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

Trevor K. Chan & Joseph E. Ford

Photonics Systems Integration Lab
UCSD Jacobs School of Engineering

UCSD

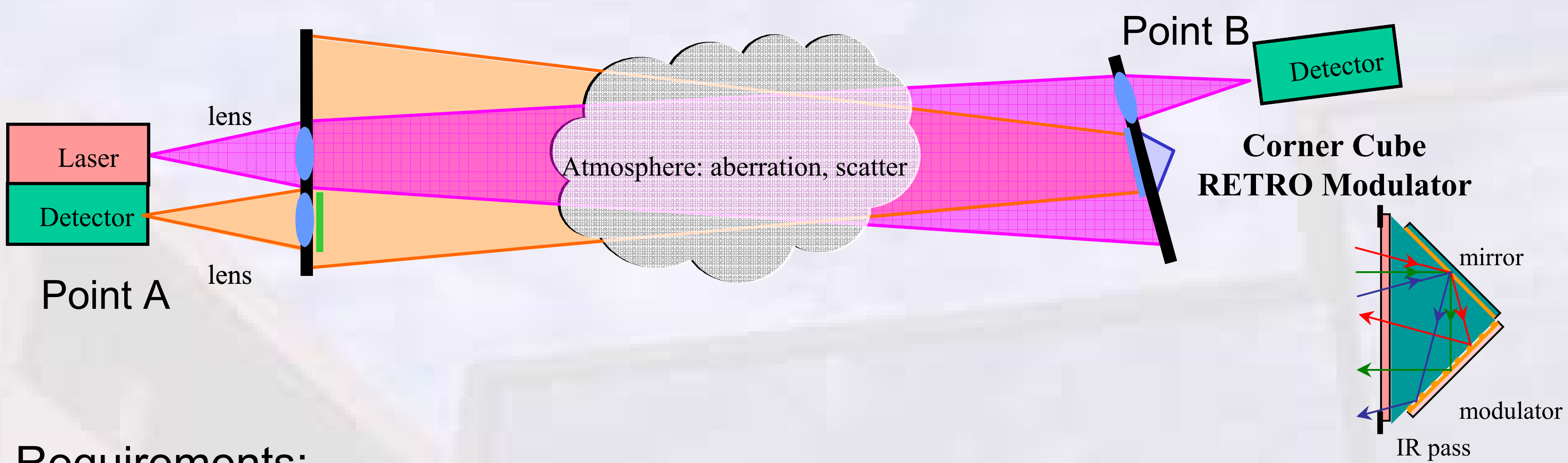
CUBIC CORPORATION

NSERC CRSNG

Photo: Kevin Walsh, OLR

Motivation and Introduction

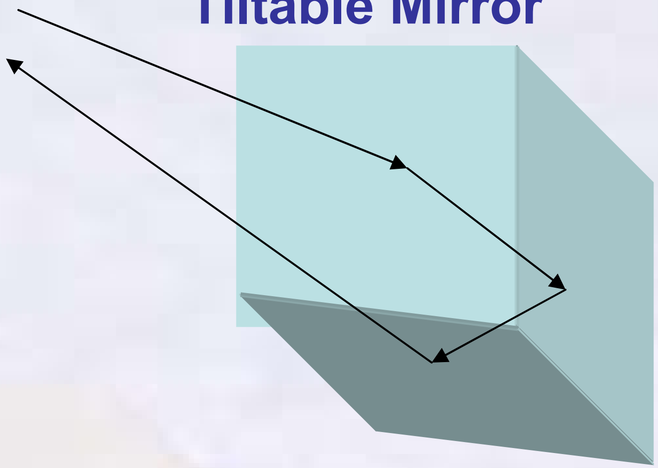
- Application:
  - Asymmetric ground-based FSO telemetry (battlefield com, remote sensors, etc.)
- Approach:
  - Modulated Corner Cube Retro-Reflectors (self-aligning return signal)



- Requirements:
  - Up to 5 km range → Low loss, low aberration, and large (cm +) aperture
  - Eyesafe wavelength (1.5 micron band)
  - Robust → Insensitive to angle (+/- 30º) 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

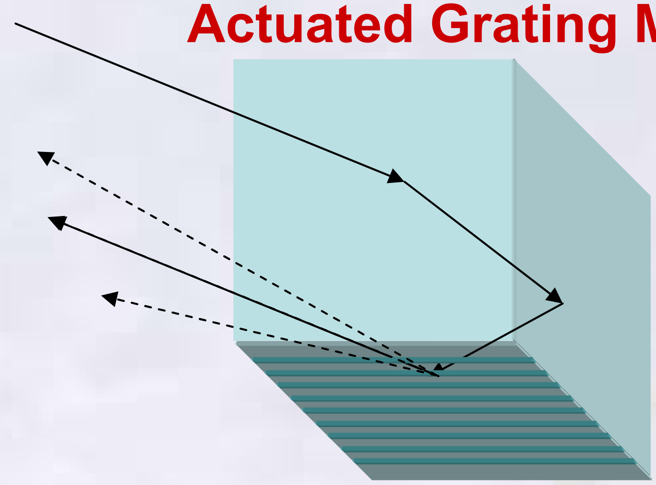
Tiltable Mirror



Zhou et al. J. MEMS 12(3), p233, 2003

(Kris Pister at UC Berkeley)

Actuated Grating Mirror



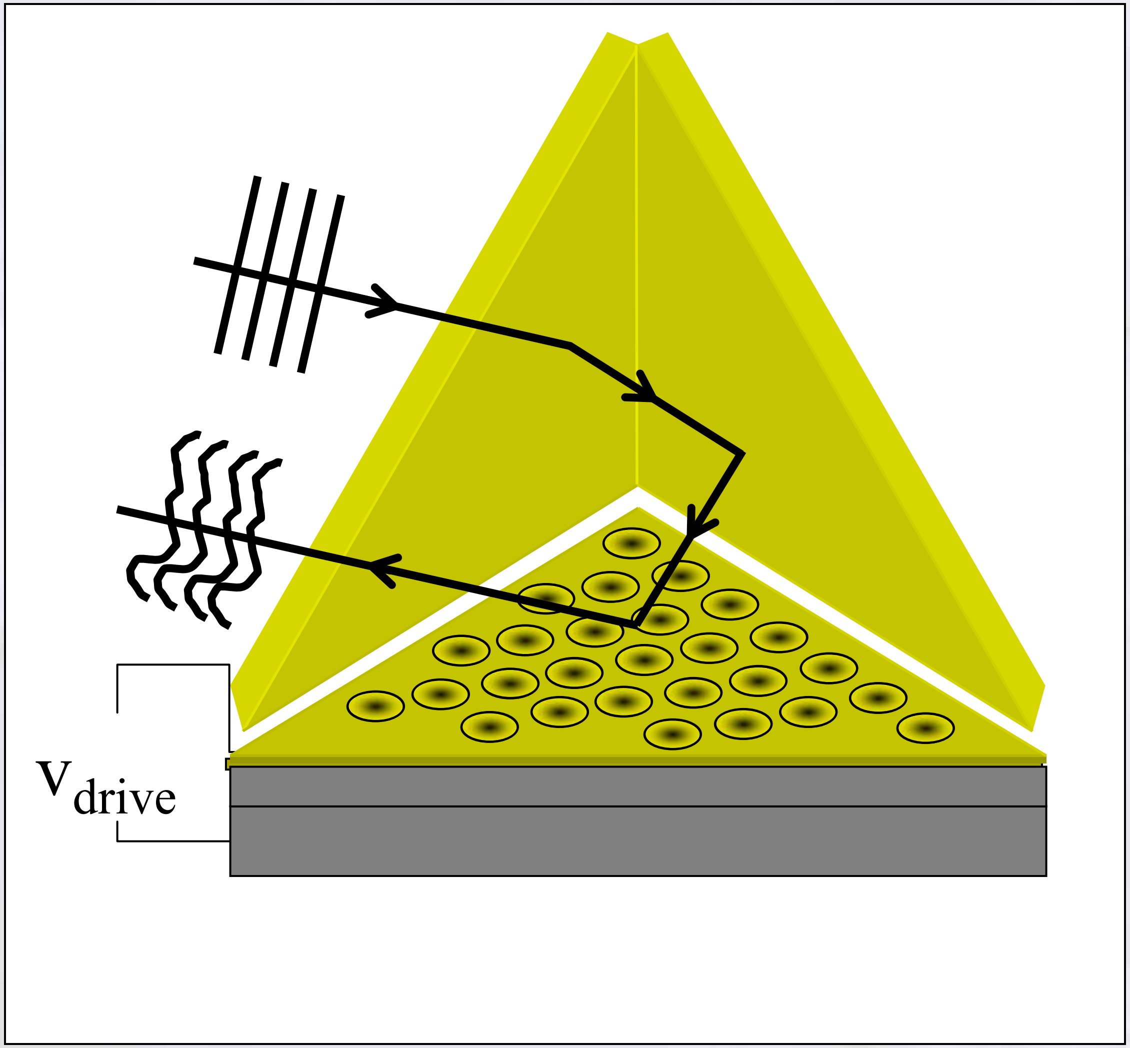
Pedersen et al. Sensors & Actuators 83, p6, 2000

(Olav Solgaard at Stanford)

CCR Modulator	Acceptance Angle	Switching Speed	Extinction Ratio	Aperture	Drive Voltage	Mechanical Deformation
Tiltable Mirror	35º	18 kHz	large	250 um	5V	20 – 30 µm
Actuated Grating	6º	100 kHz	1.16	150µm (scalable)	10 V	< 100 nm

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

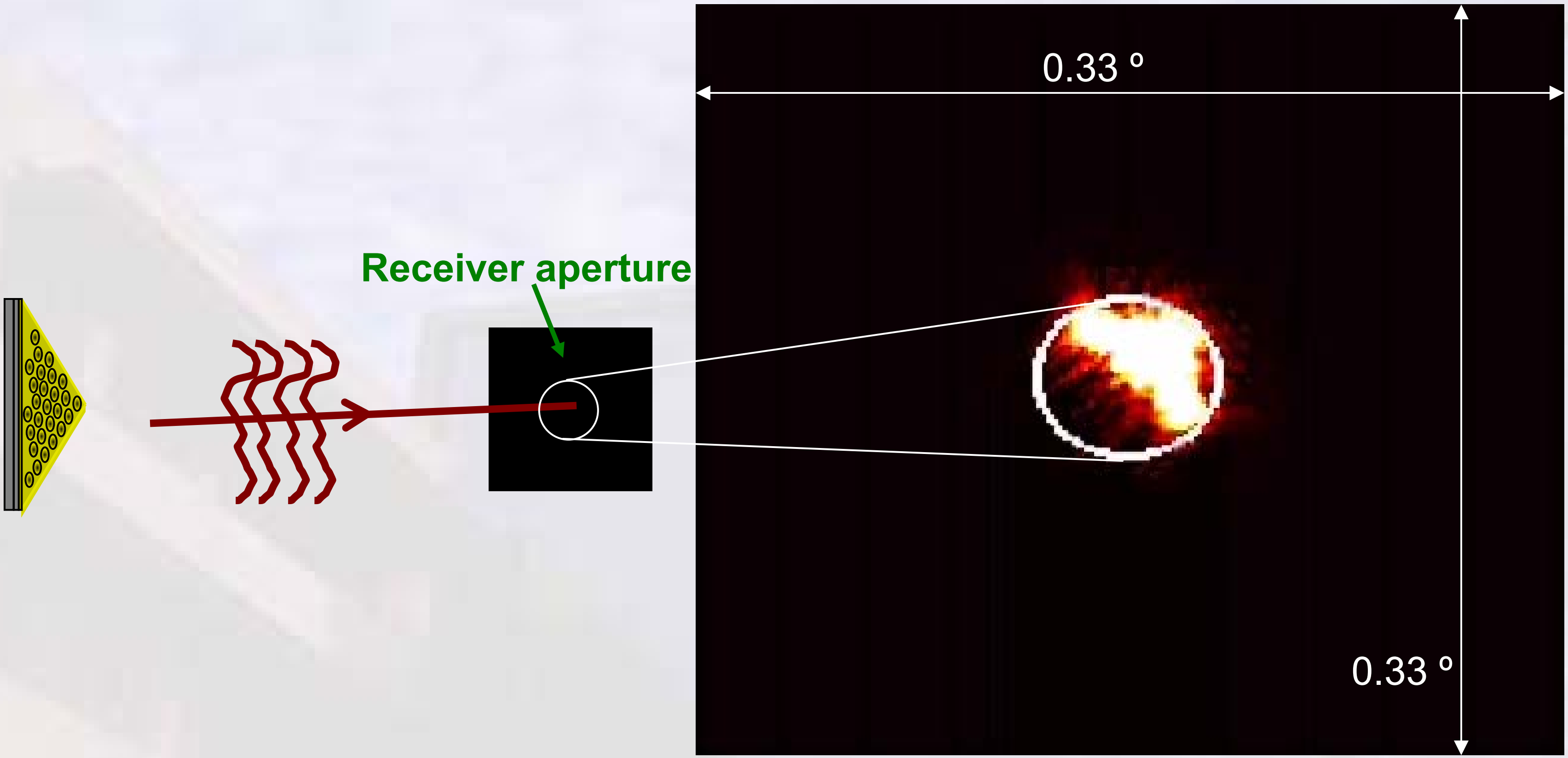


Theoretical Diffraction Analysis

- Theoretical analysis is created from Huygens-Fresnel diffraction theory
  - Mirror and far field surfaces are sampled with a finite number of points

$$u(x',y',z')=\sum_{m=1}^{M}\sum_{n=1}^{N}\frac{1}{j\lambda r_{mn}}e^{jkr_{mn}} \qquad r_{mn}=\sqrt{(x'-x_m)^2+(y'-y_n)^2+(z'-z_{mn})^2}$$

  - 1 mm pitch micromirrors, deforming up to 0.8 micron; propagation length 6.6 m
  - NOT in a corner cube



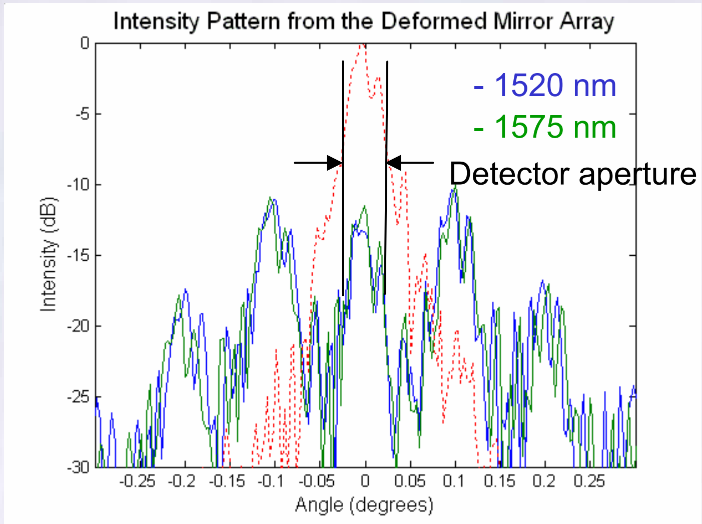
Angle and Wavelength Dependence

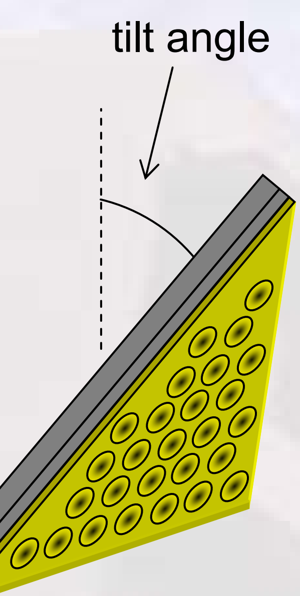
- Size of the diffraction pattern is linearly proportional to the wavelength

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

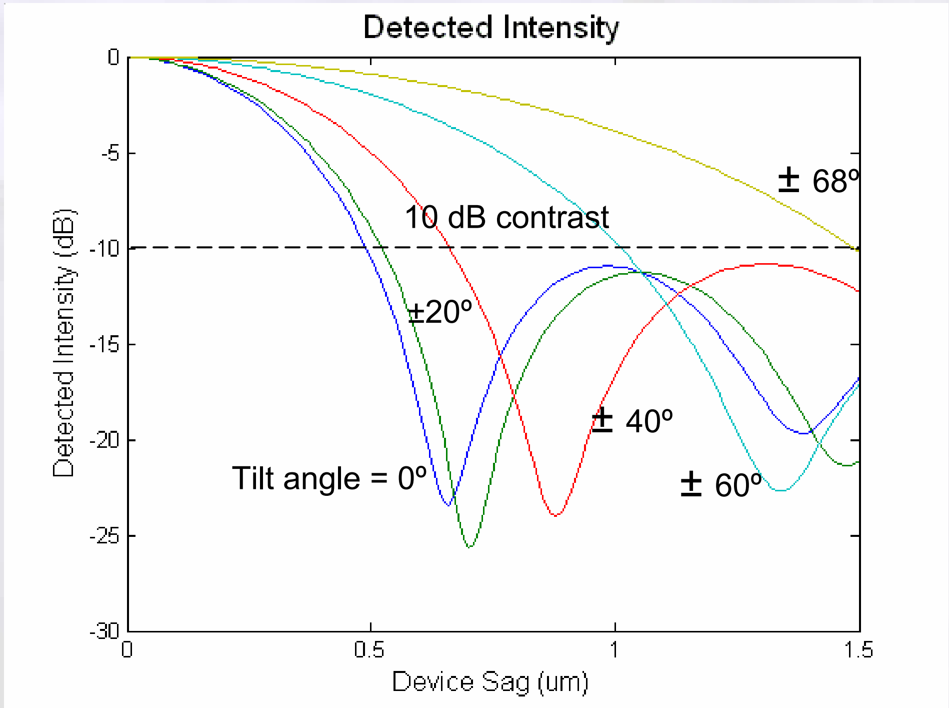
$$\theta_{period}(1520nm) = 0.101°$$

$$\theta_{period}(1575nm) = 0.104°$$

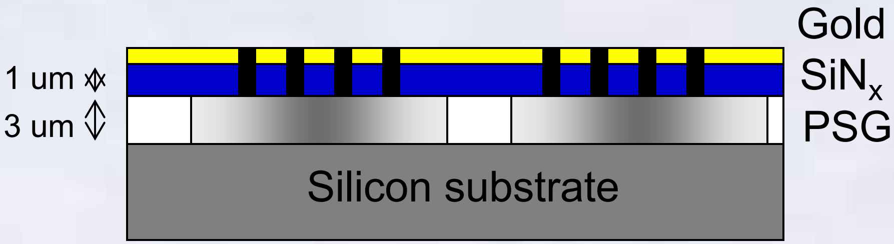




With 0.8 µm deformation we see 10 dB contrast up for a 110° angular aperture

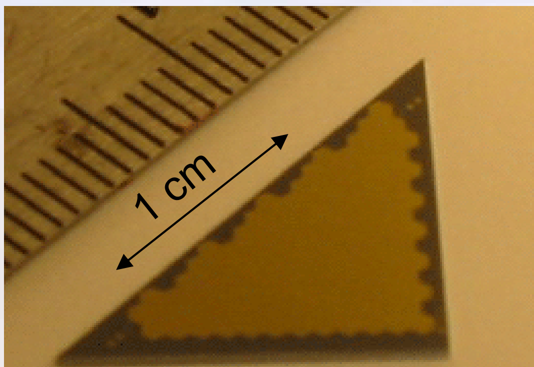


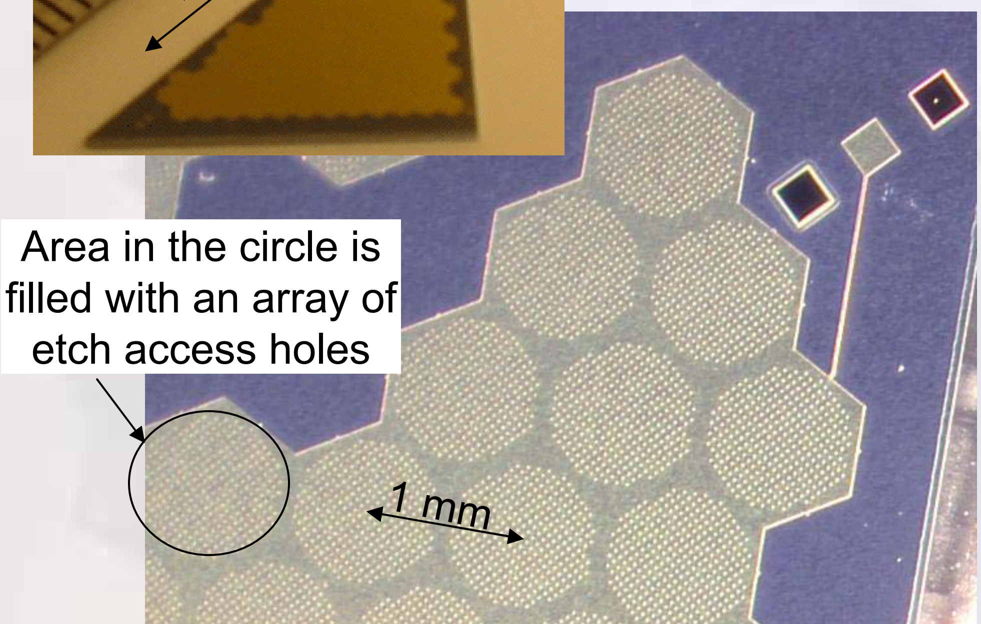
Fabricated MEMS Deformable Mirror

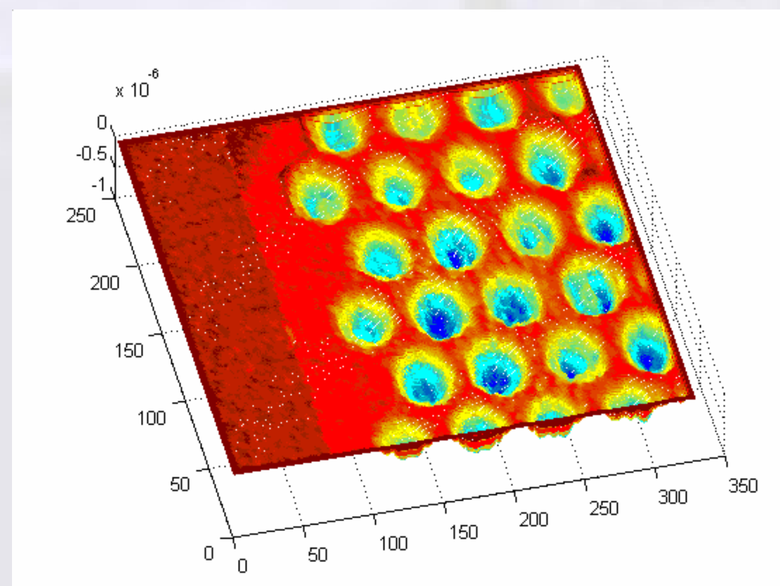


- Devices were fabricated by MEMScap
- Surface profile measured by interferometry
- Design: 0 – 85V for 0.8 um sag
- Experiment: 0 – 79V for 0.55 um sag

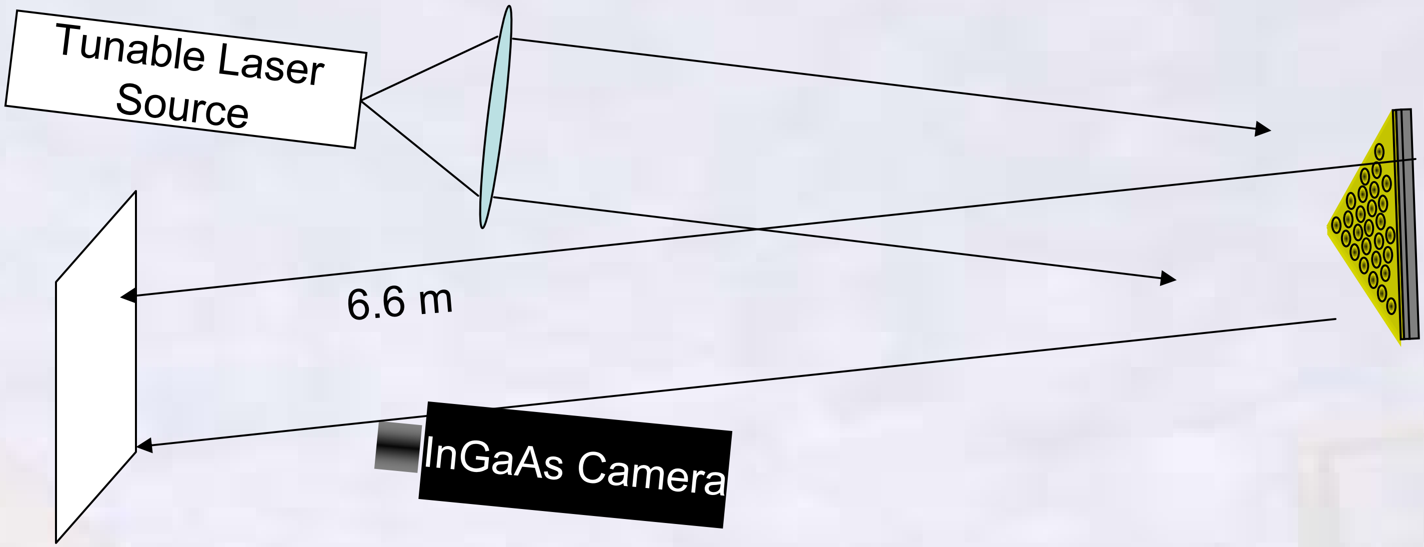
  >0.55 um sag causes device malfunction

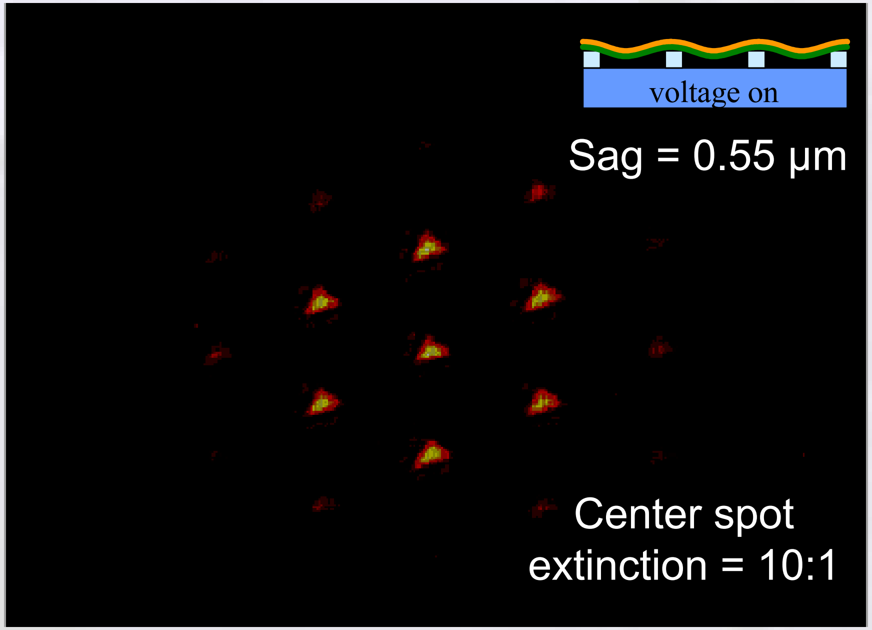






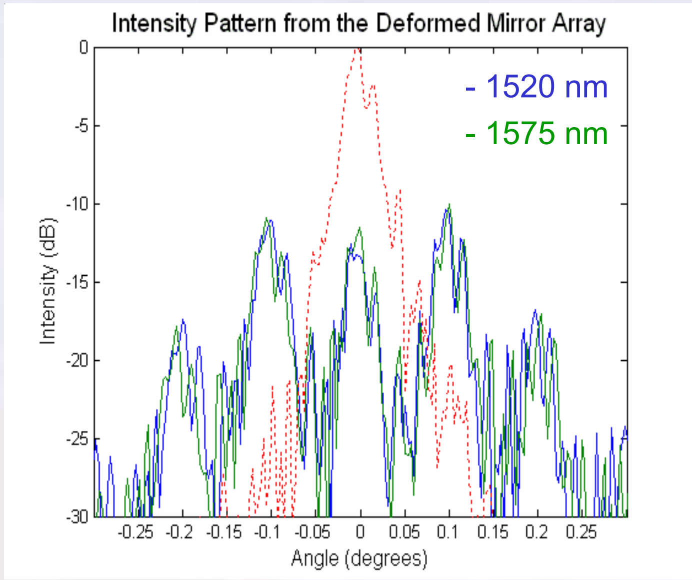
Experimental Far Field Diffraction



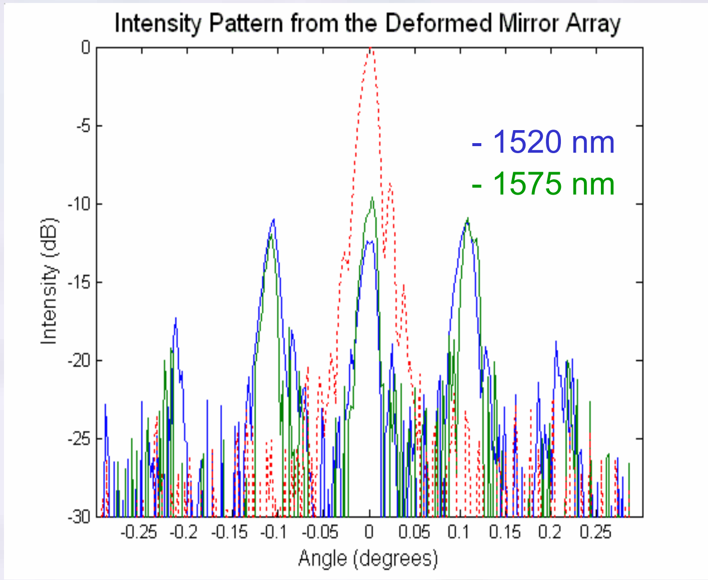


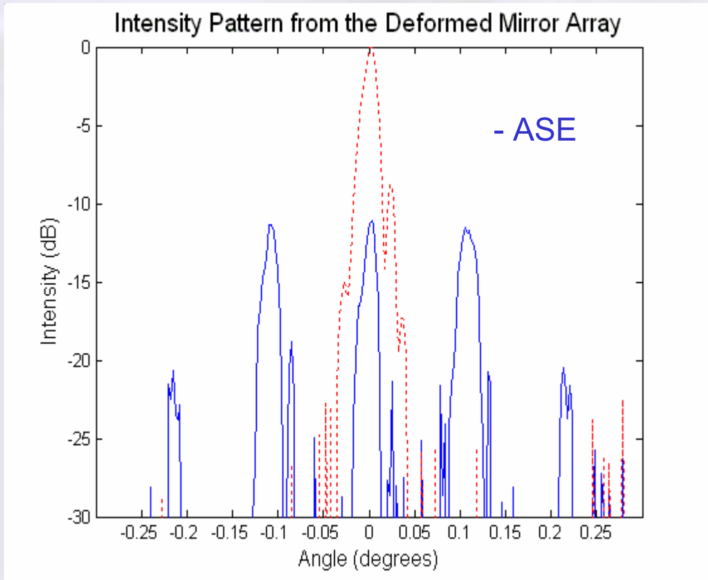
Wavelength Sensitivity

Simulation



Experiment



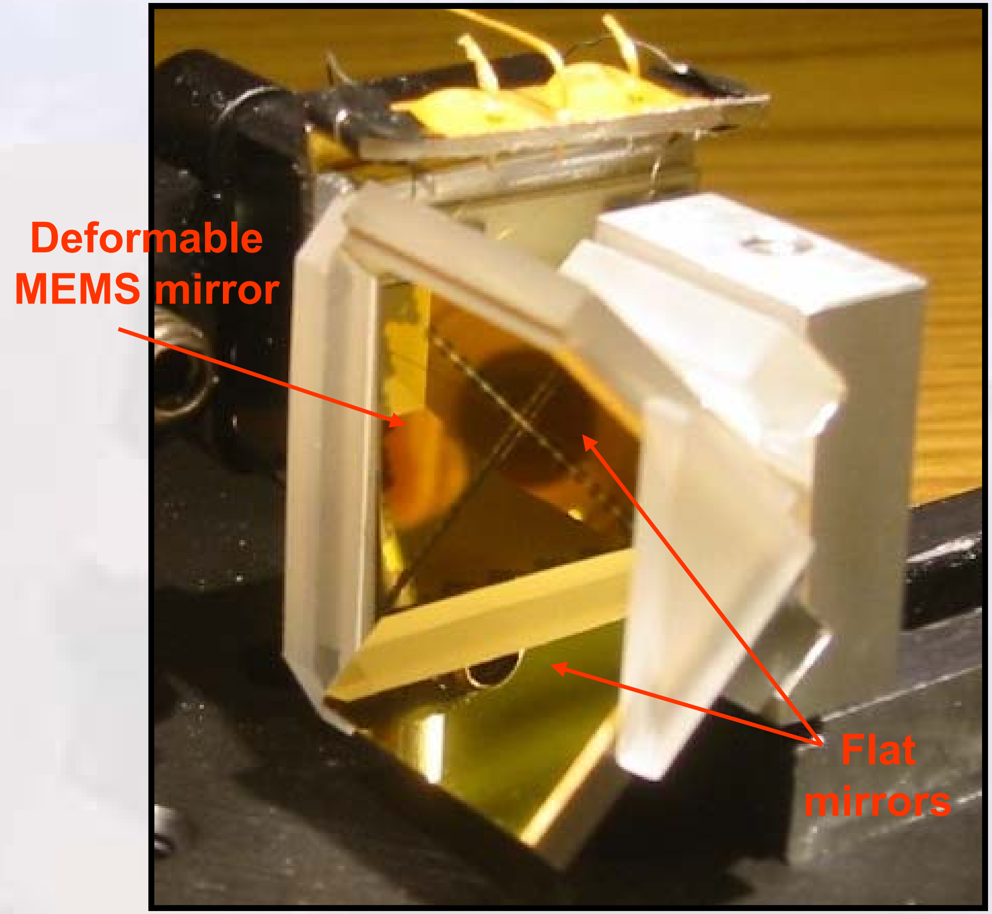


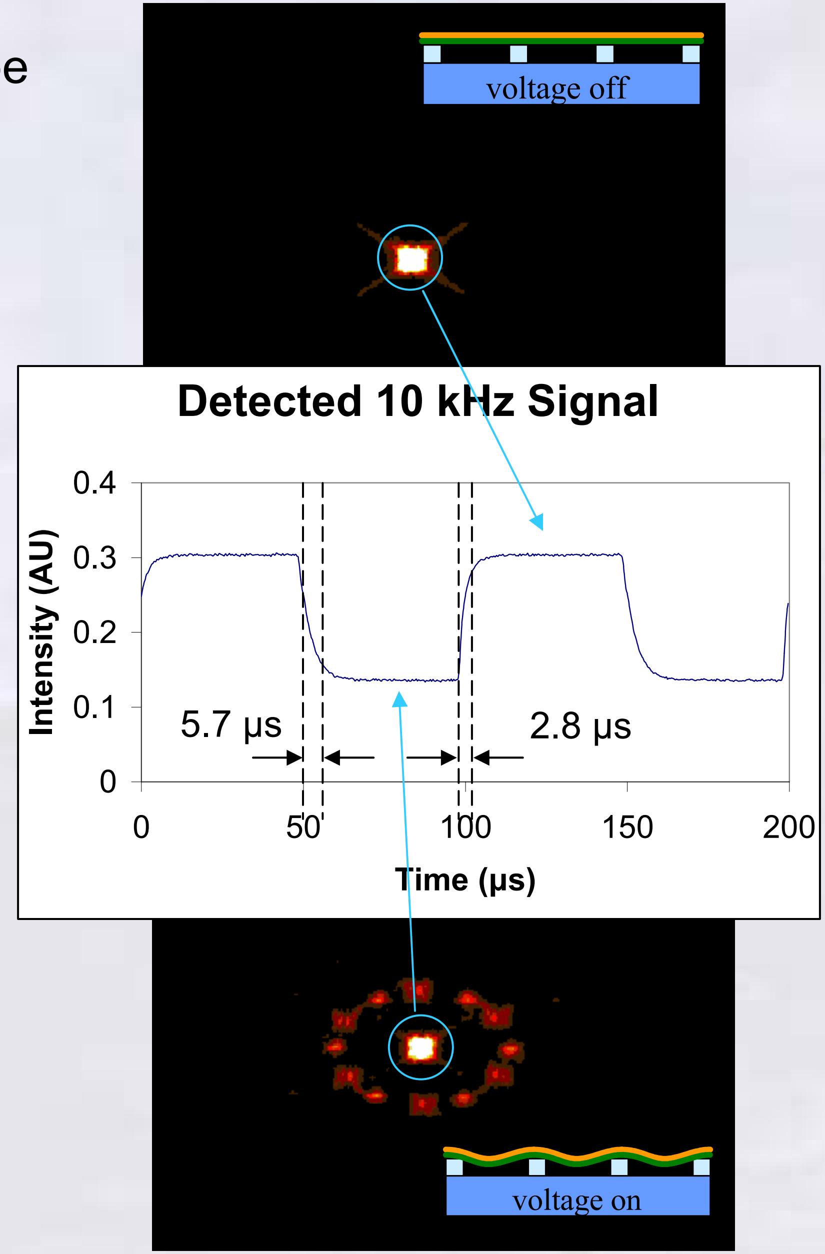
Experiment confirms broad wavelength spectrum operation

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:

	Acceptance Angle	Wavelength Range	Switching Response	Extinction Ratio	Drive Voltage	Mechanical Deformation	Aperture
This work	+/- 35º	1.4-1.6 µm	10 kHz	2.4:1 (0 - 35º)	79 V	550 nm	1 cm
Projected	+/- 35º	Visible – 1.8 µm	100 kHz	10:1	85 V	800 nm	10 cm