2.76/2.760 Multiscale Systems Design & Manufacturing

Fall 2004

MOEMS

Sang-Gook Kim,
MIT

Devices for Optical communications system

Switches and micromirror for Add/drops

Diagrams removed for copyright reasons.

MOEMS

MEMS technology

- Arrayable
- Nano-scale precision
- Reconfigurable

VGA
SVGA
XGA
SXGA
UXGA:

Various kinds of Micromachined Switches

1x2 switch

Moving fiber switch

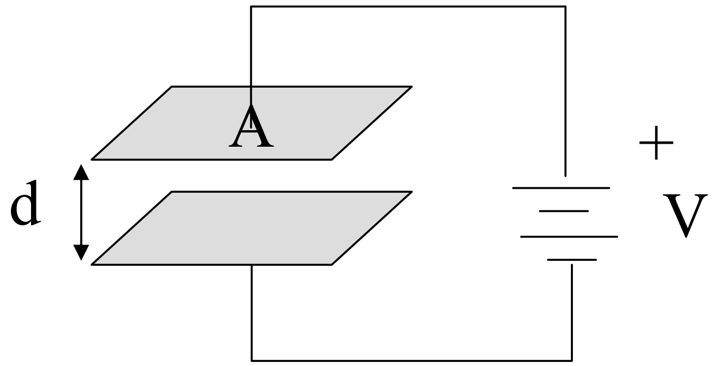
Diagrams removed for copyright reasons.

NxN switch

Arrayability

- Massive Parallel Array for display
- Texas Instrument’s Digital Micromirror Display, DLP (Digital Light Processing)
- Daewoo’s TMA (Thinfilm Micromirror Array)

Parallel Plate Electrostatic Actuator



$$C = \varepsilon A / d$$

$$F = -\nabla U(potential - energy) = \frac{\varepsilon A V^2}{2d^2}$$

$$F_{electrostatic} --> $$

$$F_{VanderWaals} = \frac{H}{6\pi} \frac{z_0}{d^3(d + z_0)}$$

$$F_{capillary} = \frac{2\gamma d_0 \cos\theta}{d^2}$$

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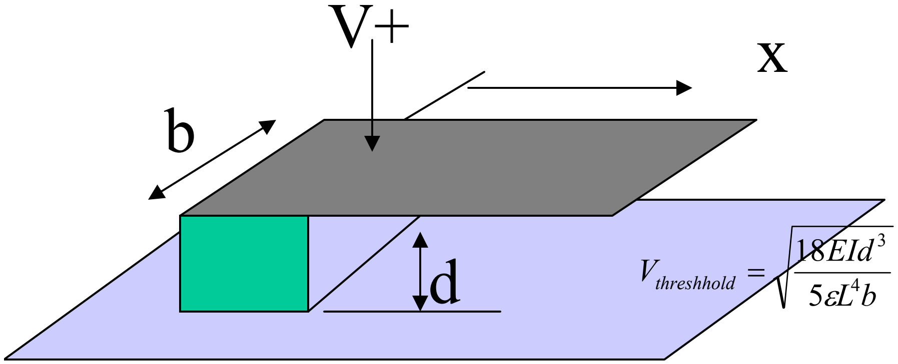
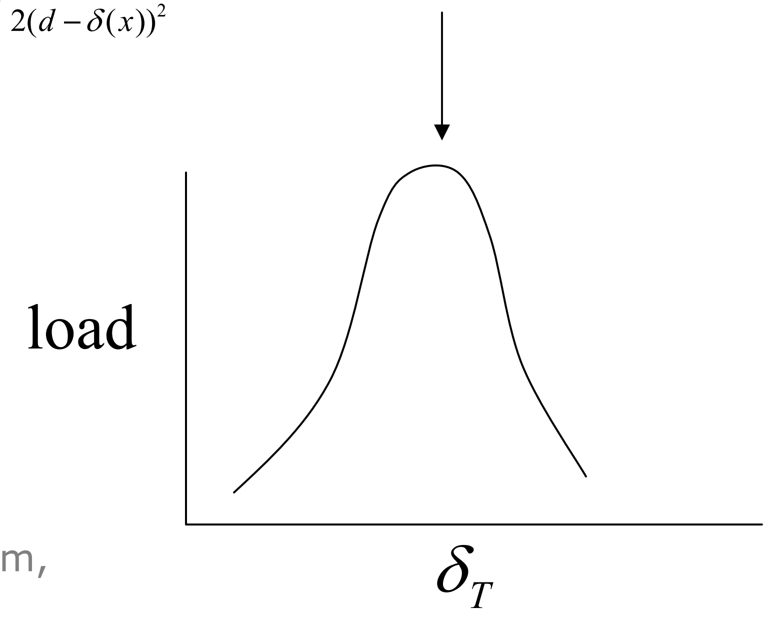
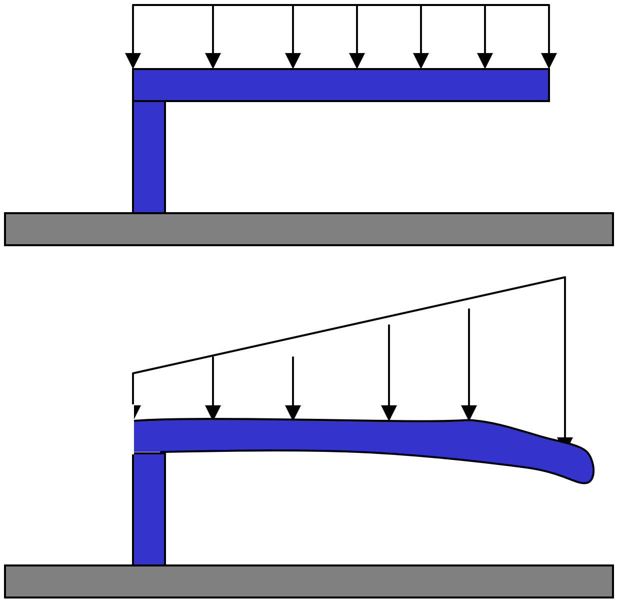
Cantilever Beam



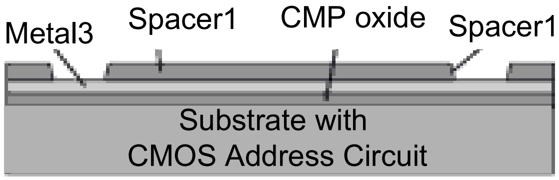
$$V_{threshhold} = \sqrt{\frac{18EId^3}{5\varepsilon L^4 b}}$$

$$F = \frac{\varepsilon A V^2}{2(d-\delta(x))^2}$$

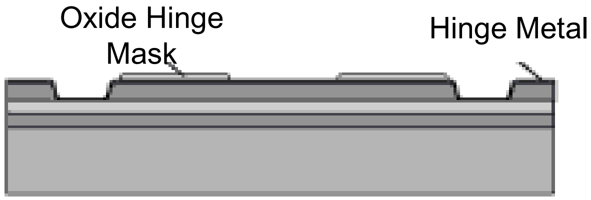




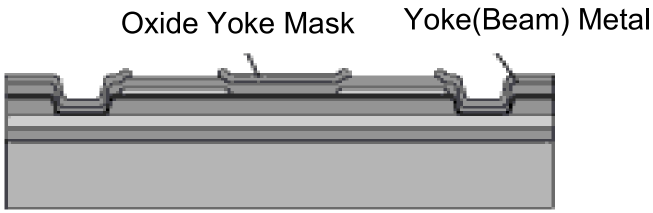
MEMS processes



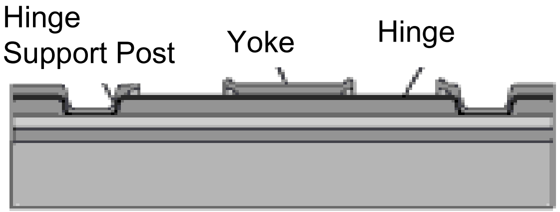
After Spacer1 Patterning



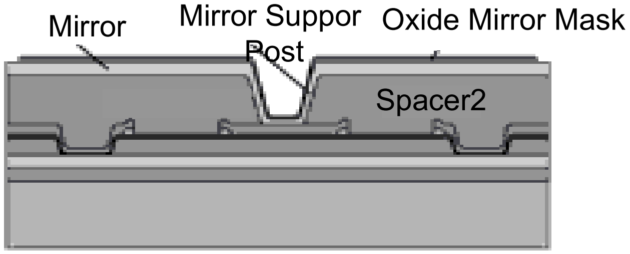
After Oxide Hinge Mask Patterning



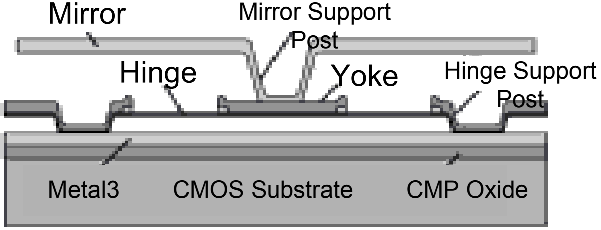
After Yoke Oxide Patterning



After Yoke/Hinge Etch and Oxide Strip



After Mirror Oxide Patterning



Completed Device

Key Features of DMD

Photos removed for copyright reasons.

Number of moving parts	Up to 2 million pixels
Mechanical motion	Makes discrete contacts or landings
Lifetime requirement	450 billion contacts per moving part
Address voltage	Limited by 5 volt CMOS technology
Mechanical elements	Al
Process	Low temp., sputter deposition, plasma etch
Sacrificial layer	Organic, dry-etched, wafer-level removal
Die separation	After removal of sacrificial spacer
Package	Optical, hermetic, surface coating
Testing	High-speed electro-optical before die separation

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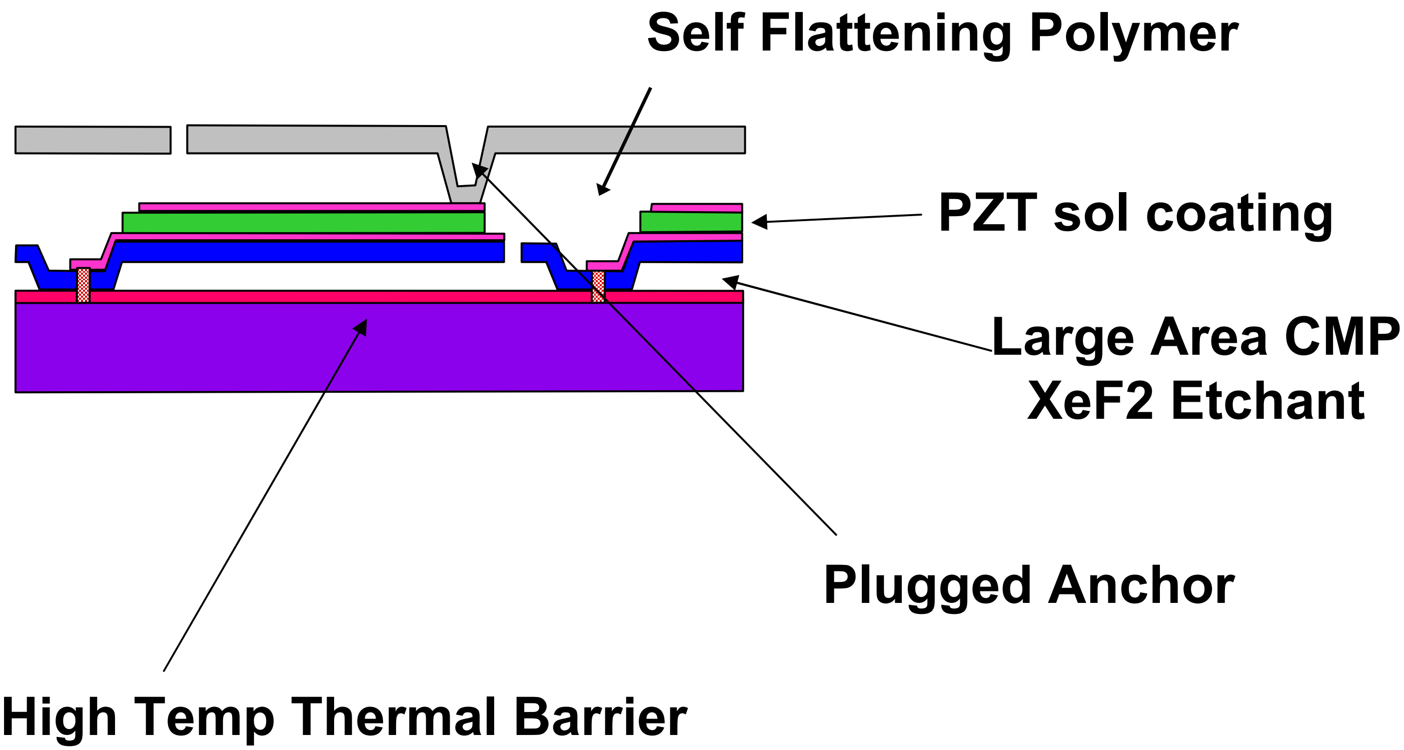
TMA Projection System

Diagrams (several slides worth) removed
for copyright reasons.

Key Processes



Self Flattening Polymer

PZT sol coating

Large Area CMP
XeF2 Etchant

Plugged Anchor

High Temp Thermal Barrier

Mirror Flatness

$$\text{MLE} = \varepsilon_f \times \varepsilon_r \times \varepsilon_m$$

$$= 0.81 \times \varepsilon_m$$

- **MLE** = **Module Light Efficiency**
- ε_f = **Fill Factor = 90%**
- ε_r = **Reflectvity = 90%**
- ε_m = **Mirror Flatness**

Diagram removed for copyright reasons.

Diagram removed for copyright reasons.

$\varepsilon_m = 50\%$

MLE $= 43\%$

Diagram removed for copyright reasons.

Diagram removed for copyright reasons.

$\varepsilon_m = 83\%$

MLE $= 70\%$

(97µm × 97µm TMA mirror)

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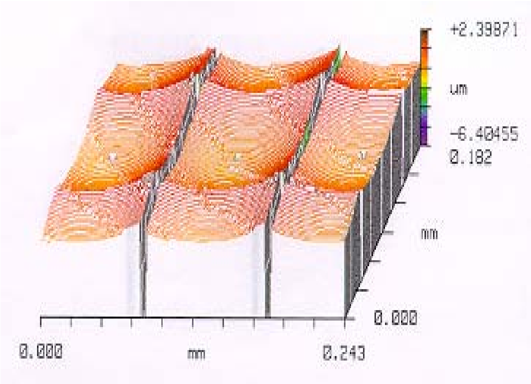
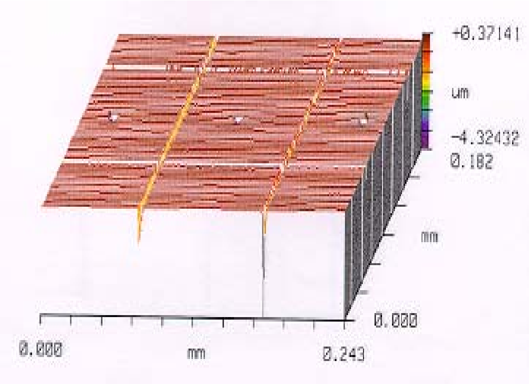
Optical Flatness of Micromirrors



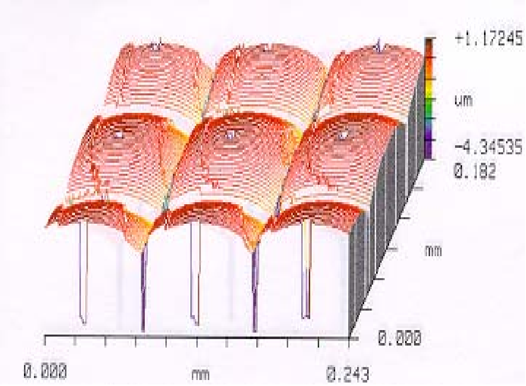
Ra=0.56 μm
rms=1.05 μm
bow=2.04 μm

MLE=49.7 %



Ra=0.11 μm
rms=0.27 μm
bow=0.01 μm

MLE=76.6 %



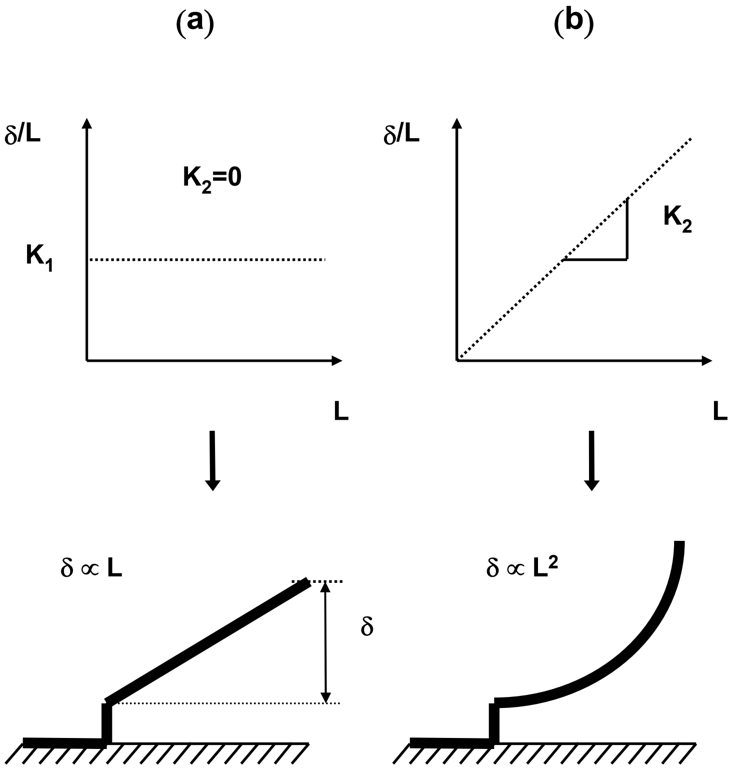
Ra=0.69 μm
rms=1.15 μm
bow=-1.77 μm

MLE=54.8 %

(Test Samples : Only mirror structure on Si wafer)

Deflection behavior of cantilever beams

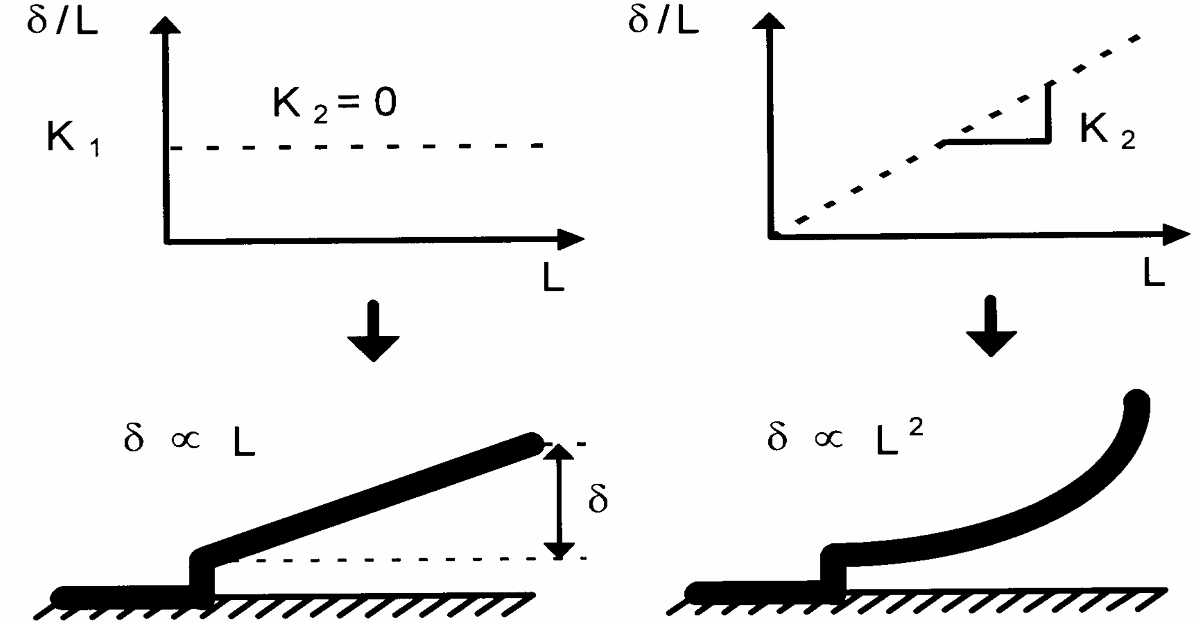
- (a) when M1 is dominant and
- (b) when M2 is dominant



Initial Deflection Model

when M_1 is dominant

when M_2 is dominant



$$\boxed{\delta = k_1 L + k_2 L^2}$$

δ = end-point deflection
L = beam length

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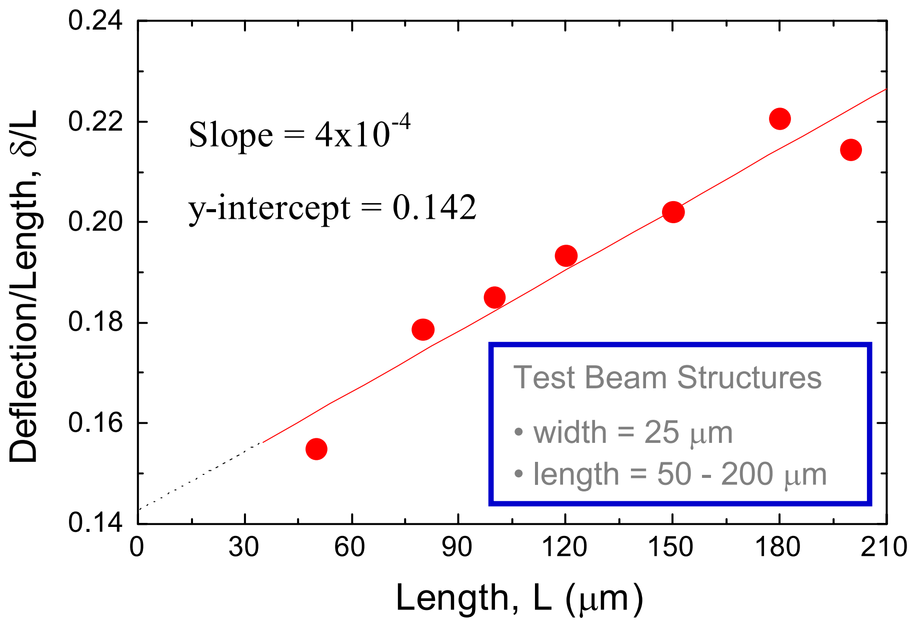
Observed Initial Deflection

$$\boxed{\delta/\mathrm{L} = k_1 + k_2\mathrm{L}}$$



For L = 100 μm

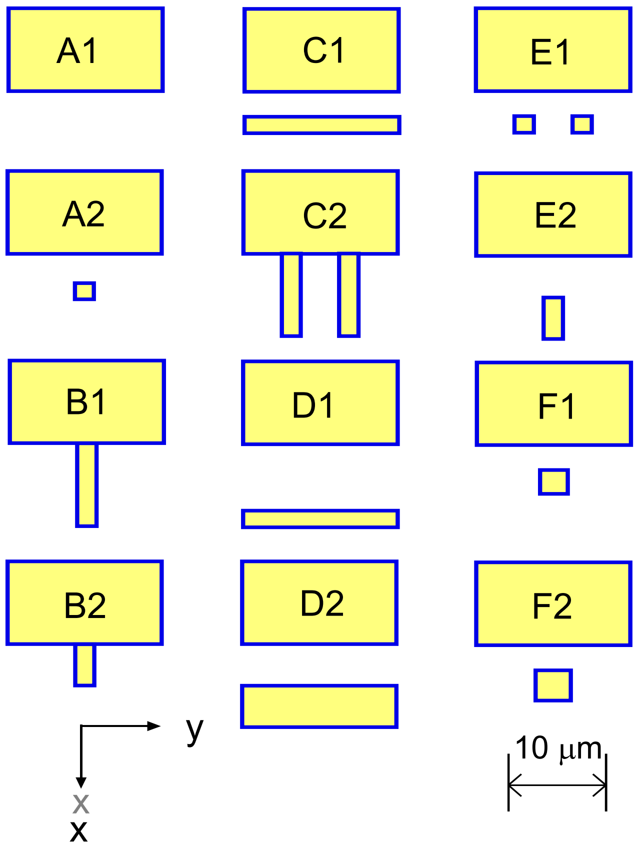
$k_1 = 4 \times 10^{-4}$

$k_2 = 0.142$

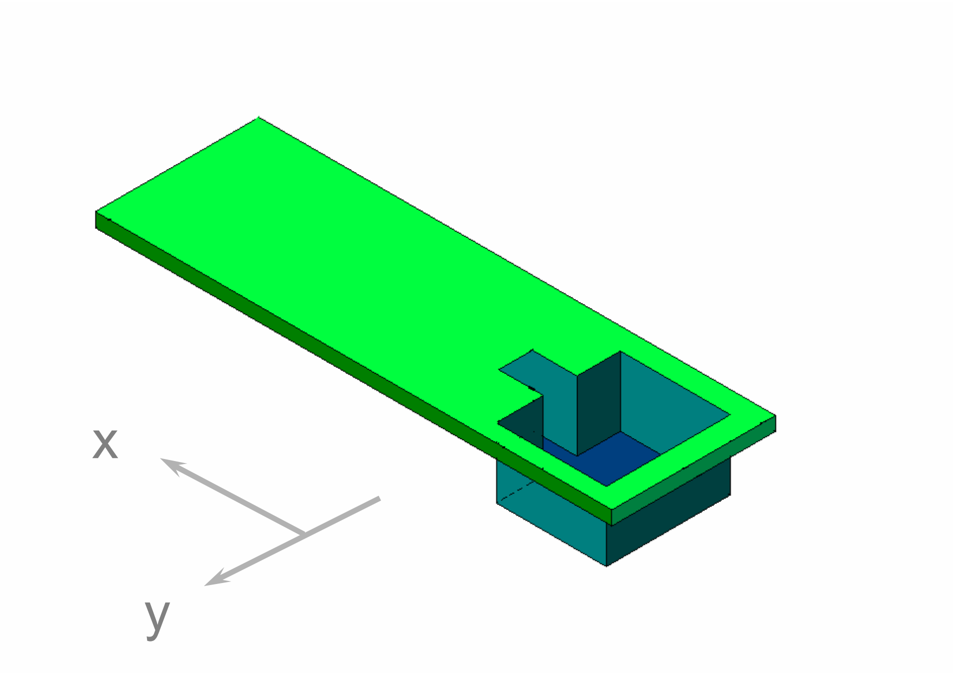
$$\boxed{\delta_{\mathrm{M}_1} \approx 2.3\ \delta_{\mathrm{M}_2}}$$

M_1 is dominant

Anchor Modification



< Tested anchor designs >



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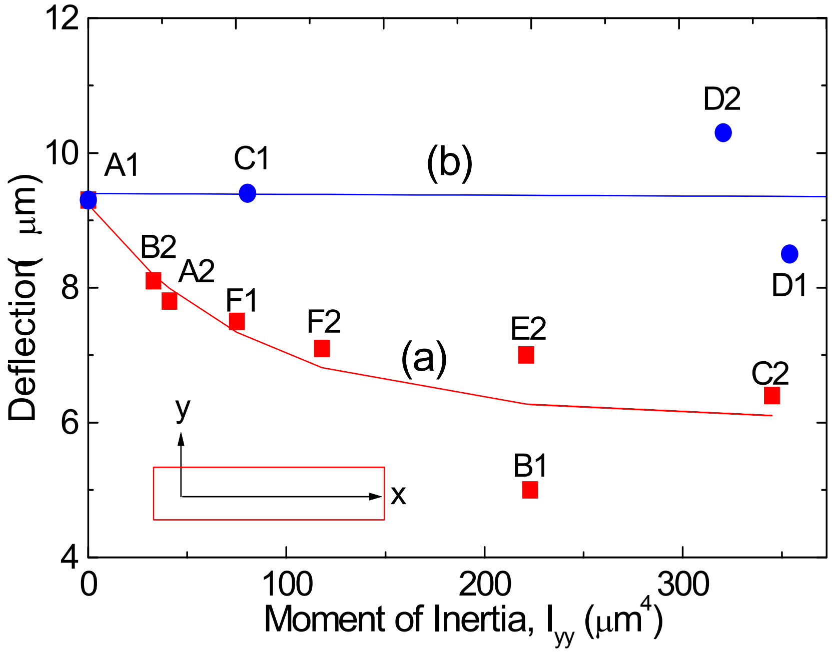
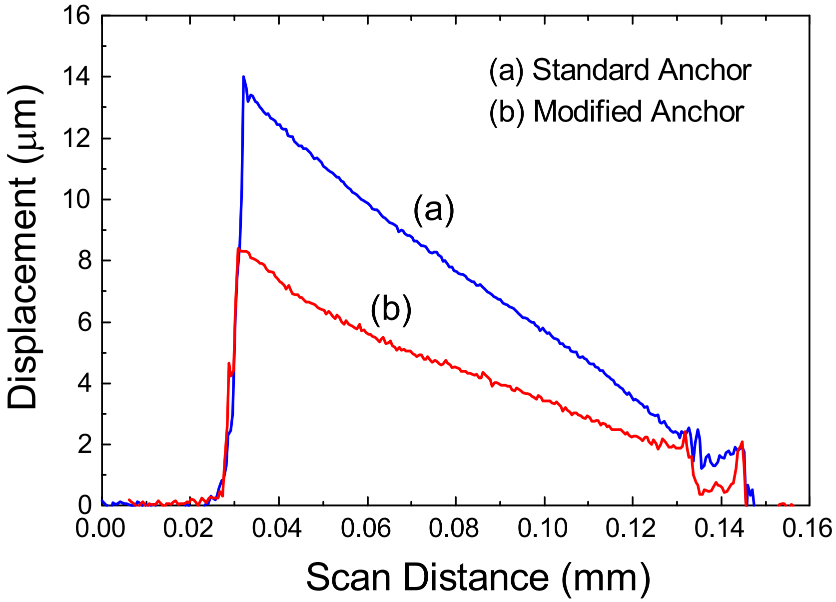
Effect of Aanchor Modification





Reduction of the initial deflection ⇒ up to 35 %

XGA
1024 X 768
786,432 pixels
(1999.8)

Photos removed for copyright reasons.

VGA
640 X 480
307,200 pixels
(1998. 7)

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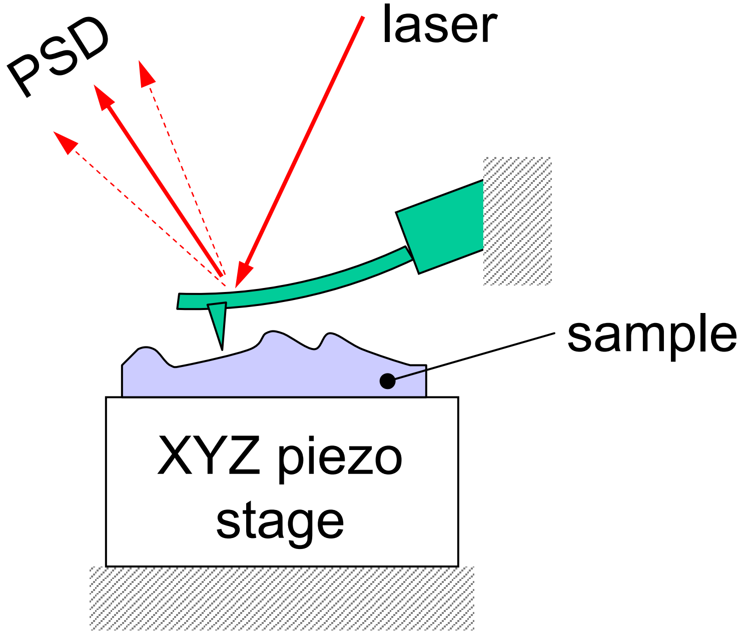
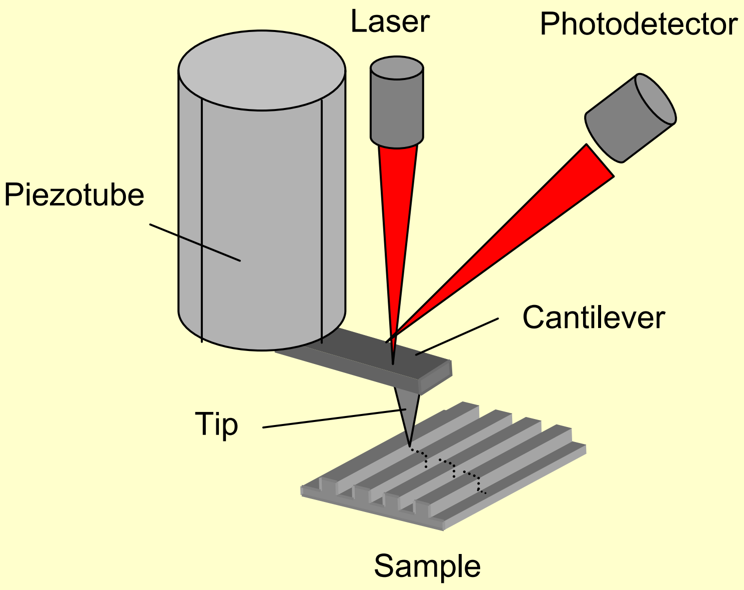
Conventional AFM: Cantilever with a sharp tip

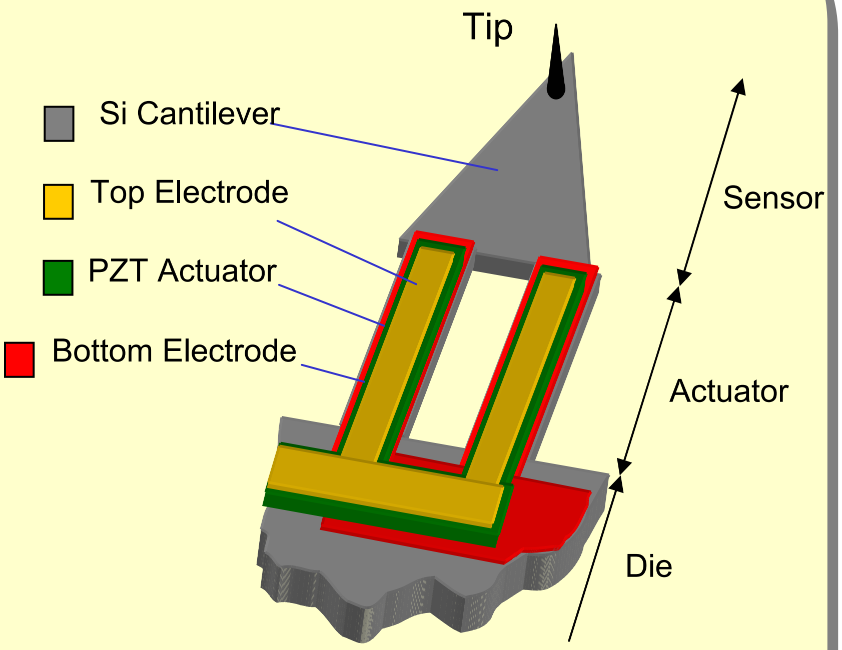
- Detailed Resolution: 10 nm in XY, 0.1 nm in Z.
- Very Slow: ***5 minutes for (40 um)²*** (typical, contact mode).



AFM(**Atomic Force Microscope**)



AFM
(Atomic Force Microscope)



AFM Cantilever with
Built-in Piezoelectric Actuator

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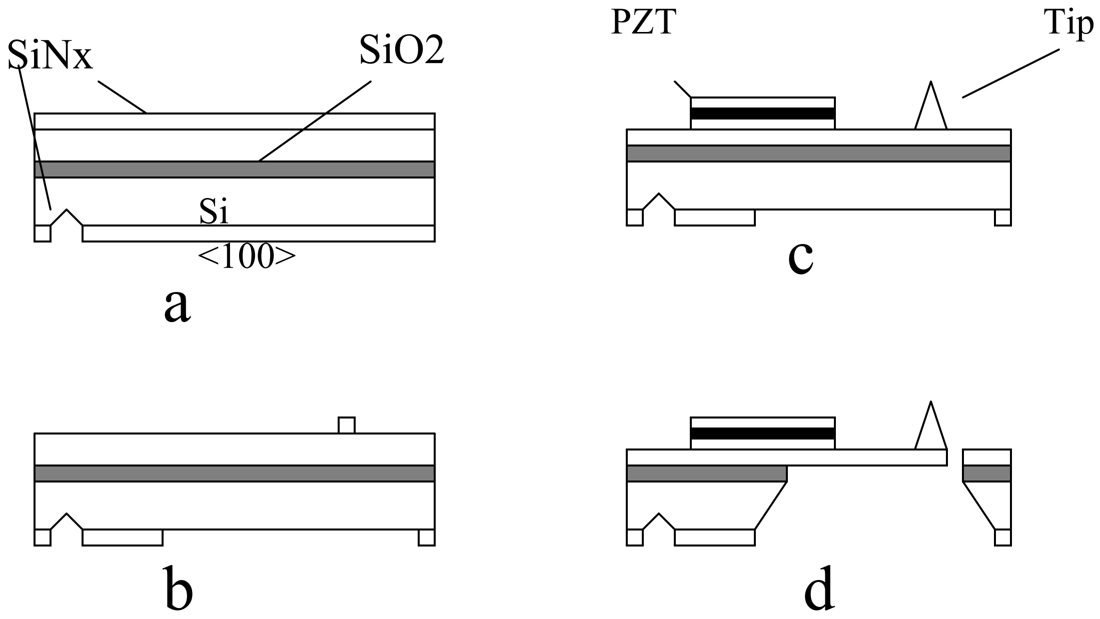
High Speed AFM Cantilever

with Built-in Piezoelectric Actuator

Photos removed for copyright reasons.
See Y. K. Kim, J. M. Bae, S. Y. Son, J. H. Choi, and S. G. Kim, "High Speed Atomic Force Microscope Cantilevers with Built-in Piezoelectric Actuator", Proc. of MOEMS '99, Mainz, Germany, September 1999.

Actuator built-in cantilever



(a) Crystal axis exposure pit on a low stress silicon nitride mask with SOI wafer
(b) Double sided aligning of bottom bulk etch mask and top tip mask
(c) Tip sharpening and PZT actuator patterning
(d) Silicon cantilever pattern with oxide insulator removal and backside bulk etch.

AFM Cantilevers' Actuators

	Conventional	Stanford	Nikon	Daewoo
Type	**Piezo-tube**	**Thin Film Actuator**		
Material	**PZT**	**ZnO**	**PZT**	**PZT**
Resonant Frequency	**0.2 ~ 20 kHz**	**50 ~ 100 kHz**	**40 kHz**	**200 ~ 300 kHz**
Displacement	**~ 0.1μm/V**	**0.03μm/V**	**0.05μm/V**	**0.8μm/V**

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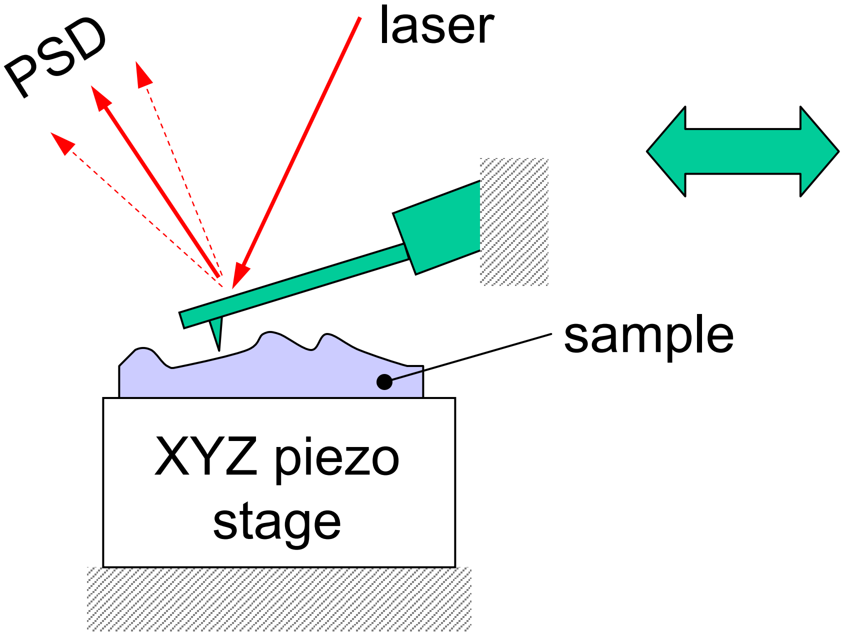
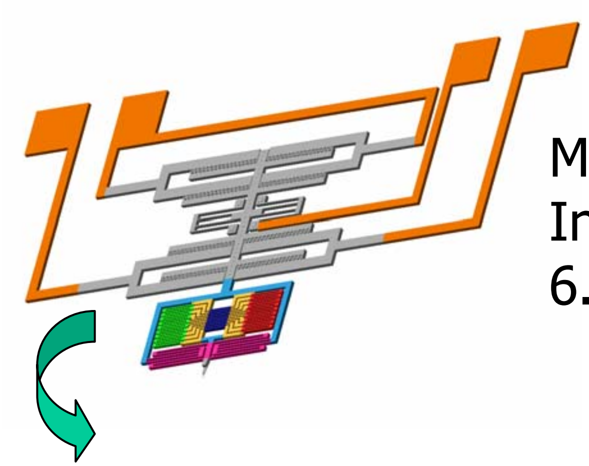
In-Plane AFM Probe with Dual Stiffness



Conventional
Cantilever AFM



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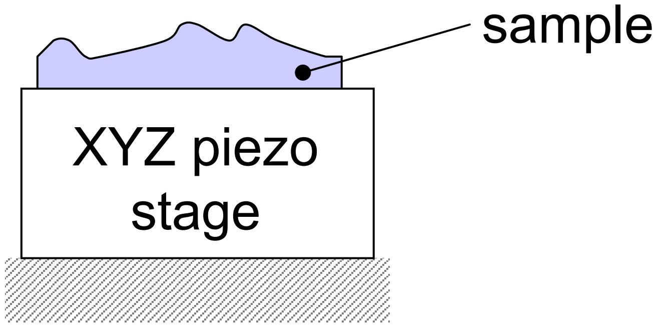
In-plane AFM
6.777

Diagram removed for copyright reasons.



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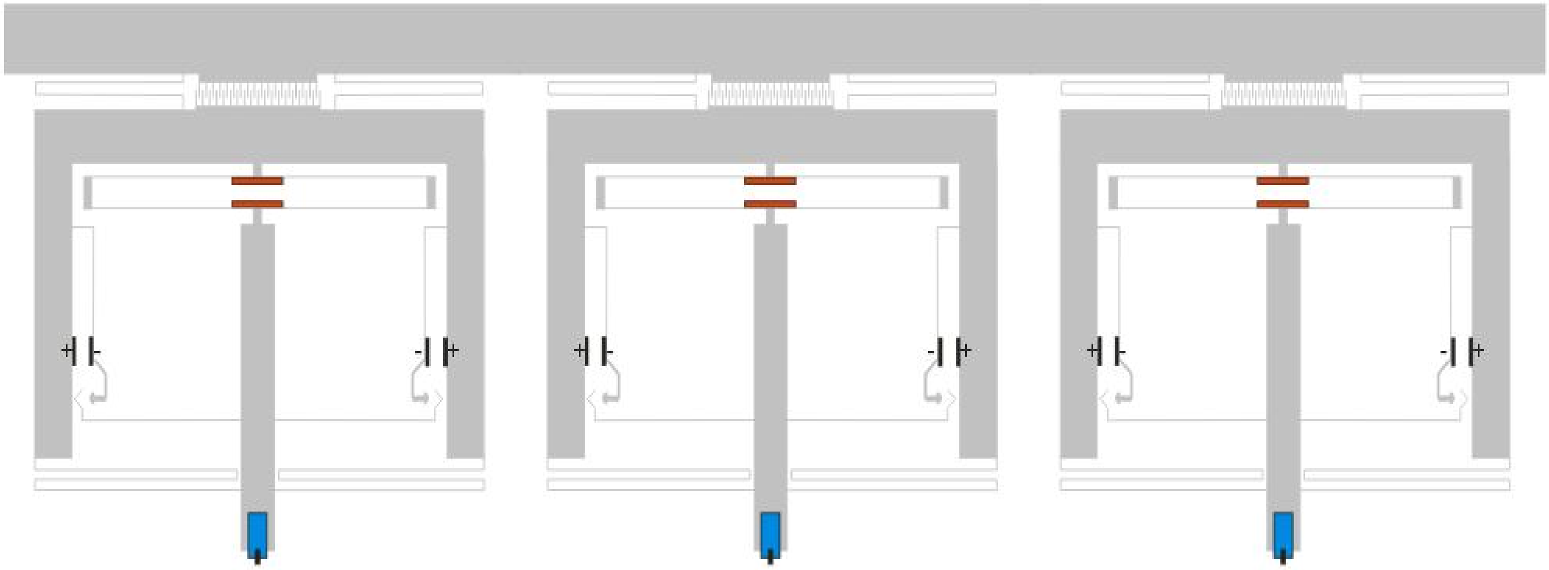
Specifications of Proposed In-Plane AFM Probe

- **Dimensions:** Height 250 μm; Length 500μm; Thickness 10 μm
- **Stiffness:** low mode 0.2 N/m; high mode 1.5 N/m
- **Z stroke:** 5 μm
- **Resonant frequency:** low mode 3 kHz; high mode 9 kHz
- **Pull in voltage of clutches:** less than 50 V

Design for arrayability

- Massively parallel arrays of in-plane AFM probes in 1D and 2D



M.I.T. Case No. 10665, US patent pending, Sang-Gook Kim, Yong-Ak Song, Clemens Mueller-Falcke, 1-28-2004

MOEMS

MEMS technology

- Arrayable
- Nano-scale precision
- Reconfigurable

Functionality
Scale-order