Large-Stroke Deformable Mirror Array for Adaptive Optics

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Center for Adaptive Optics Fall Retreat  November 13, 2004
Design Features

- 20 µm of vertical displacement achievable with a low voltage (~ 100V) applied to the underlying electrodes

- Designed from the bottom up – different then the flip-chip bonding technique we used for CCIT mirror arrays

- High fill-factor devices achievable by bonding an additional Si wafer onto stack and grinding and polishing to final mirror thickness

- Self-aligned vertical comb drive structure - have been used in my group at Stanford to achieve large angle torsional mirrors for scanning applications – can be used for large vertical displacements if the springs are designed correctly

- Resonance frequency specification for MEMS mirrors for the vision science application is low – so springs were designed to accommodate this specification

- Single-crystal silicon is used as the structural material for the mirror and actuator

- 4x4 arrays designed for 3 different spring designs
Combdrive vs. parallel plate

Parallel plate: \( F_{pp} = \frac{A_{pp} \varepsilon_0 V^2}{2s^2} \)

Combdrive: \( F_{cd} = \frac{N\varepsilon_0 h V^2}{g} \)

\[
\frac{F_{cd}}{F_{pp}} = \frac{2s^2 Nh}{A_{pp} g}
\]

For the combdrive I have designed, using \( A_{pp} = (885\,\mu\text{m})^2 \):

\[
\frac{F_{cd}}{F_{pp}} = 21
\]

Combdrives good for large displacements and large forces (broad-band AO/Tip-tilt)
Self-Aligned Actuator Fabrication Process

(a) DRIE of coarse patterns (Mask 1)
(b) Thermal oxidation, fusion bonding, grinding, and polishing
(c) Self-alignment mask patterning (Mask 2) after LTO deposition
(d) Partial etching of the LTO layer (Mask 3)
(e) DRIE of the upper device layer followed by directional oxide etch
(f) DRIE of lower device layer patterned by Mask 2 and the upper device layer patterned by Mask 3

Legend:
- SCS
- Thermal oxide
- Masking LTO
Work at Stanford in Vertical Comb Drives

Bonding of Two Silicon Layers above a Gap to Fabricate a Fast Scanning Micromirror

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Japanese Journal of Applied Physics
Vol. 43, No. 1A/B, 2004, pp. L50–L52
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Fabricated Mirror/Actuators

Mirror and post underneath actuator

Outer axis

Inner axis
Analytical Modeling of the Springs OD7

4 springs $\rightarrow$ $k_z = \frac{2Ewt^3}{L^3}$

$k_z = 2 \cdot 1.69 \times 10^{11} \left[ \frac{N}{m^2} \right] 10 \times 10^{-6} \left[ m \right] 5 \times 10^{-6} \left[ m \right]^3 \left( 330 \times 10^{-6} \left[ m \right] \right)$

Ratio:

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>$k_x/k_z$</td>
<td>33</td>
</tr>
<tr>
<td>$k_y/k_z$</td>
<td>798.6</td>
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CoventorWare – Voltage Applied to All Bottom Comb Teeth

OD7
CoventorWare – Voltage Applied to All Bottom Comb Teeth

OD7

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Displacement</th>
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<tbody>
<tr>
<td>0V</td>
<td>0.00 µm</td>
</tr>
<tr>
<td>0.2V</td>
<td>0.41 µm</td>
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<tr>
<td>0.4V</td>
<td>1.69 µm</td>
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<tr>
<td>0.6V</td>
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<td>0.8V</td>
<td>7.77 µm</td>
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<td>1.0V</td>
<td>12.63 µm</td>
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<tr>
<td>1.2V</td>
<td>17.3 µm</td>
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<tr>
<td>1.4V</td>
<td>22.42 µm</td>
</tr>
</tbody>
</table>
Voltage Vs. Displacement – CoventorWare and Analytical Results – OD7
Mode 1: 3.59kHz

Mode 2: 4.07kHz

Mode 3: 5.72kHz
Microscope Images of Mask 1 for all Optical Designs

Optical Design #1
- 775 µm

Optical Design #5
- 830 µm

Optical Design #7
- 885 µm
Zygo White-Light Interferometric Microscope Images of STS Etched Rough Comb Teeth

PV: 32.734 µm
PV: 23.441 µm
Ra: 11.139 µm
850 µm
Fabrication Progress

Silicon Layer 1
SOI device layer (25um) has been patterned with Mask #1 (rough combs, wires, bond pads, etc.)
BLUE = COMPLETED STEPS

Silicon Layer 2
The second silicon layer has been bound to the original SOI stack. It was then ground and polished to the correct thickness for the top comb/spring layer. Will be patterned and etched NEXT WEEK.

Silicon Layer 3
Will begin to fabricate this layer by the end of next week. It will take approximately 1 month to complete.