OPTICAL MEMS SWITCHES

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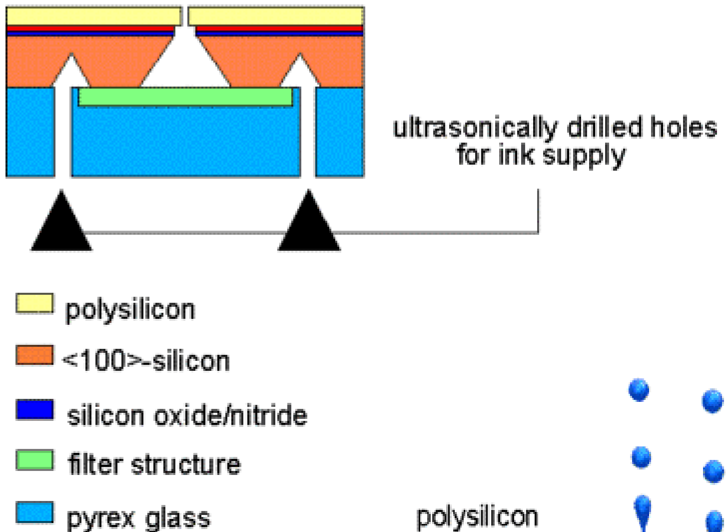
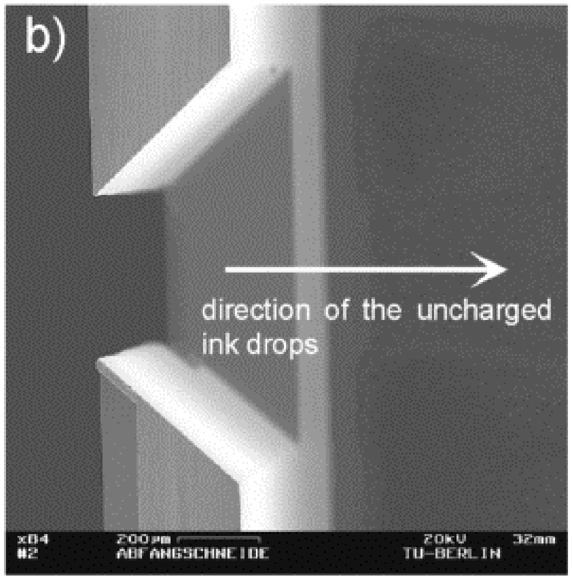
Outline

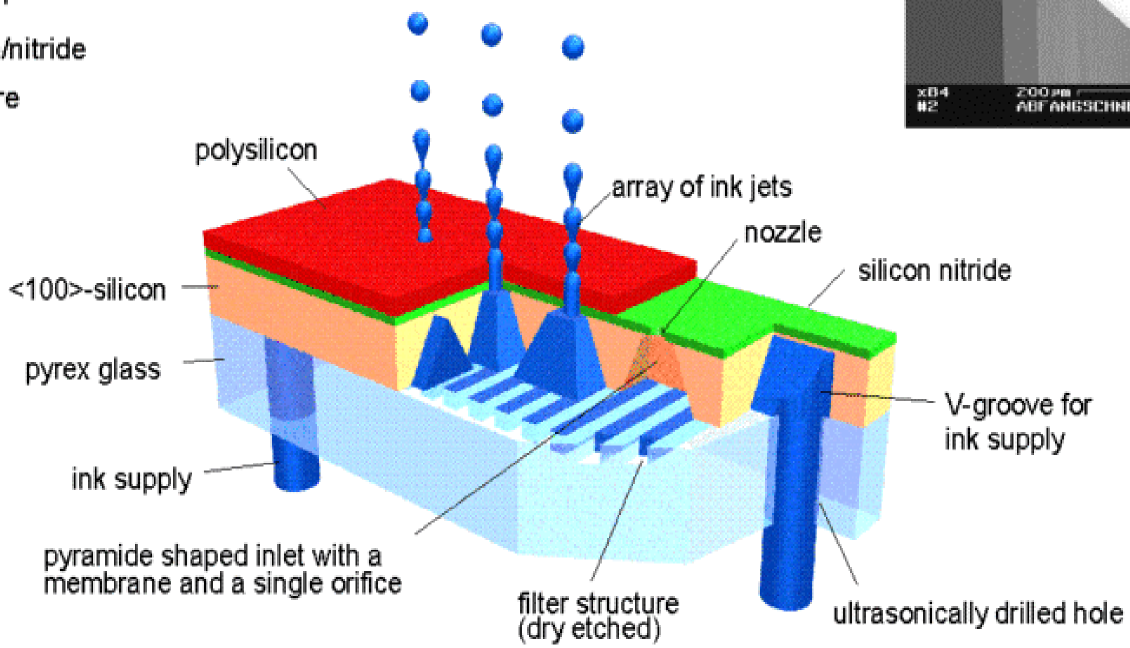
- What is MEMS?
  - Bulk and Surface micromachining
  - Actuators
  - Reliability
- Why is O-MEMS useful?
  - Allows miniaturization, parallel processing and integration
  - Mechanical motion =>*Dn=1*
  - Enables many applications including fiber switches
- What are the problems?
  - Optical quality, Scaling, Speed, Packaging, Reliability

Traditional Bulk Micromachining

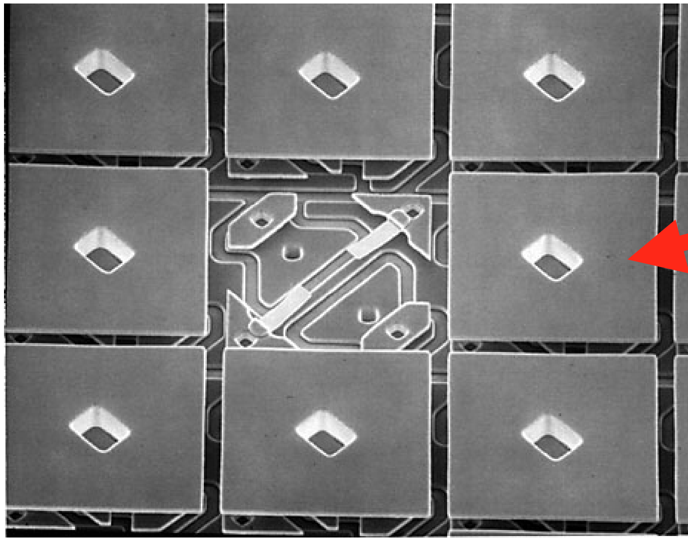
Courtesy: Microtechnology group, TU Berlin





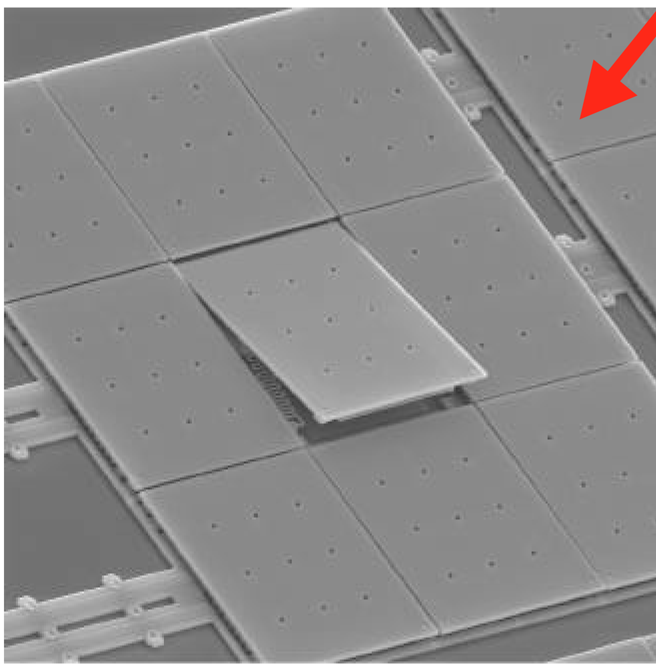


μMIRRORS

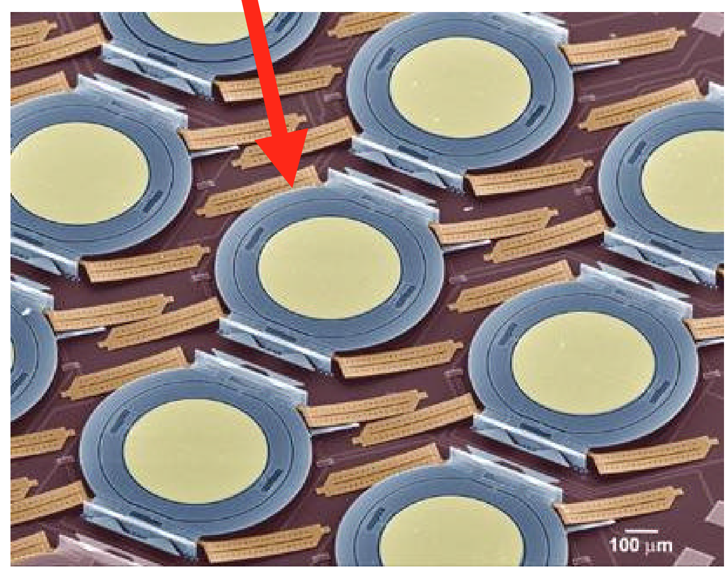


Texas Instrument’s DMD

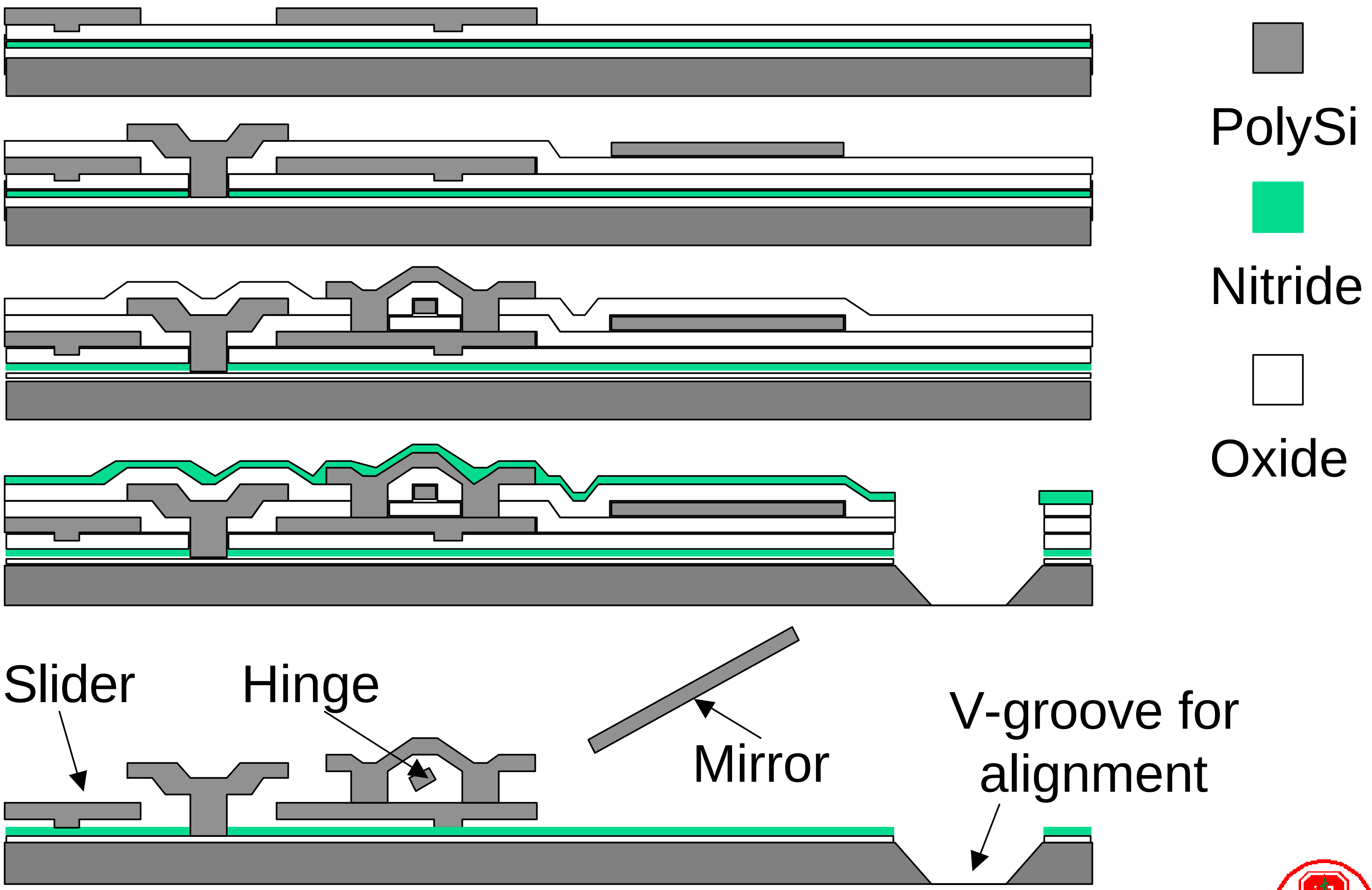
NASA's Next Generation Space Telescope (2008) with 4M micromirrors by Sandia NL



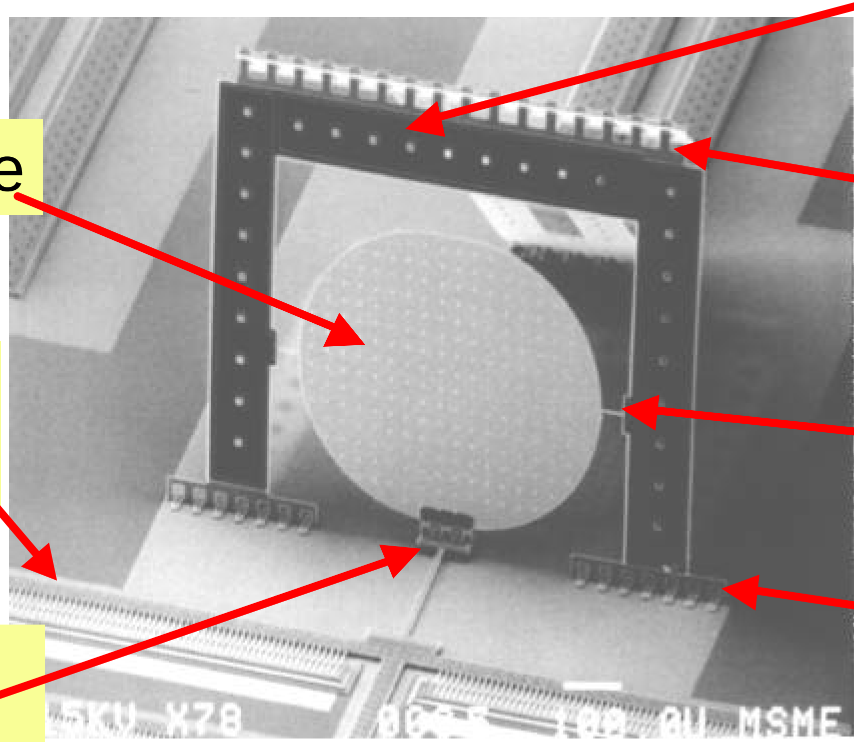
Lucent’s Optical X-Connect



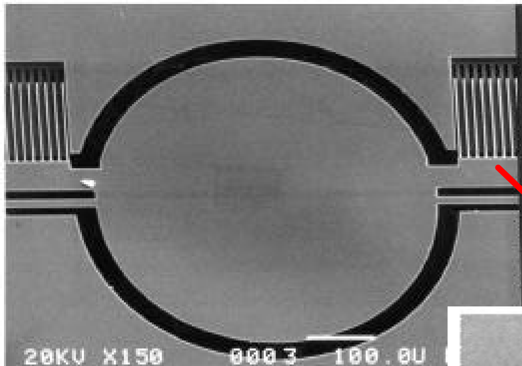
Surface Micromachining



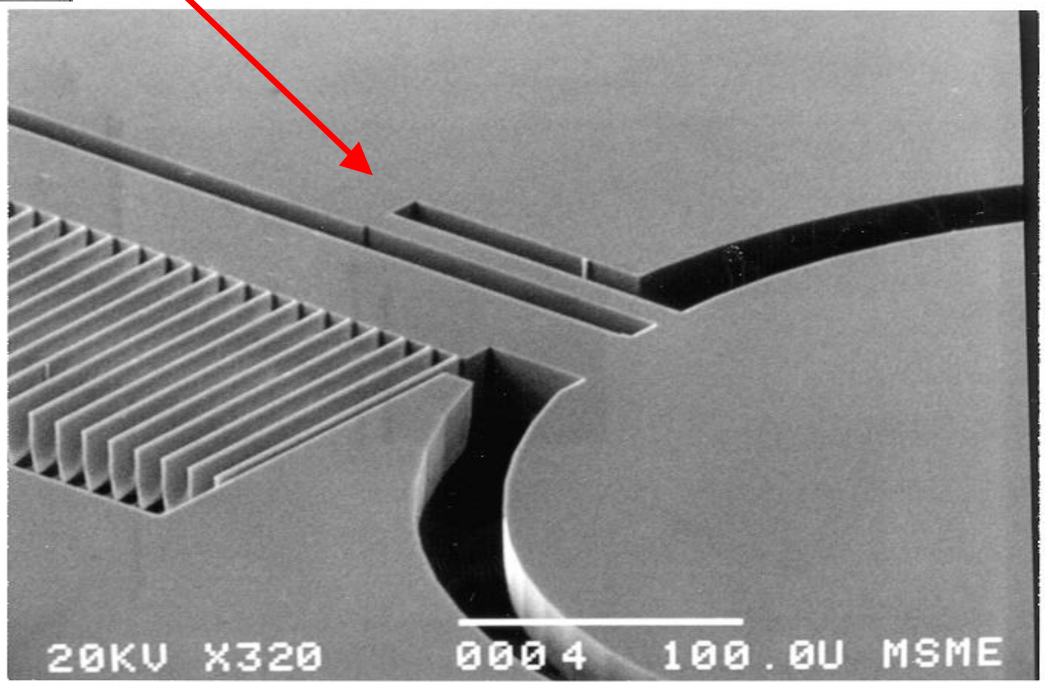
Surface Micromachined Mirror



DRIE of SOI materials



- Torsional mirror fabricated using DRIE of SOI

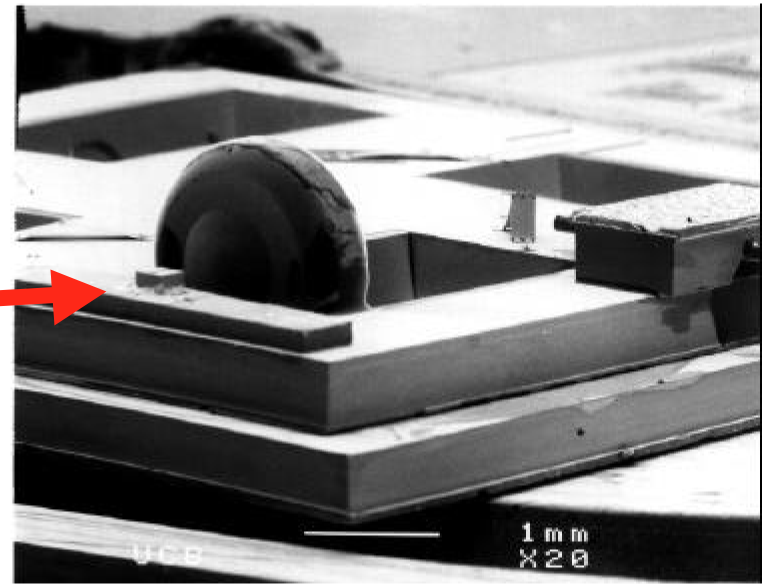


Courtesy Robert A. Conant, Berkeley Sensors and Actuator Center

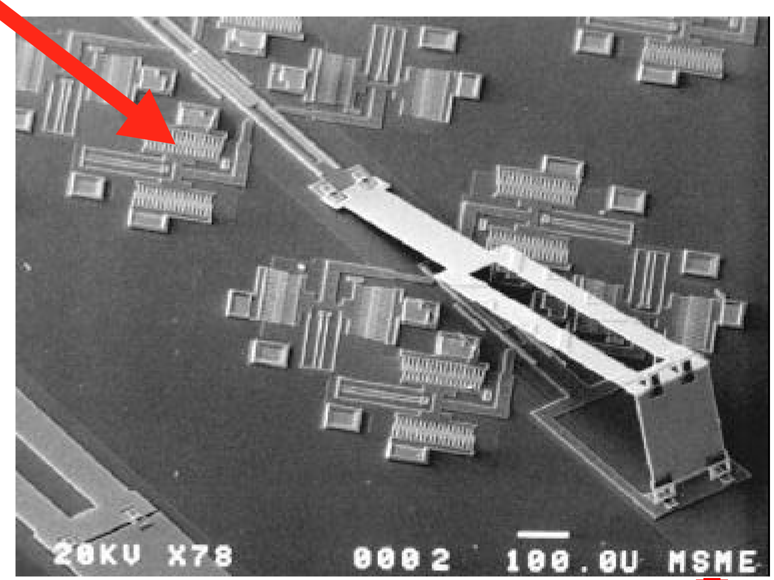
Integration

System on a chip

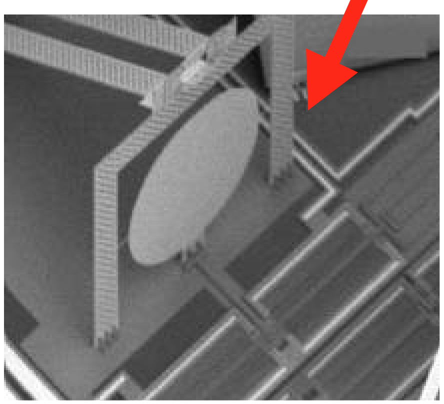
Laser-to-fiber coupling

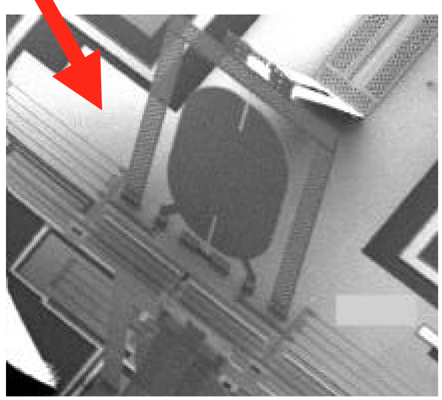


Micropositioners for mirrors and gratings



High-resolution raster scanner





Microactuators

	Force	Speed	Throw	Supply	Compatibility	Repeatability	Function
Piezo-electric	+	+	-	V	-	+	C
Magnetic	+	-	+	I	-	+	C
Thermal	+	-	+	I	+	-	A
Surface tension	+	-	+	T	+/-	-	A
Electro-static	-	+	+/-	V	+	+	C/A

Parallel-Plate Electrostatic Actuator

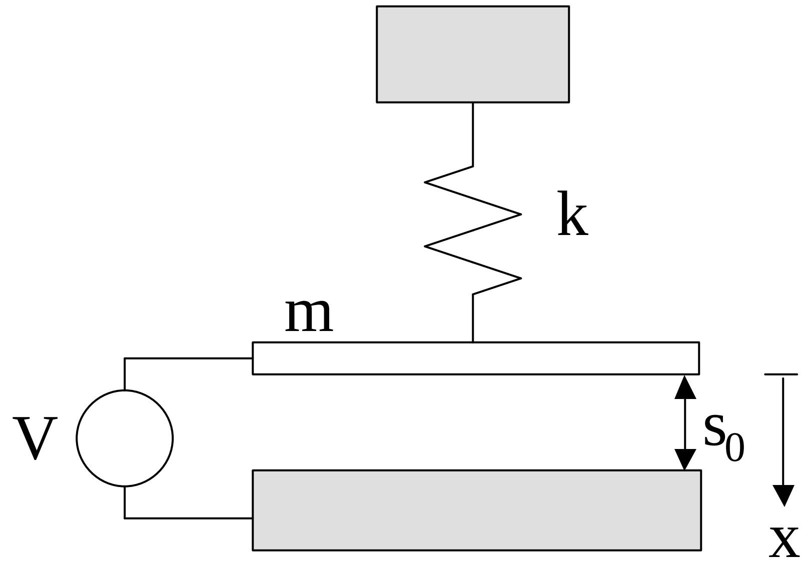
Electrostatic instability

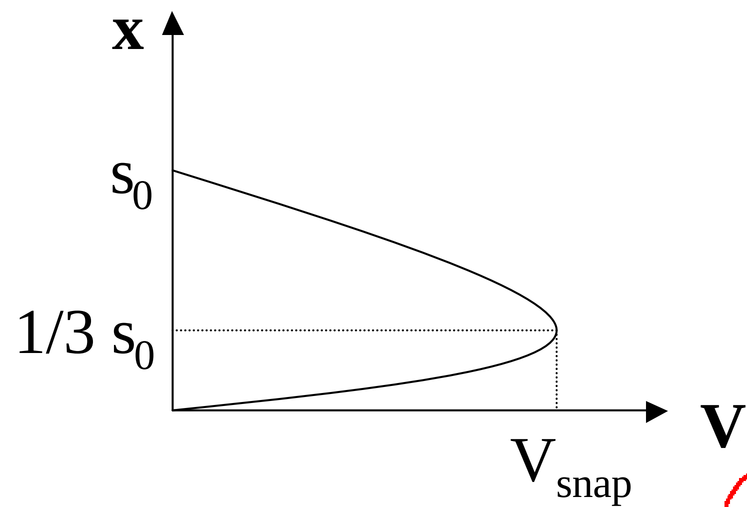
$$F = \frac{e_0 V^2}{2(s_0 - x)^2} = kx \Rightarrow$$

$$V = \sqrt{\frac{2kx}{e_0}}(s_0 - x)$$

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

$$V_{snap} = \sqrt{\frac{8ks_0^3}{27e_0}}$$





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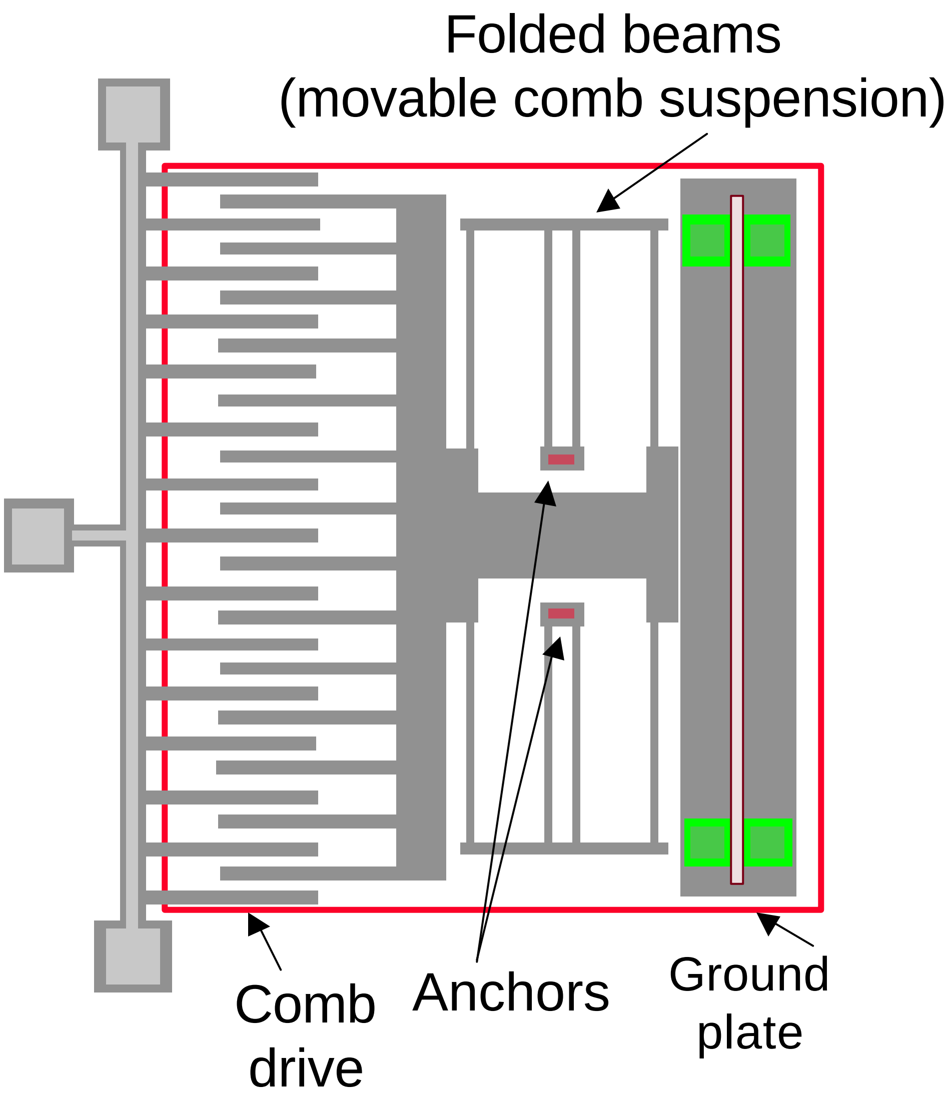
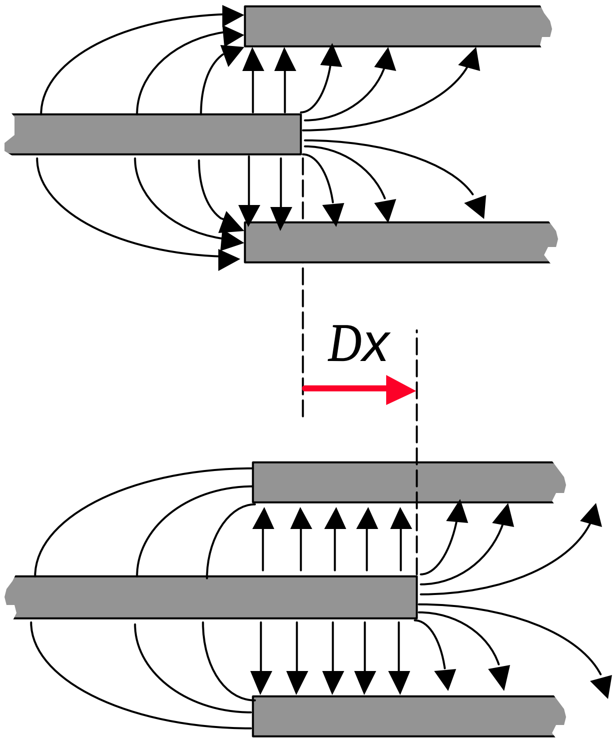
Electrostatic-combdrive





Electric field distribution
in comb-finger gaps

Combdrive vs. parallel plate

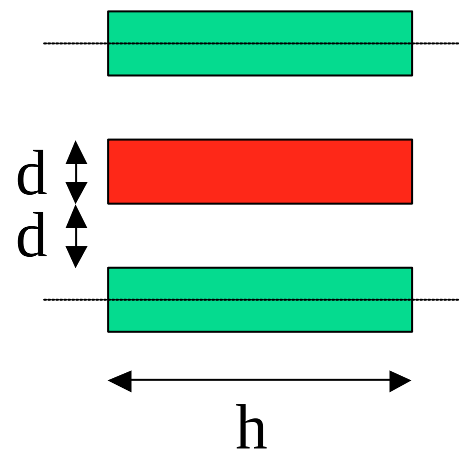
$$\text{Combdrive}: \; F_{cd} = \frac{N\varepsilon_0 h V^2}{d}$$

$$\text{Parallel plate}: \; F_{pp} = \frac{A_{pp}\varepsilon_0 V^2}{2s^2}$$

$$A_{cd} = 4Ndh \Rightarrow F_{cd} = \frac{A_{cd}\varepsilon_0 V^2}{4d^2}$$

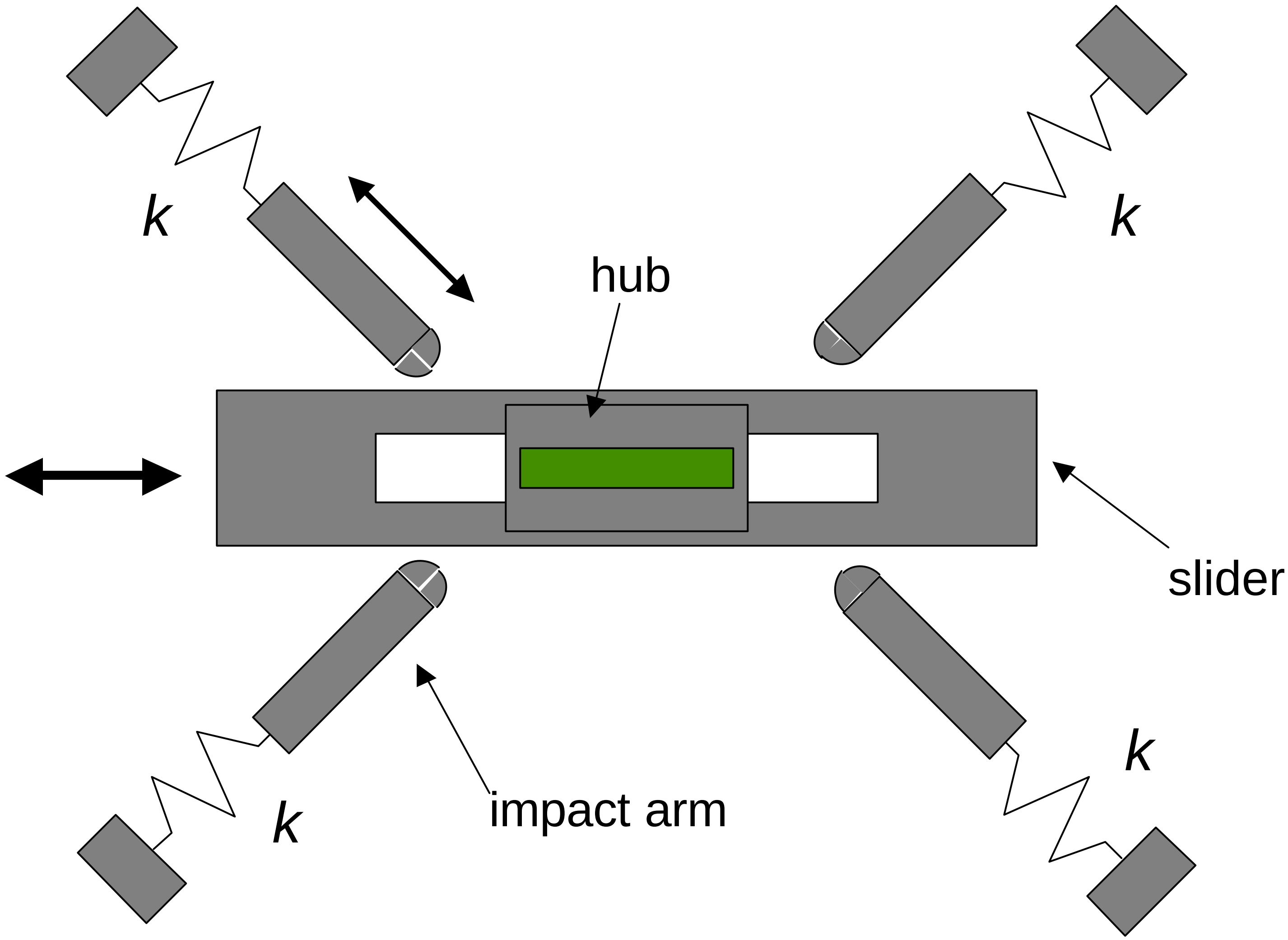
$$\boxed{\frac{F_{cd}}{F_{pp}} = \frac{s^2}{2d^2} = \frac{9}{2}\frac{throw^2}{linewidth^2}}$$

End view

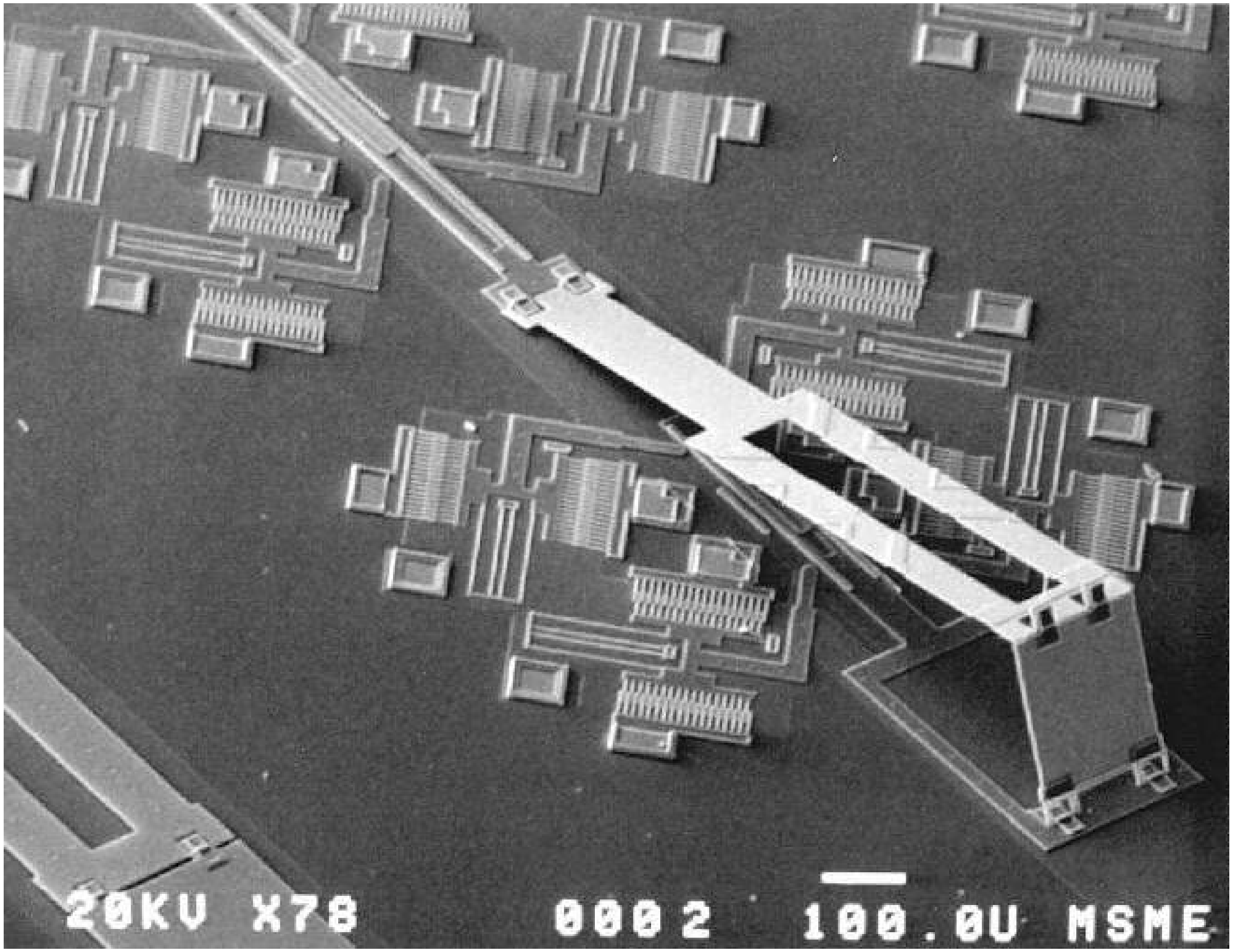


A_{cd}=4Ndh

Vibromotor (concept)



Vibromotor-Actuated Micromirror

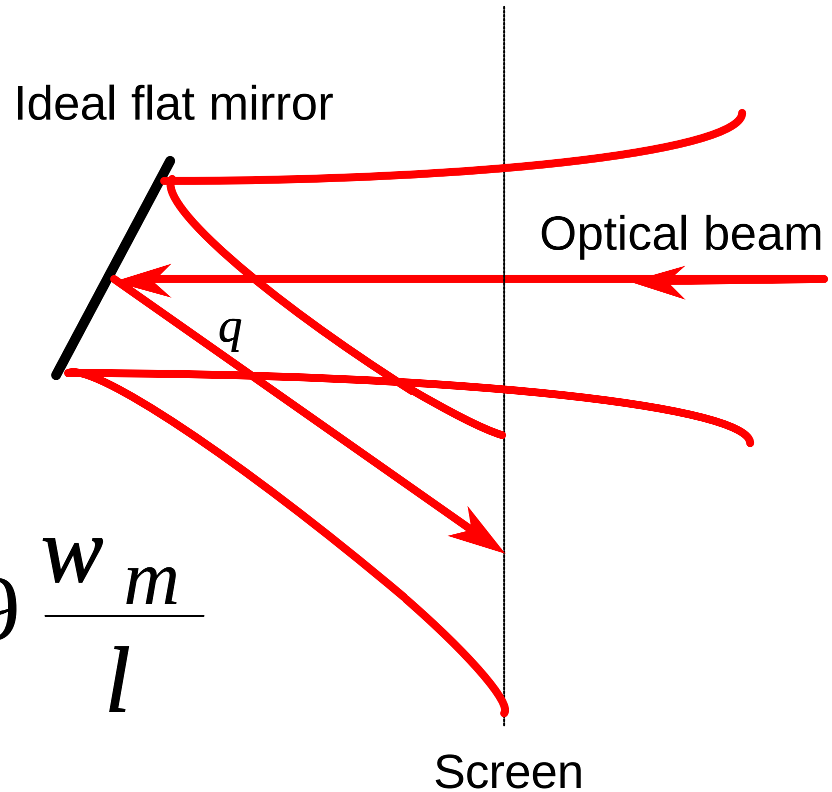


Scanning Resolution

For a transverse Gaussian profile on an ideal flat, infinite mirror, the pixel count is:

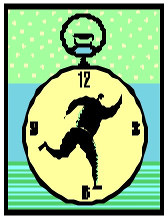
$$N = \frac{qpw_m}{1.18\, l}$$

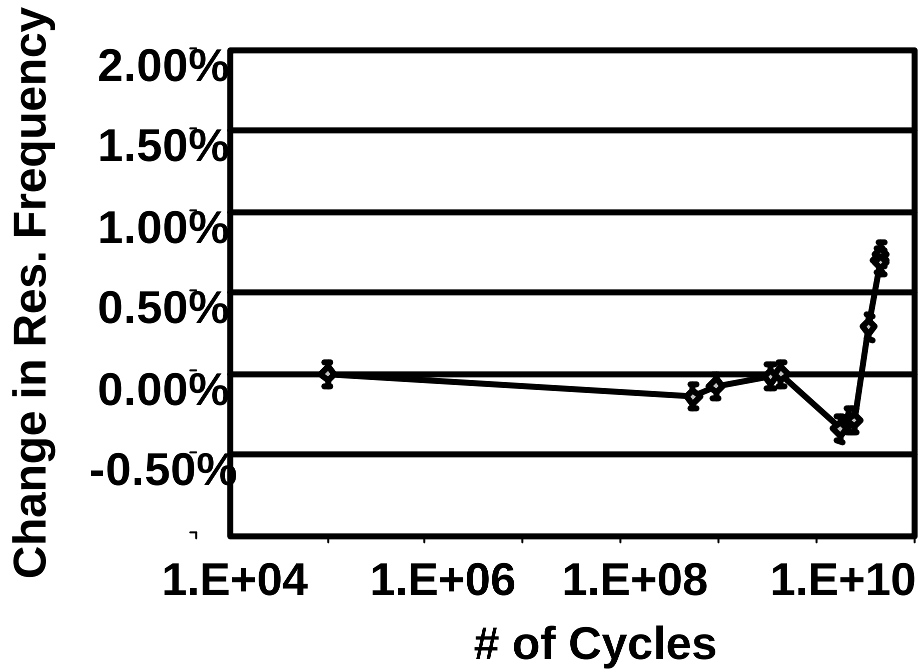
$$\approx \frac{0.35 \cdot p}{1.18} \frac{w_m}{l} \approx 0.9 \frac{w_m}{l}$$

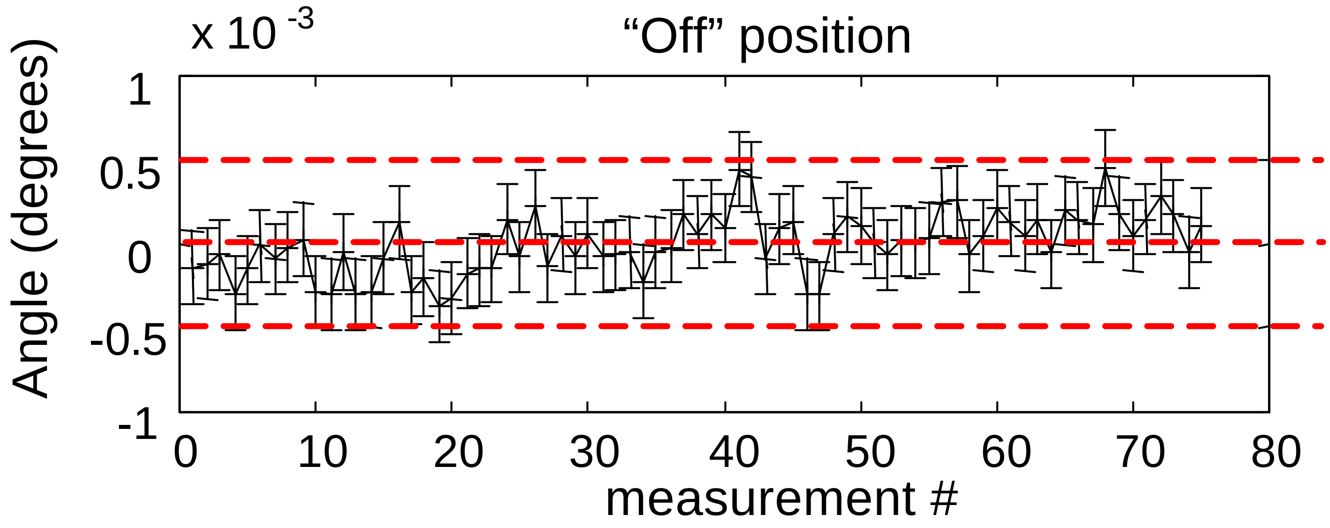


Mirror curvature and the aperture effect reduce the resolution below this value.

Micromirror Reliability







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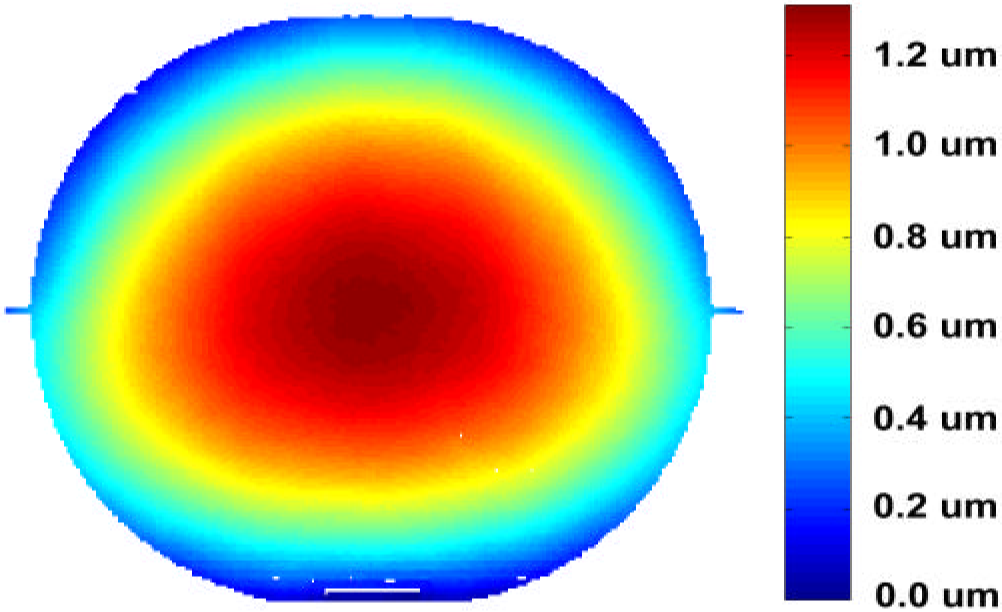
Mirror Curvature Measurement

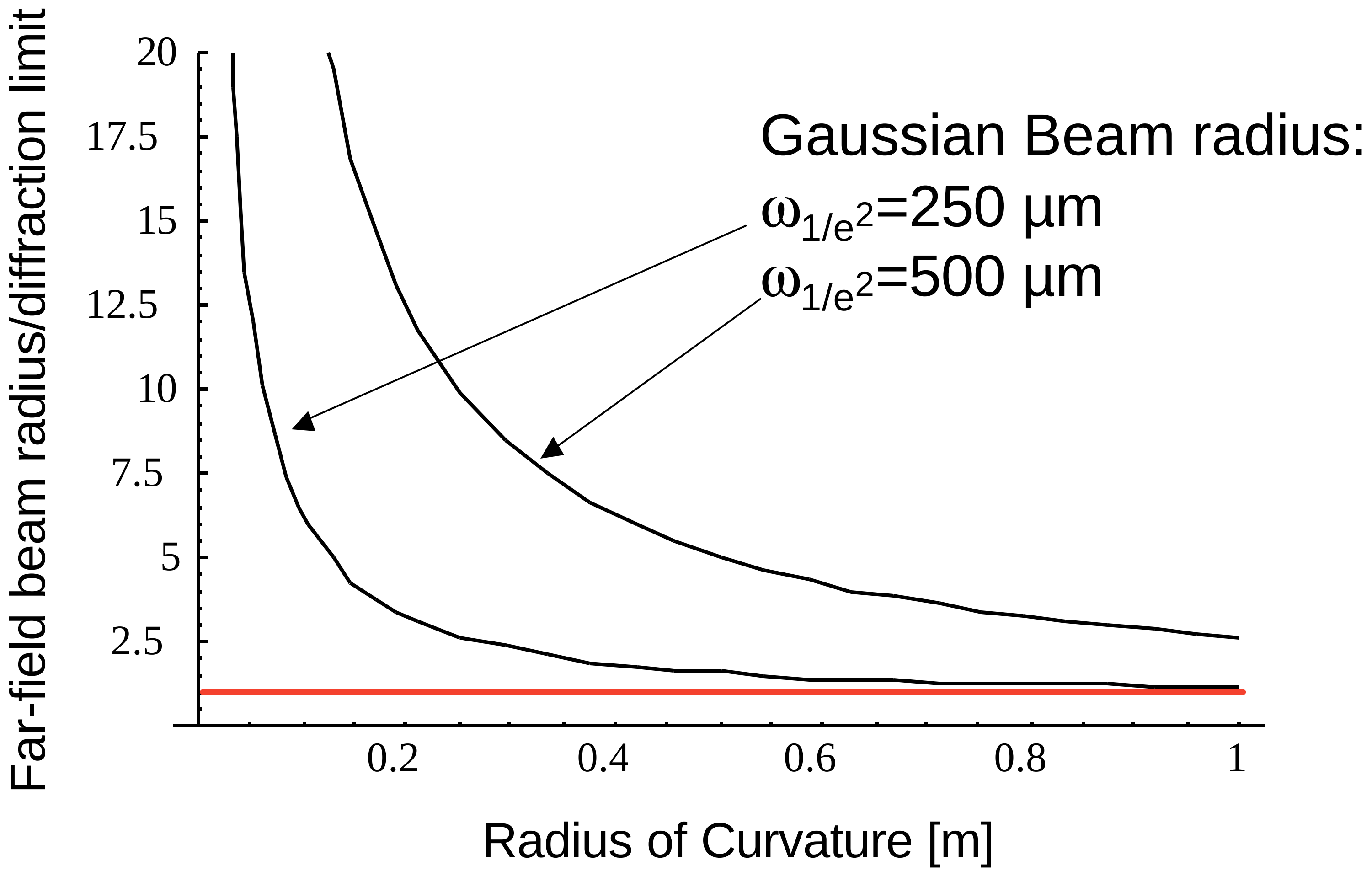
- **2-D Interferometry**
- **Optical far-field measurements**

MUMPS Poly2



Static deformation 1.2 µm

Mirror Curvature => Reduced resolution



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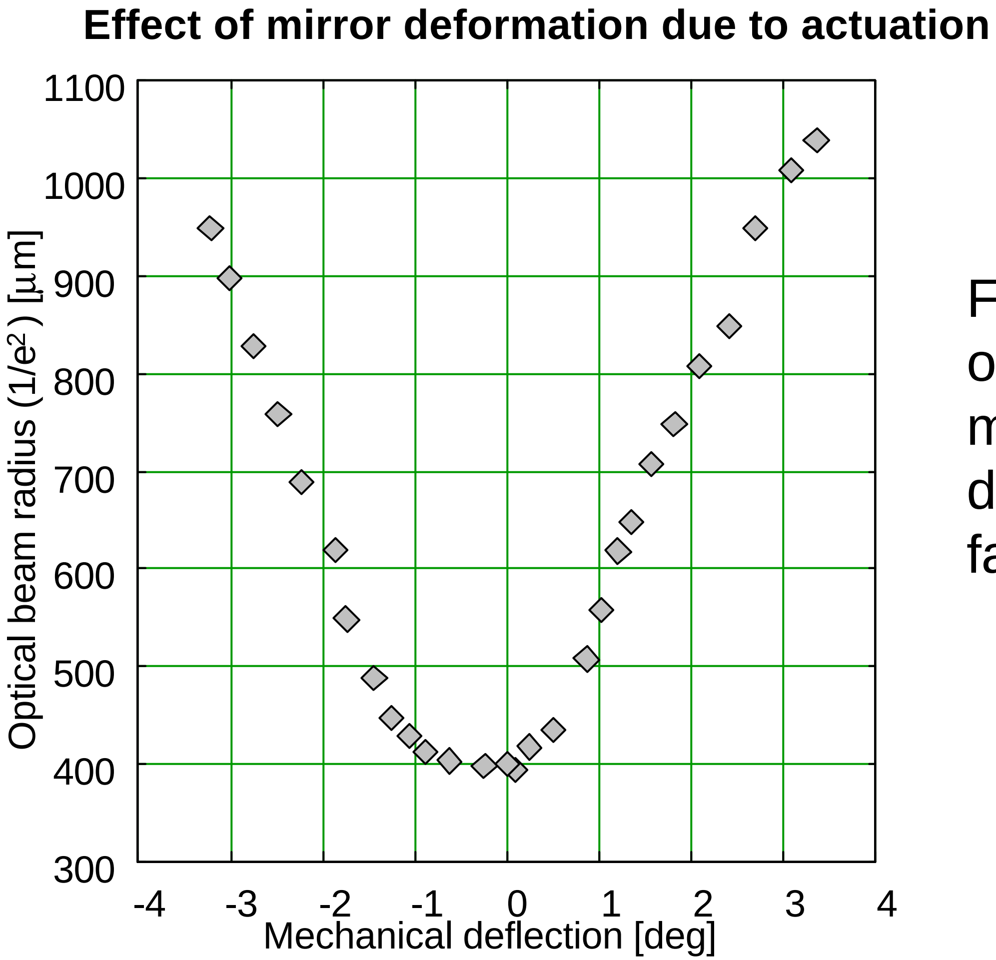
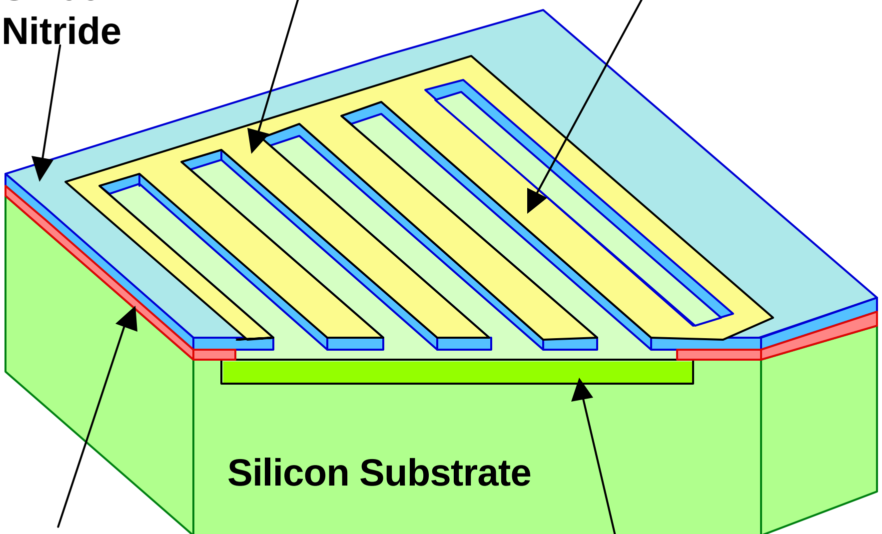
Mirror curvature due to actuation

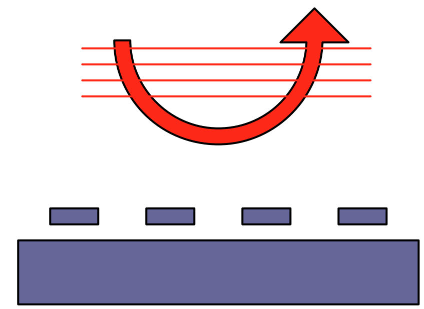


Forces coupled into the optical surface of the mirror by the comb-drives can increase the far-field optical beam size.

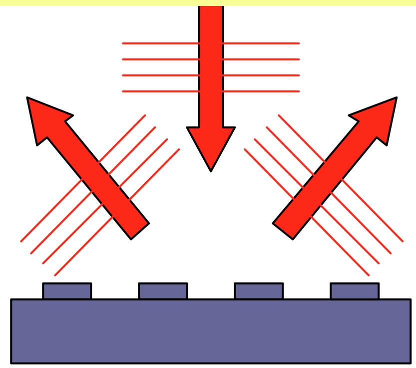
Grating Light Modulator



Beams up, reflection



Beams down, diffraction



Cross section

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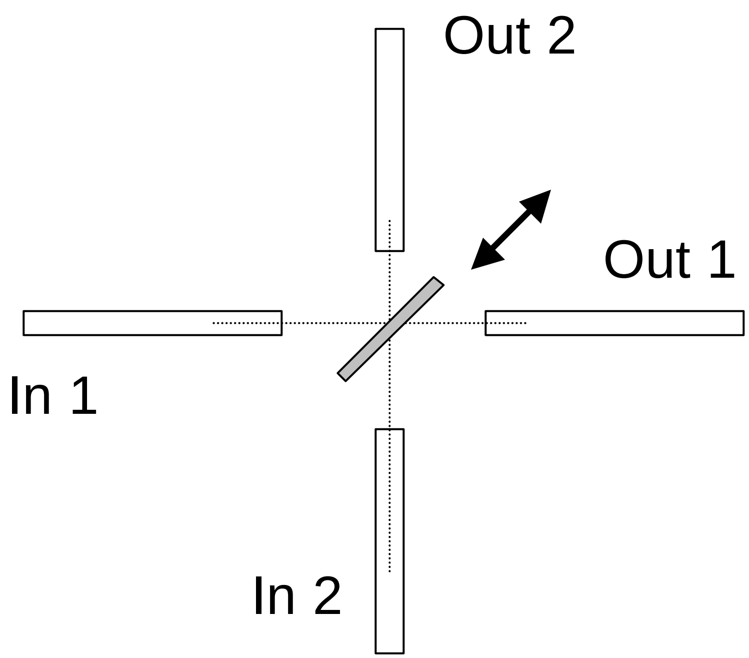
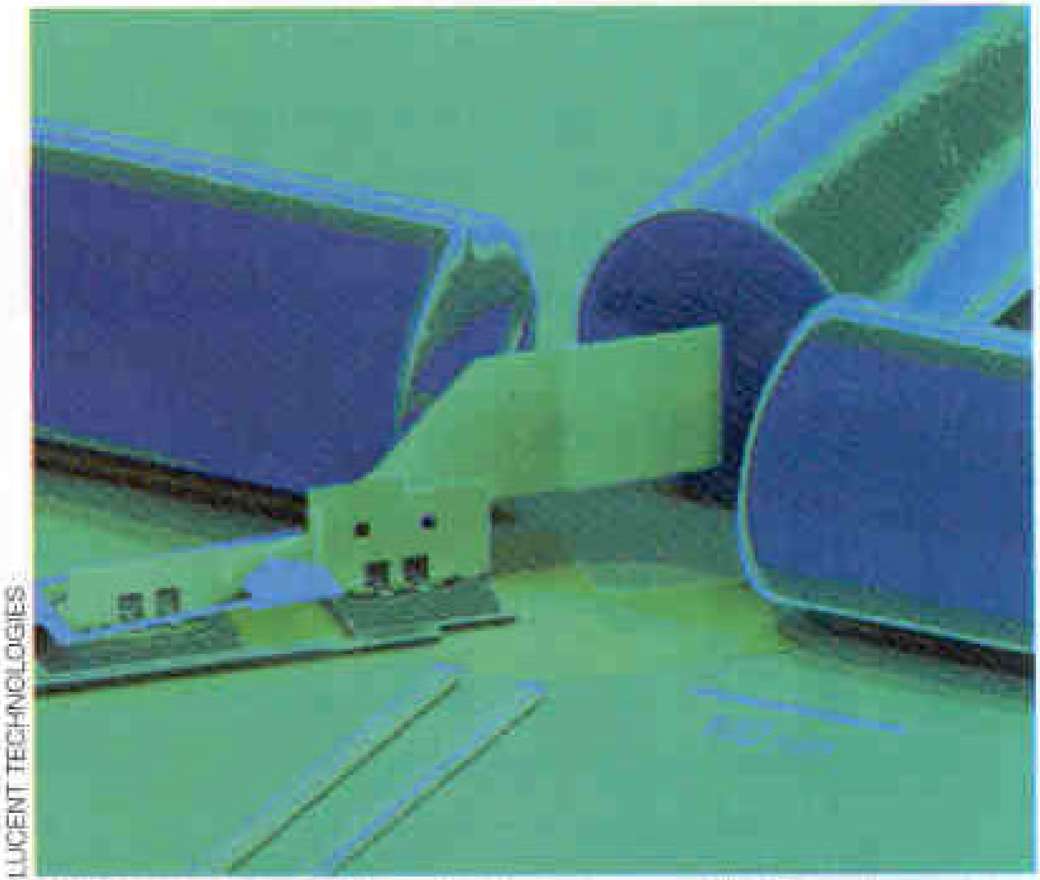
2 x 2 fiber-optic switch



- Compact design
- One-mask fabrication using DRIE on SOI
- Integration of fibers, lenses, and micromirrors
- 2 by 1 operation
- By-pass switch
- AT&T, JDSU......

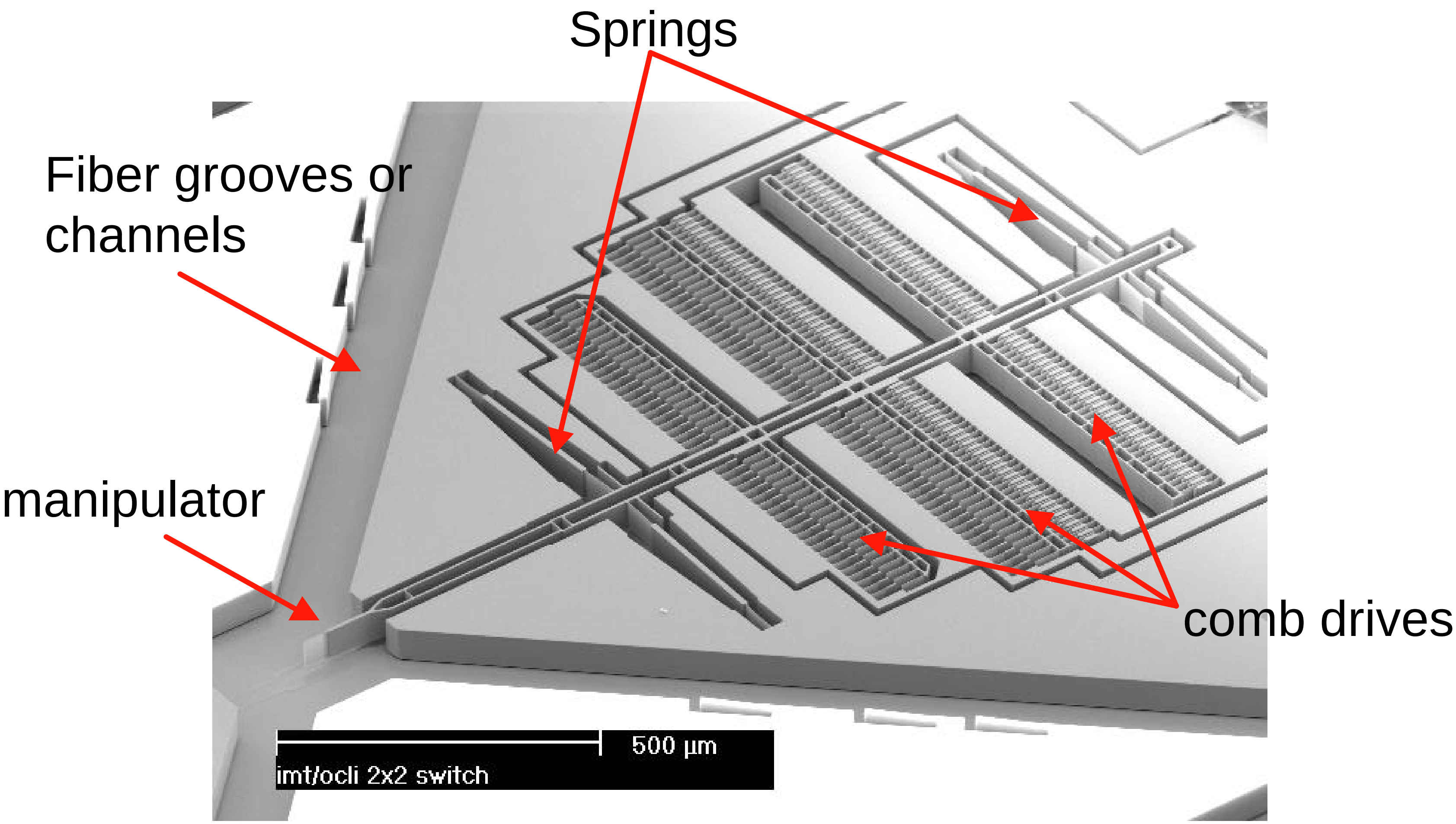
1 x 2 Matrix Switch



LUCENT TECHNOLOGIES

FIGURE 1. This 1 × 2 MEMS optical switch can route light from the input fiber to one of two output fibers.

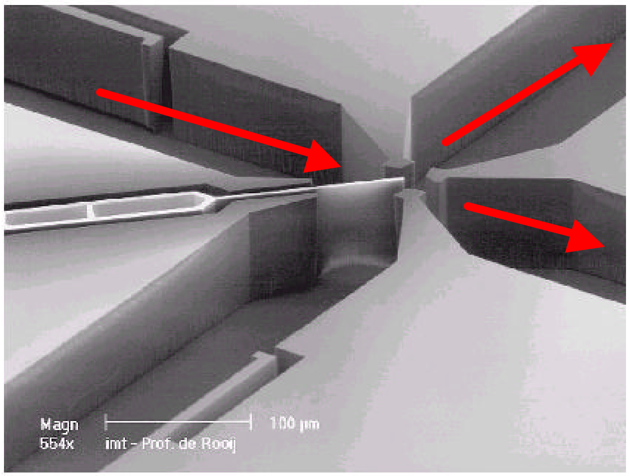
μactuators – Electrostatic Combdrives



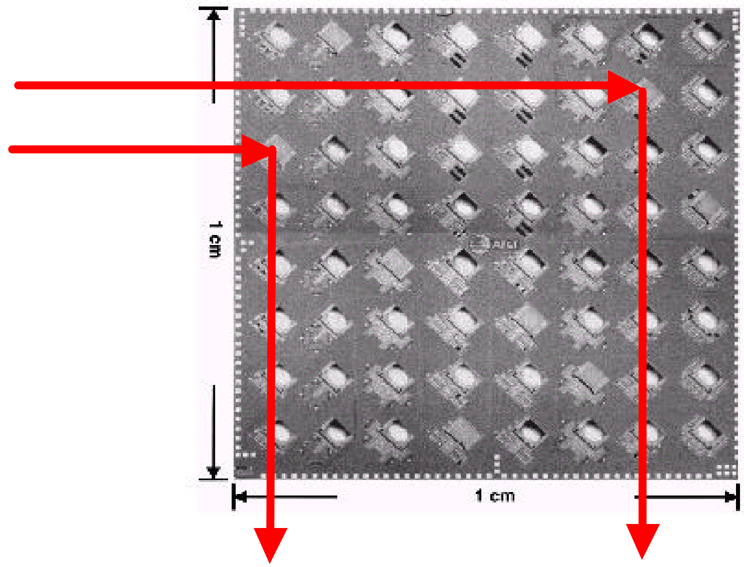
Bryant Hichwa etal, OCLI/JDS Uniphase, "A Unique Latching 2x2 MEMS Fiber Optics Switch", Optical MEMS 2000, Kauai, August 21-24th, 2000.

MEMS-based OXC switches

2X2 Fiber-optic switch [1]



8x8 Fiber-optic switch [2]

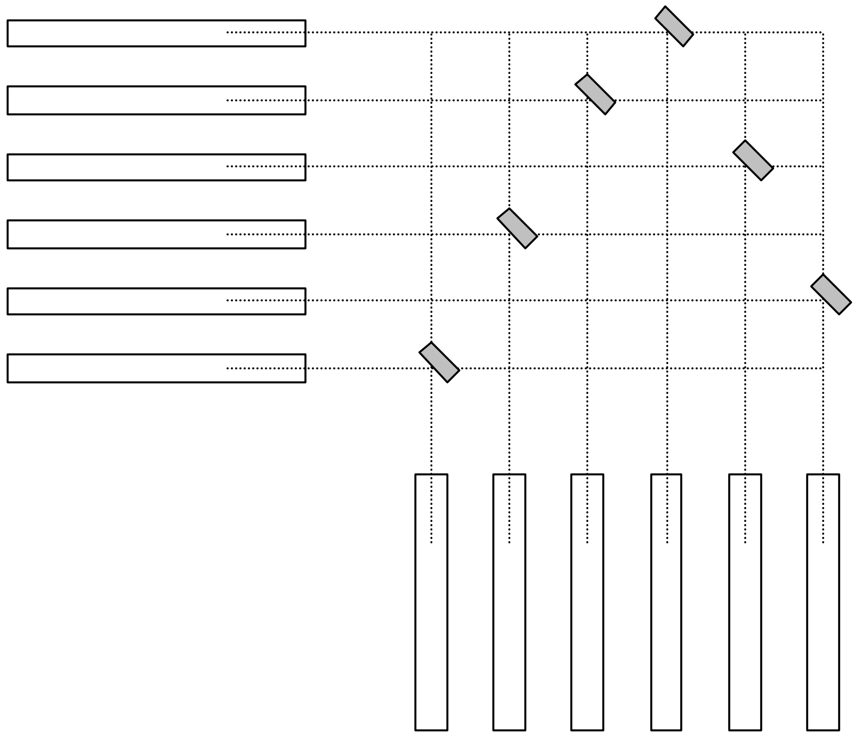


- *Some issues:*
  - **Switch scalability with minimum insertion loss**
  - **Large device count**
  - **Non-standard fabrication processes**
  - **Actuator reliability problems**

[1] C. Marxer, N.F. de Rooij, Jrnl of Lightwave Tech., Vol. 17, No. 1, Jan 1999

[2] L.Y. Lin, E.L. Goldstein, R.W. Tkach, Jrnl of selected topics in Quantum Electronics, Vol. 5, No. 1, Jan 1999

NxN Matrix OXC



- Simple 1 by 2 cross-points
- Digital mirrors
- N^2 scaling
- Large motion
- Reliability??
- OMM, Onix, AT&T, Agilent.....

Scaling of NxN Matrix OXC

$$s = N \cdot k\omega_l =$$

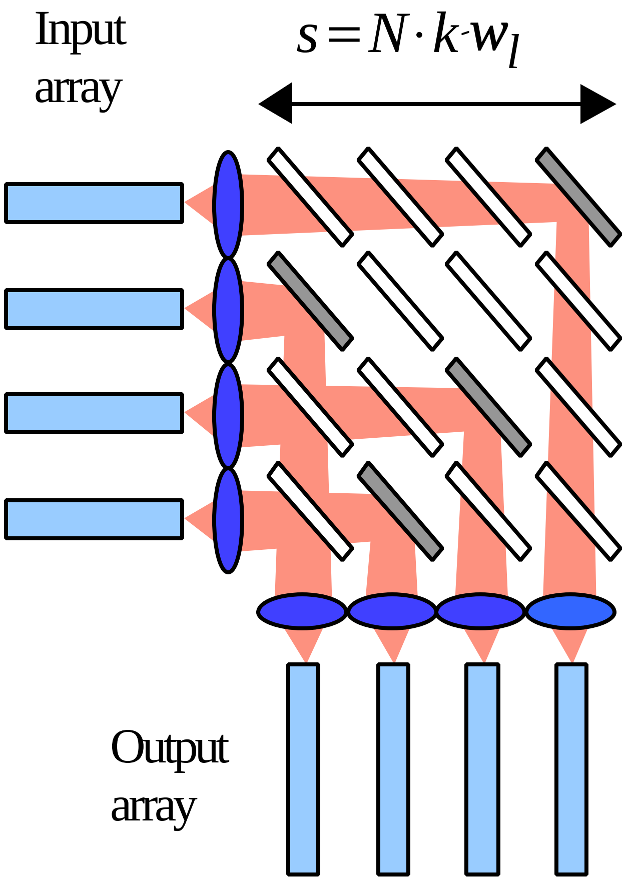
$$N \cdot k\omega_0 \left[1 + \left(\lambda s / \pi\omega_0^2\right)\right]^{1/2}$$

$$\Rightarrow N = \frac{s}{k\omega_0 \left[1 + \left(\lambda s / \pi\omega_0^2\right)\right]^{1/2}}$$

$$\Rightarrow N_{max}(s) = \frac{1}{k}\sqrt{\frac{\pi s}{2\lambda}}$$

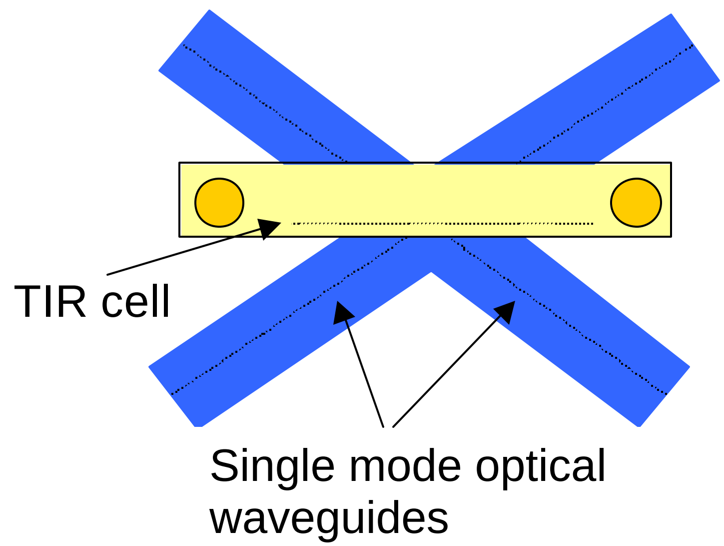
$$\Rightarrow s = \frac{2N^2 \cdot k^2 \lambda}{\pi} =$$

$$\frac{N^2 \cdot 50 \cdot 1.55\mu m}{\pi} \approx N^2 \cdot 25\mu m$$

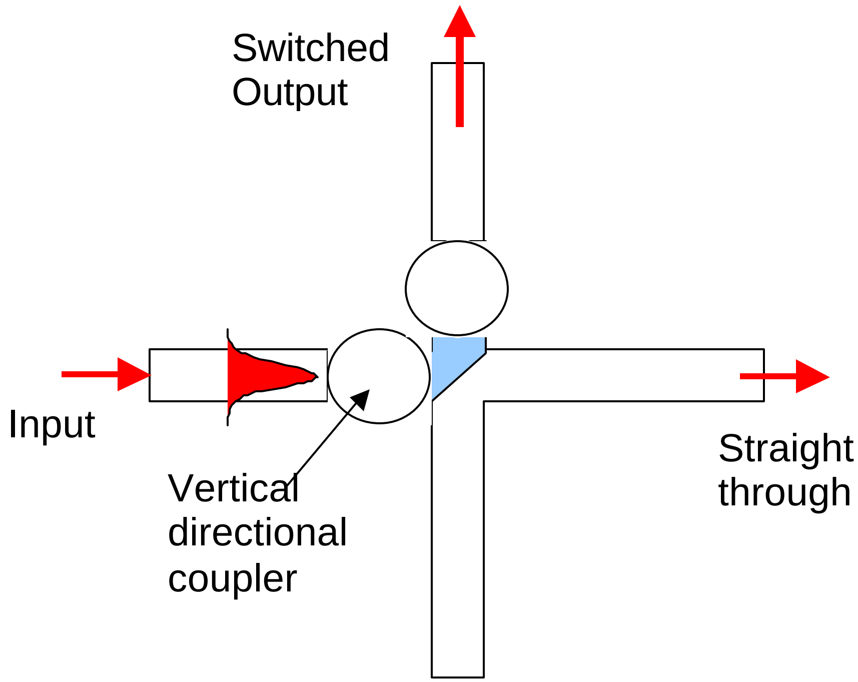


Non-dispersive switches

Champagne Switch (Agilent)

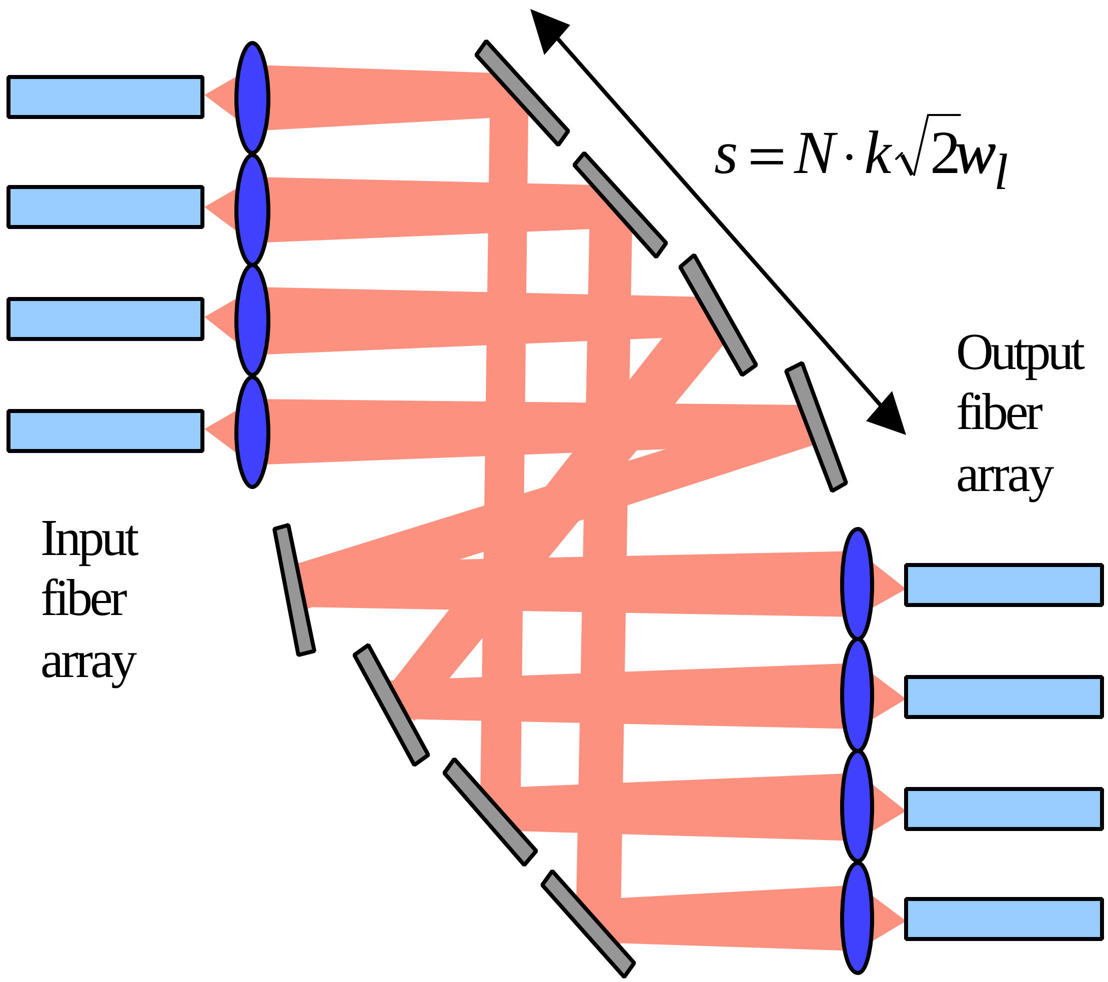


Vertical Directional Coupler[3]



[3] S. Yu, M. Owen, R. Varrazza, R.V. Plenty, I.H. White, "High speed optical packet routing demonstration of a vertical coupler cross point switch array", Proceedings of the Conference on Lasers and Electro-optics(CLEO), San Francisco, May 7-12, 2000, pp. 256-257

Beam Steering Optical Switch



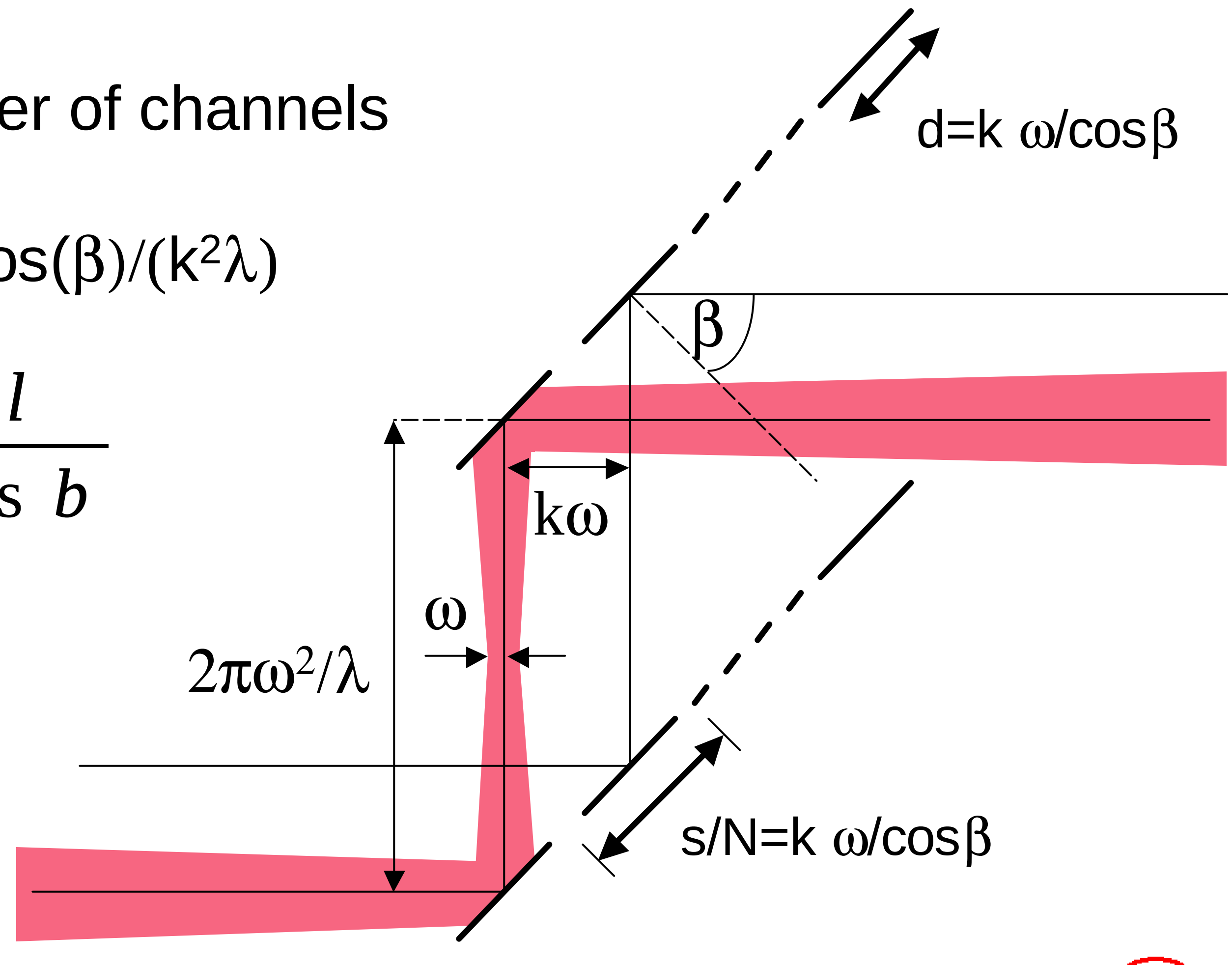
- Analog mirrors
- 2N scaling
- Lucent, C-speed, Xros(NT),.....

Scaling of Beam Steering Switch

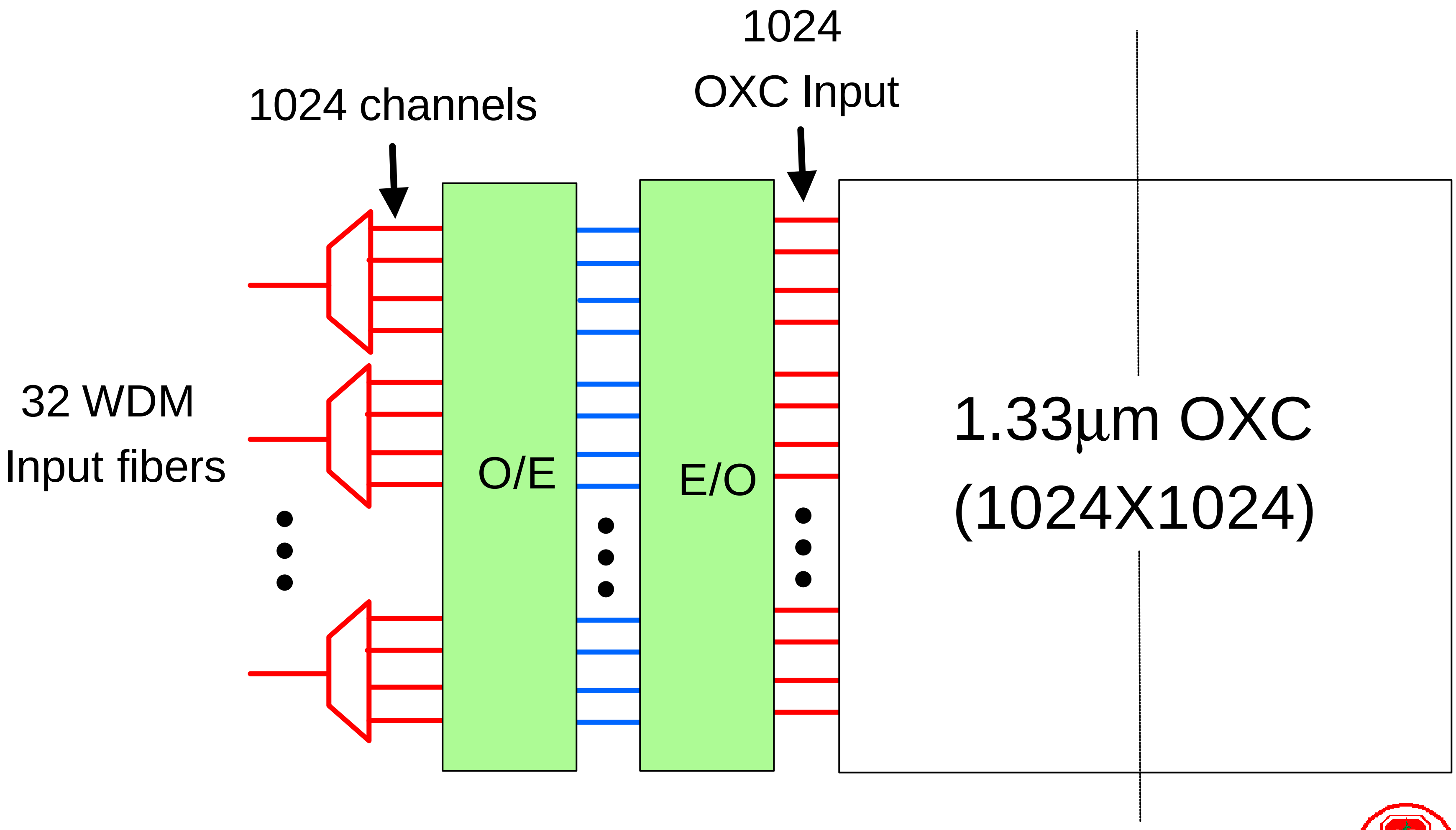
Maximum number of channels
(Small angles):
$N_{1\text{-}D}$=1+8π·d·θ·cos(β)/(k²λ)

$$s = \frac{N^2 \cdot k^2 l}{8p \cdot q \cdot \cos b}$$

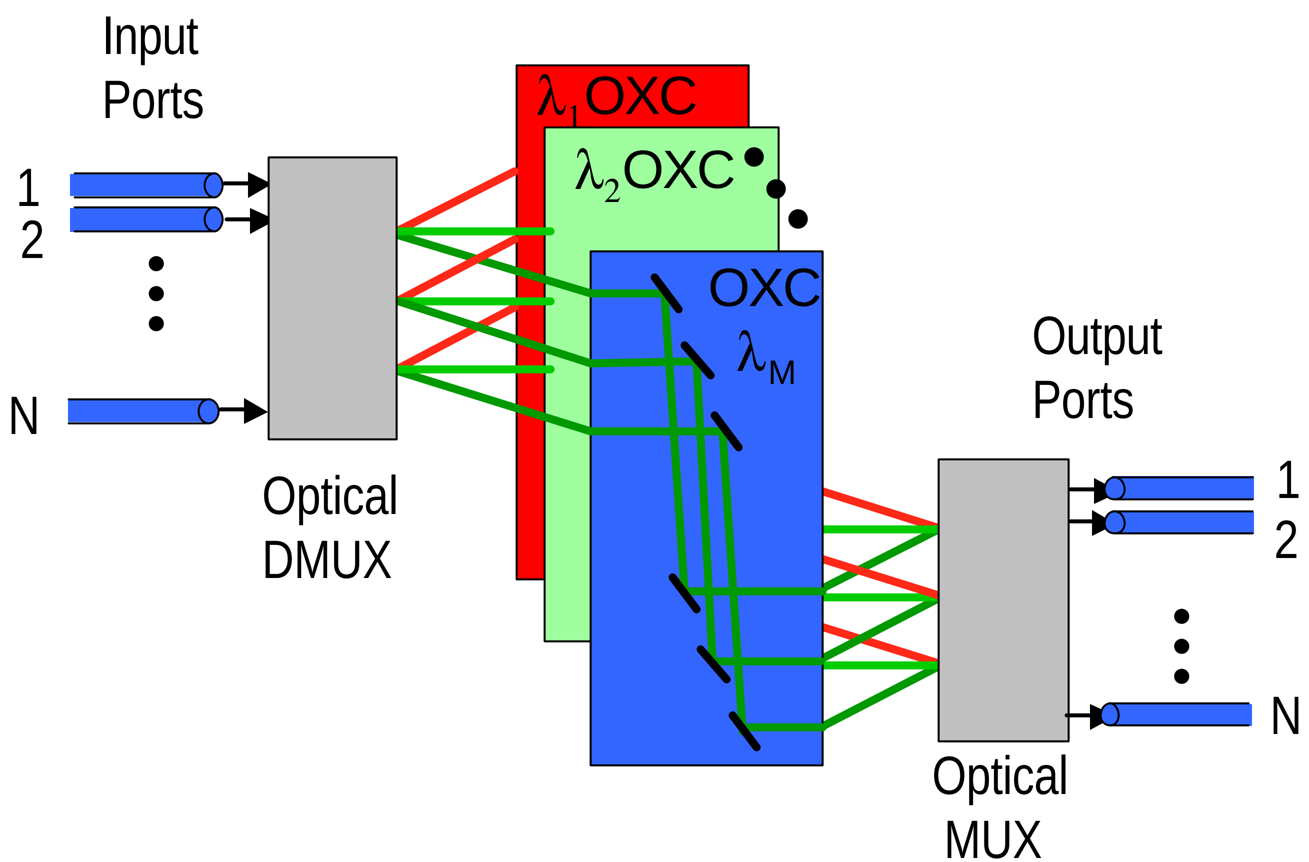
$$\approx N^2 \cdot 10\,mm$$



Why do we need large switches?



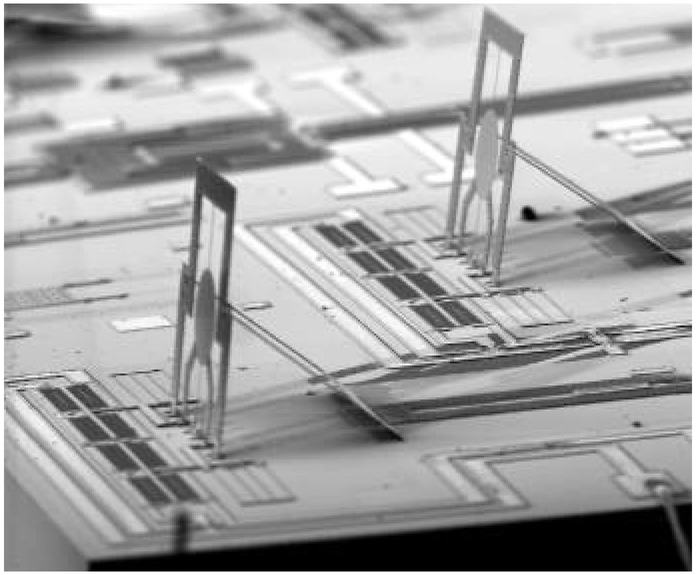
WDM Crossbar Switch

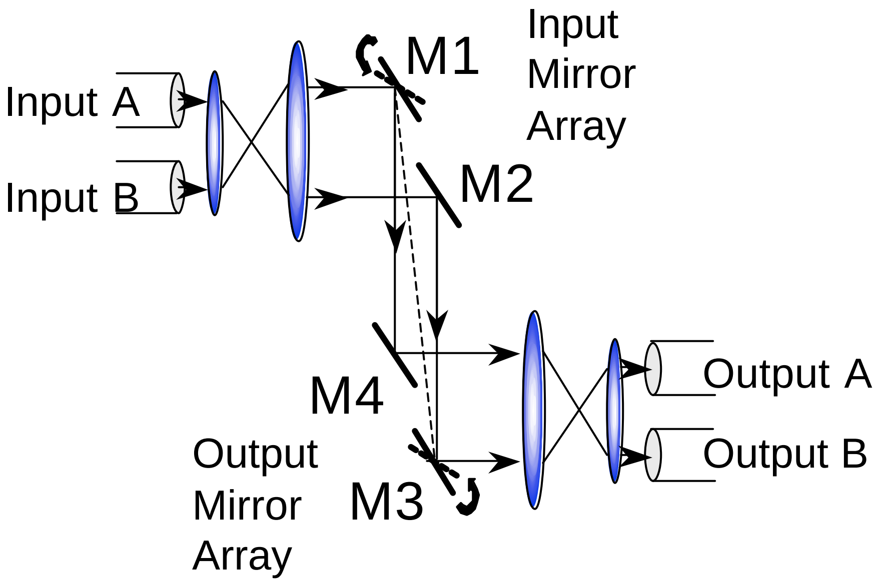


Architecture of WDM Switch

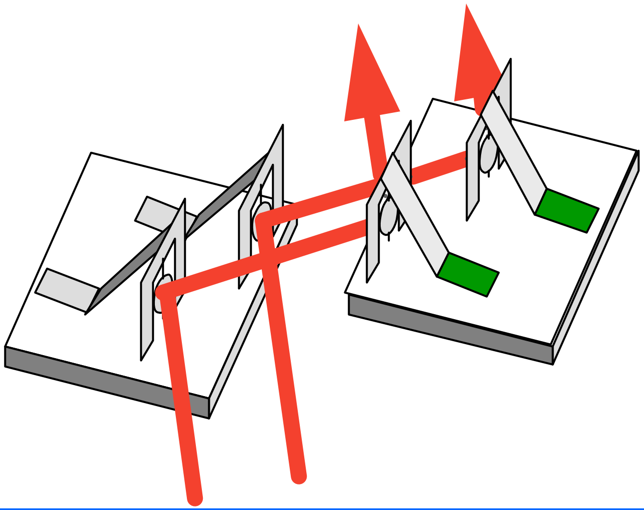
The optical input signals are demultiplexed, and each wavelength is routed to an independent *NxN* spatial cross-connect

2x2 Beam Steering Switch Demonstration *



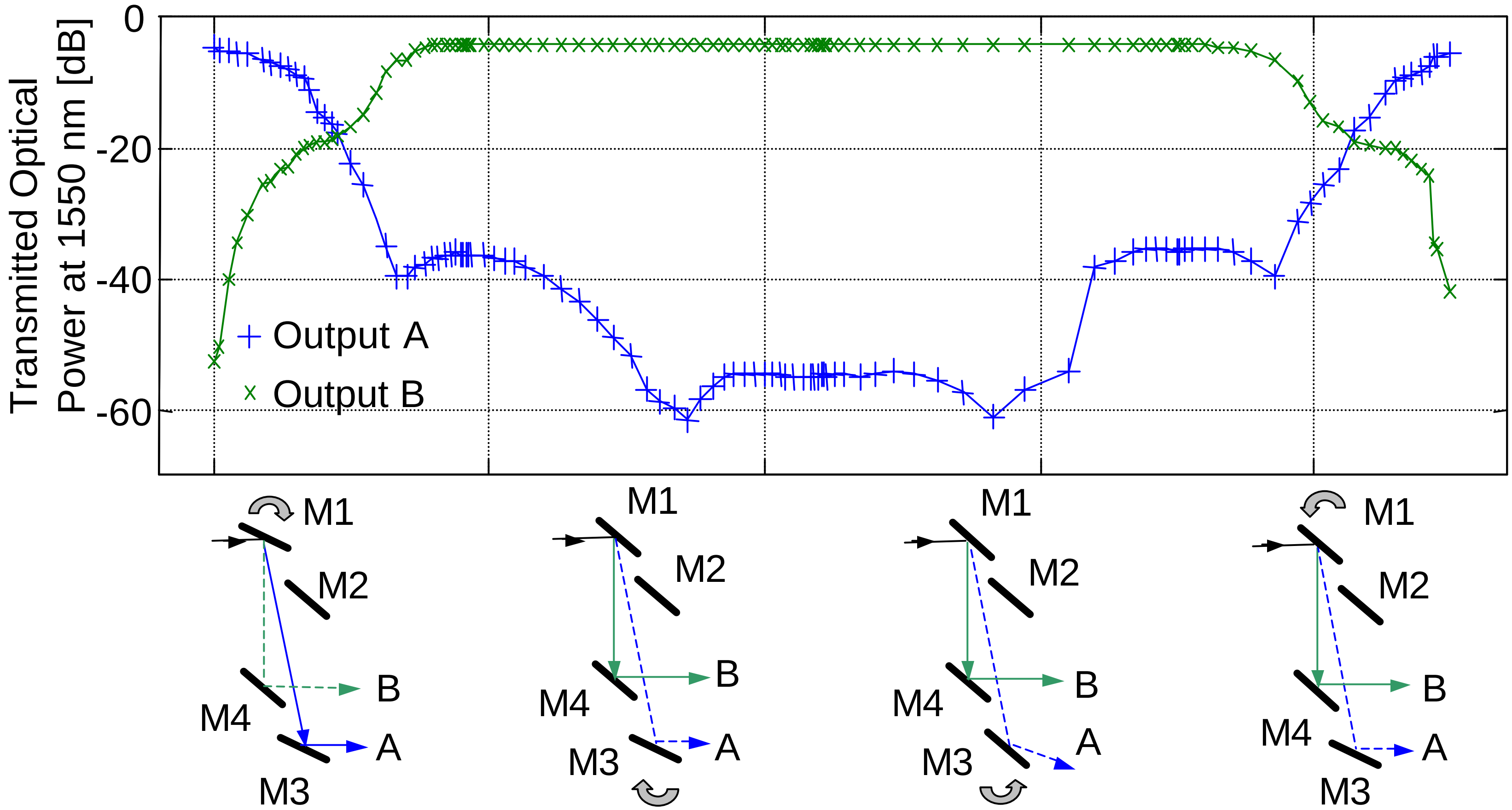


*P.M. Hagelin, U. Krishnamoorthy, et. al, paper published in *Photonics Technology Letters*, July 2000.



- Silicon micromachined v-grooves
- 1.55µm diode laser source
- Comb-drive actuated mirrors
- Bulk optics for optical field scaling
- -4.2 dB measured insertion loss
- -54 dB measured cross-talk

Switching Characteristics



M1: 21.65V to 0V
M3: 25.52V

M1: 0V
M3: 25.52Vto 0V

M1: 0 V
M3: 0Vto 25.52V

M1: 0V to 22.24V
M3: 25.52V

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Conclusion

- Motivation for O-MEMS
  - **Miniaturization, integration, parallel processing => Microsystems**
- Micromachined optical switches
  - **Wavelength independent architecture**
  - **2N mirrors for NxN matrix (yield)**
  - **Standardized foundry fabrication process**
- Challenges
  - **Optical quality, large switches, reliability, speed**
- Micromachining is an enabling technology
  - **Optical communication, displays, fiber switches, data storage, barcode readers, femtosecond laser-pulse shaping, optical coherence tomography, adaptive optics, external cavity lasers, printing, vector scan, surveillance, optical interconnects, spectroscopy ......**

MEMS applications

- Sensor applications
  - **Pressure sensors**
  - **Accelerometers**
  - **Inkjet nozzle arrays**
  - **Temperature sensors**
  - **Displacement sensors**
  - **Gas sensors, …**
- Fluidics applications
- Some optical applications
  - **Adaptive optics**
  - **Free-space communication systems**
  - **External cavity laser tuning**
  - **Spectroscopy**
  - **Scanners (head mounted displays)**
  - **Optical cross-connect (OXC) switches, …**