Deformable MEMS Micromirror Array for Wavelength and Angle Insensitive Retro-Reflecting Modulators

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Motivation and Introduction

• Application:
  – Asymmetric ground-based FSO telemetry (battlefield com, remote sensors, etc.)

• Approach:
  – Modulated Corner Cube Retro-Reflectors (self-aligning return signal)

• Requirements:
  – Up to 5 km range → Low loss, low aberration, and large (cm +) aperture
  – Eyesafe wavelength (1.5 micron band)
  – Robust → Insensitive to angle (+/- 30°) wavelength (1450 – 1550 nm) and temperature
  – Data modulation → >100 KHz, >2:1 contrast (10:1 preferred)

• No previously demo’d retromodulator (MQW or MEMS) satisfy all requirements
Previous MEMS Retro Modulators

(Kris Pister at UC Berkeley)

Pedersen et al. Sensors & Actuators 83, p6, 2000
(Olav Solgaard at Stanford)

<table>
<thead>
<tr>
<th>CCR Modulator</th>
<th>Acceptance Angle</th>
<th>Switching Speed</th>
<th>Extinction Ratio</th>
<th>Aperture</th>
<th>Drive Voltage</th>
<th>Mechanical Deformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tiltable Mirror</td>
<td>35°</td>
<td>18 kHz</td>
<td>large</td>
<td>250 µm</td>
<td>5V</td>
<td>20 – 30 µm</td>
</tr>
<tr>
<td>Actuated Grating</td>
<td>6°</td>
<td>100 kHz</td>
<td>1.16</td>
<td>150µm (scalable)</td>
<td>10 V</td>
<td>&lt; 100 nm</td>
</tr>
</tbody>
</table>
Deformable Mirror Retromodulator Concept

• One mirror is a patterned deformable membrane
  – Initial state is flat
  – 100% of area is reflective

• Electrostatic attraction pulls the surface membrane down
  – Creates a hexagonal array of reflective lenses
  – 75% of area is deformed

• Deformed mirror distorts the returning wavefront
  – Dispersed return signal does not enter receiver so is attenuated
Theoretical Diffraction Analysis

- Theoretical analysis is created from Huygens-Fresnel diffraction theory
  - Mirror and far field surfaces are sampled with a finite number of points
    \[ u(x', y', z') = \sum_{m=1}^{M} \sum_{n=1}^{N} \frac{1}{\lambda r_{mn}} e^{jkr_{mn}} \]
    \[ r_{mn} = \sqrt{(x' - x_m)^2 + (y' - y_n)^2 + (z' - z_{mn})^2} \]
  - 1 mm pitch micromirrors, deforming up to 0.8 micron; propagation length 6.6 m
  - NOT in a corner cube
Angle and Wavelength Dependence

- Size of the diffraction pattern is linearly proportional to the wavelength

\[
\tan \theta_{\text{period}} = \frac{\lambda}{T \cos \left( \frac{\pi}{6} \right)}
\]

\[
\theta_{\text{period}}(1520\text{nm}) = 0.101^\circ
\]

\[
\theta_{\text{period}}(1575\text{nm}) = 0.104^\circ
\]

With 0.8 µm deformation we see 10 dB contrast up for a 110° angular aperture
Fabricated MEMS Deformable Mirror

- Devices were fabricated by MEMScap
- Surface profile measured by interferometry
- Design: 0 – 85V for 0.8 um sag
- Experiment: 0 – 79V for 0.55 um sag
  >0.55 um sag causes device malfunction

![Image of MEMS deformable mirror with labels for Gold, SiNₓ, PSG, and Silicon substrate.](image)

Area in the circle is filled with an array of etch access holes.
Experimental Far Field Diffraction

Tunable Laser Source

6.6 m

InGaAs Camera

Sag = 0 µm

Sag = 0.55 µm

Center spot extinction = 10:1
Wavelength Sensitivity

Simulation

Experiment

Experiment confirms broad wavelength spectrum operation
Prototype MEMS Retromodulator

Assembled deformable mirror into corner cube
• Received retroreflected signal:
  • 2.8 µs and 5.7 µs rise and fall times
  • 2.4:1 extinction at 10 kHz
  • 1.5:1 contrast at 100 kHz
Conclusion

- Designed and tested novel MEMS deformable mirror retro-modulator
  - Wavelength/angle insensitivity and ‘fast’ response with large apertures

- Theoretically analyzed & experimentally characterized deformable mirror
  - Simulations accurately predicted device performance
  - Performance limited by maximum deformation of fabricated mirror

- Demonstrated prototype MEMS retro modulator:

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</thead>
<tbody>
<tr>
<td>+/- 35°</td>
<td>1.4-1.6 μm</td>
<td>10 kHz</td>
<td>2.4:1 (0 - 35°)</td>
<td>79 V</td>
<td>550 nm</td>
<td>1 cm</td>
</tr>
<tr>
<td>+/- 35°</td>
<td>Visible – 1.8 μm</td>
<td>100 kHz</td>
<td>10:1</td>
<td>85 V</td>
<td>800 nm</td>
<td>10 cm</td>
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This work

Projected