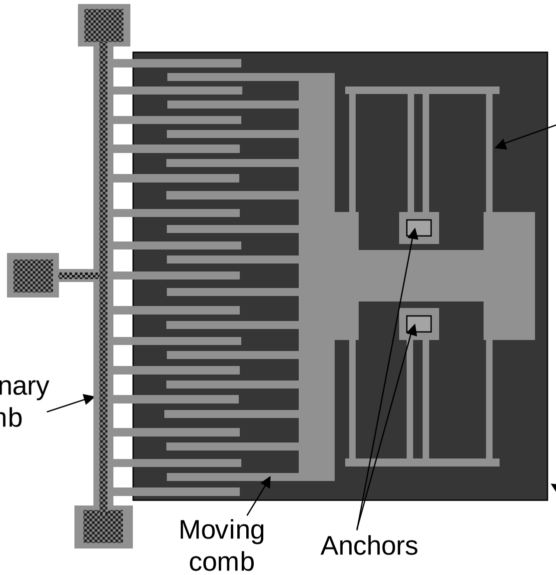


Sandia cascaded comb drive (High force)



Close-up

Layout of electrostatic-combdrive



Folded beams (movable comb suspension)

Tang, Nguyen, Howe, MEMS89

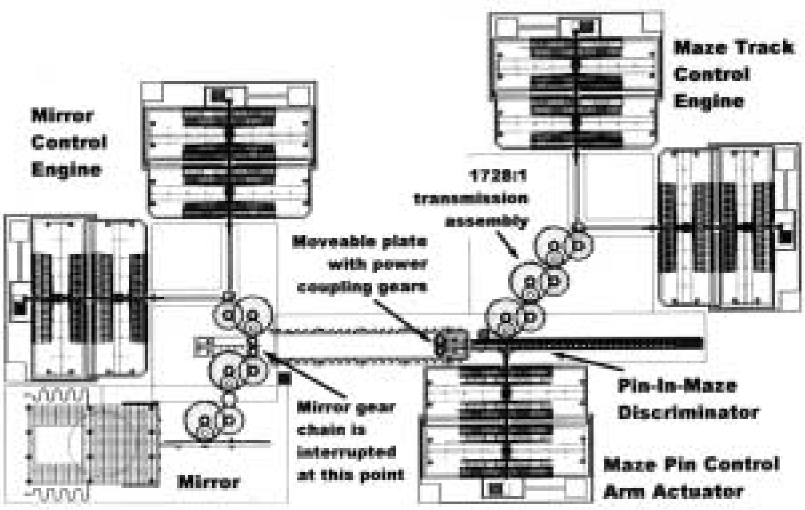
Stationary comb

Moving comb

Anchors

Ground plate

Most complex micro-mechanical system to date?



Buckling-beam actuation in the Sandia process

Micro-Flex Mirror and Instability actuation Technique

Ernest J. Garcia
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Albuquerque, NM, 87185-0329 USA

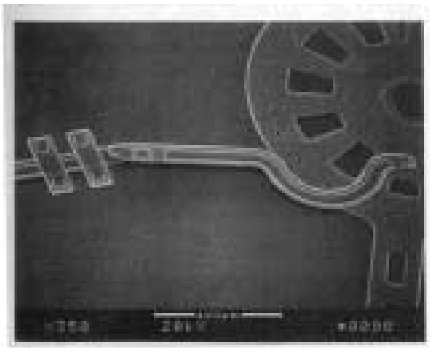

Fig. 9 Drive Link

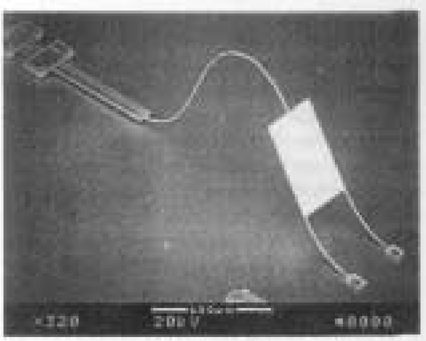

Fig. 10 Actuate Position

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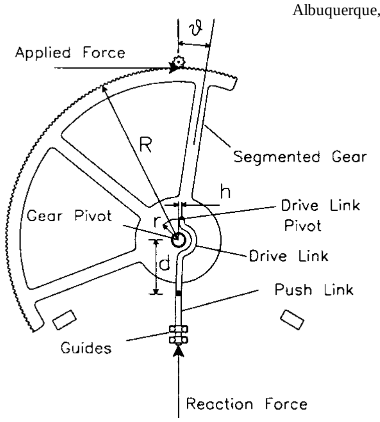

Fig. 5 Linkage System for Force Amplification

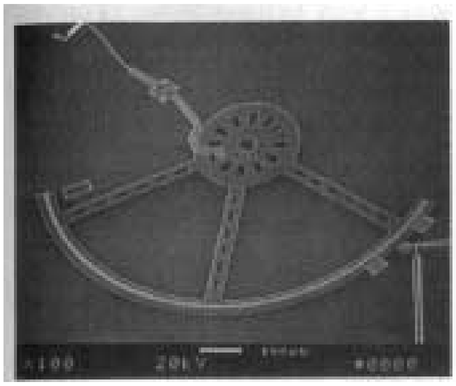

Fig. 8 Micro-Flex Mirror Linkage System.

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Parallel-Plate Electrostatic Actuator Pull-in

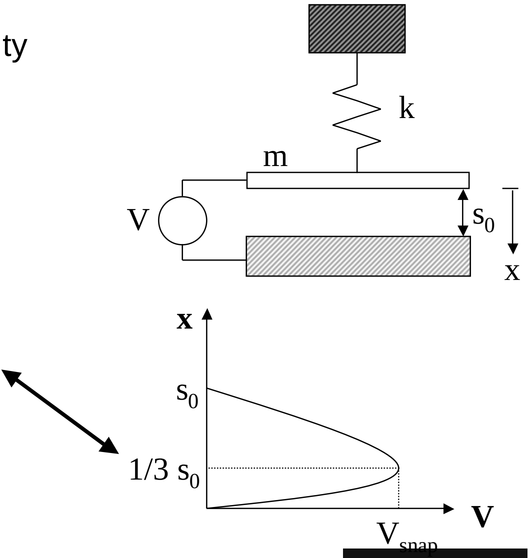
Electrostatic instability

$$F = \frac{\varepsilon_0 V^2}{2(s_0 - x)^2} = kx \Rightarrow$$

$$V = \sqrt{\frac{2kx}{\varepsilon_0}}(s_0 - x)$$

$$\frac{\partial V}{\partial x} = 0 \Rightarrow x_{snap} = \frac{s_0}{3}$$

$$V_{snap} = \sqrt{\frac{8ks_0^3}{27\varepsilon_0}}$$



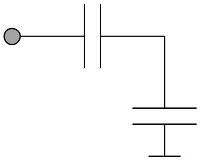
Controlling the instability

- Charge control
  - Requires on-chip circuitry

$$F = \frac{Q^2}{2A\varepsilon_0} = kx$$

Joe Seeger, UCB

- Series capacitor
  - Increases required voltage



Electrostatic spring

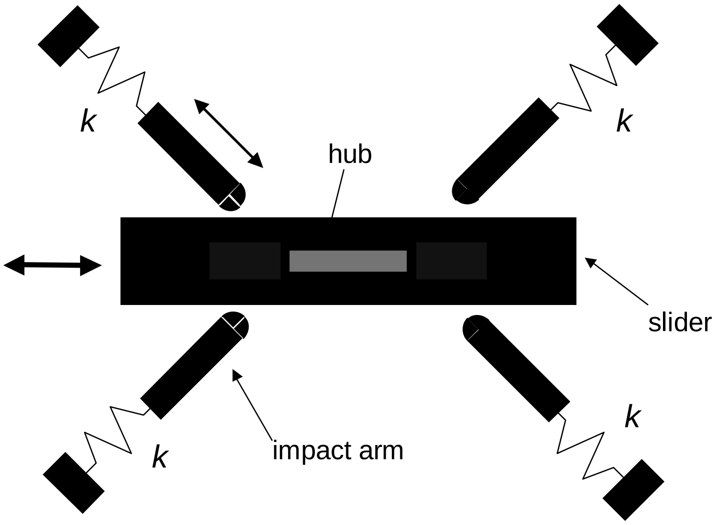
$$F=\frac{\varepsilon_0 V^2}{2(s_0-x)^2}\approx\frac{\varepsilon_0 V^2}{2(s_0-x_0)^2}\left(1+2\frac{x-x_0}{s_0-x_0}\right)$$

$$F=m\ddot{x}+kx\approx\frac{\varepsilon_0 V^2}{2(s_0-x_0)^2}\left(1+2\frac{x-x_0}{s_0-x_0}\right)\Rightarrow$$

$$m\ddot{x}+\left(k-\frac{\varepsilon_0 V^2}{(s_0-x_0)^3}\right)x=\frac{\varepsilon_0 V^2}{2(s_0-x_0)^2}\left(1-\frac{2x_0}{s_0-x_0}\right)$$

- Adjustable stiffness (sensitivity) and resonance frequency

Vibromotor



M. Daneman et al, JMEMS, vol. 5, no. 3, pp. 159-165, 1996.

Vibromotor-Actuated Micromirror for Fiber-Optic Alignment

Daneman, IEEE Photonics Techn. Letters, vol. 8, no. 3, pp. 396-398, March 1996.

Summary

- Electrostatics use moderate to high voltage
  - Force goes as V^2/g^2
  - Paschen limits convenient voltages to 200
  - Force is *scale independent*
- Easy process integration
- Many mechanism options