Large-Stroke Continuous Membrane Deformable Mirror for Medical Diagnosis

Jet Propulsion Laboratory
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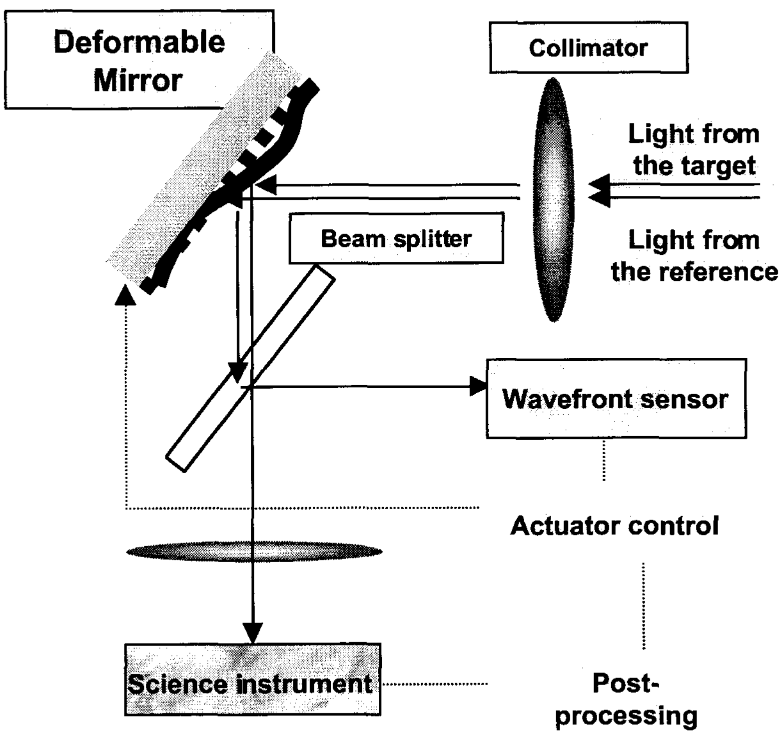
NASA Medical Technology Summit
Pasadena, CA

Adaptive Optics



- **Adaptive Optics**

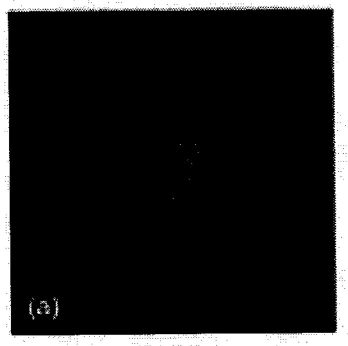
: Optical system to compensate for optical effects introduced by the medium between the object and its image.

- **Deformable mirror**

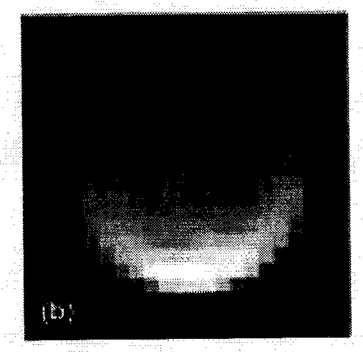
: Device capable of correcting time-varying aberrations in image.

Without Adaptive Optics

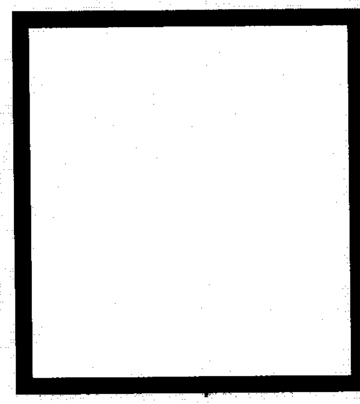
Titan (Saturn's Largest Moon)

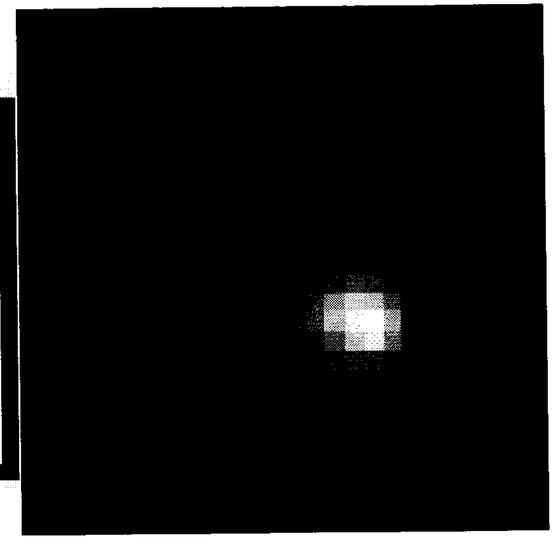


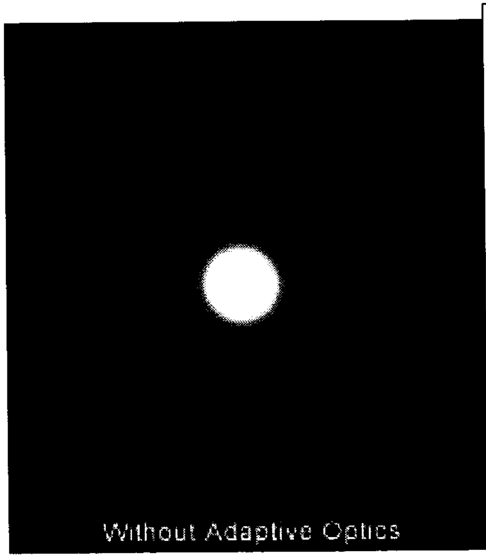
Conventional Telescope



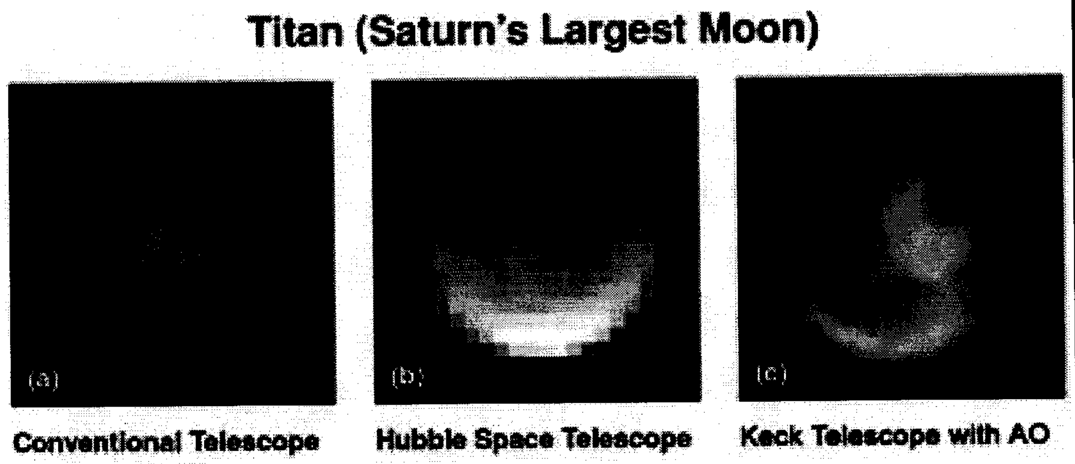
Hubble Space Telescope

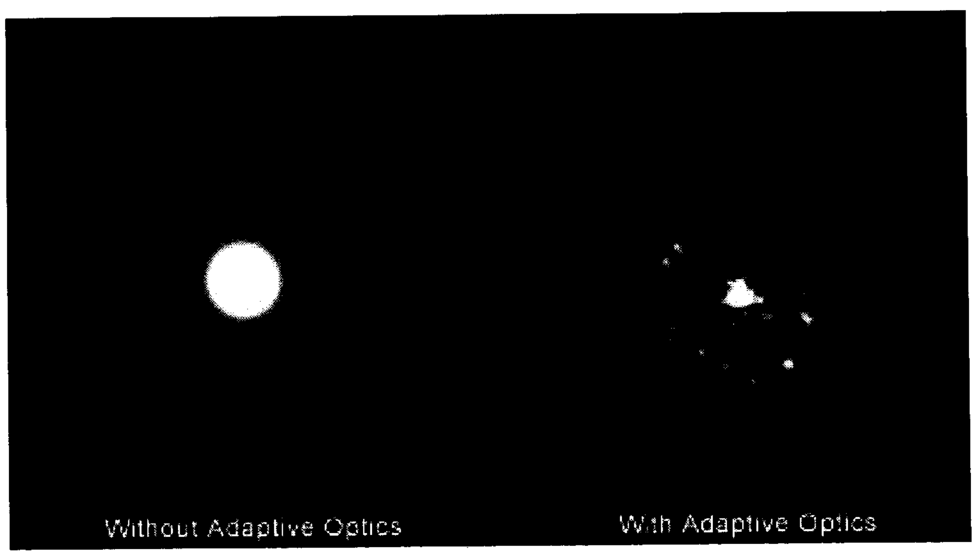


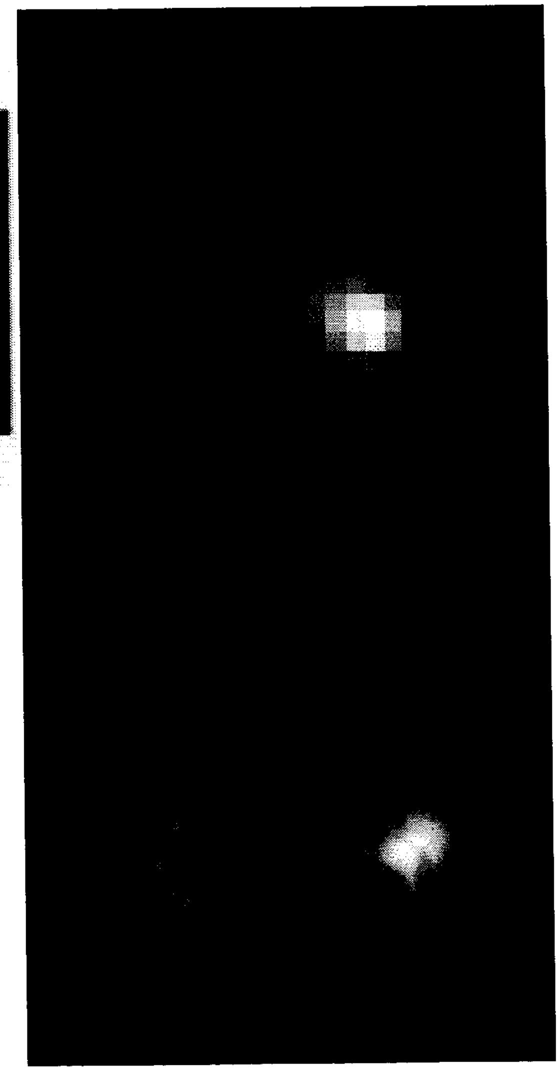




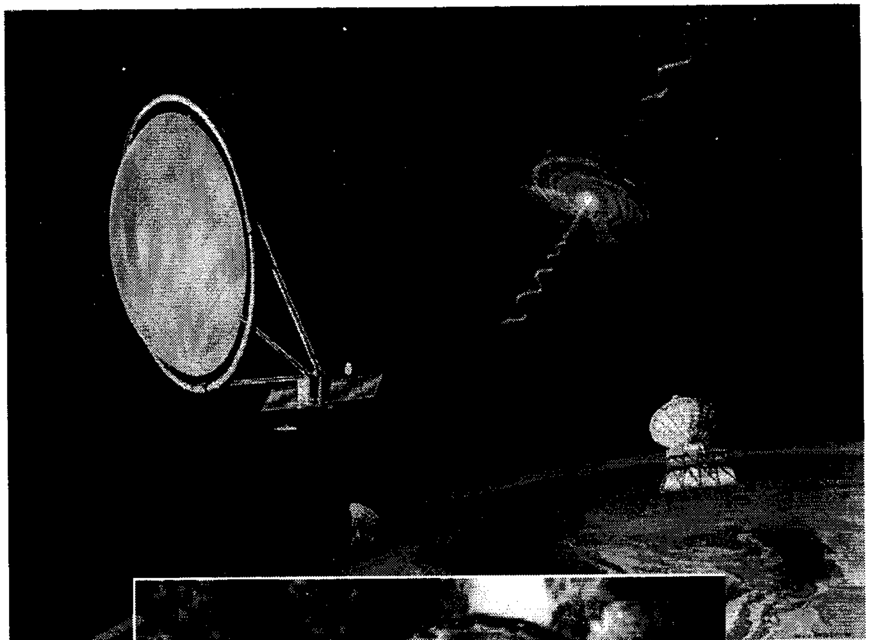
With Adaptive Optics

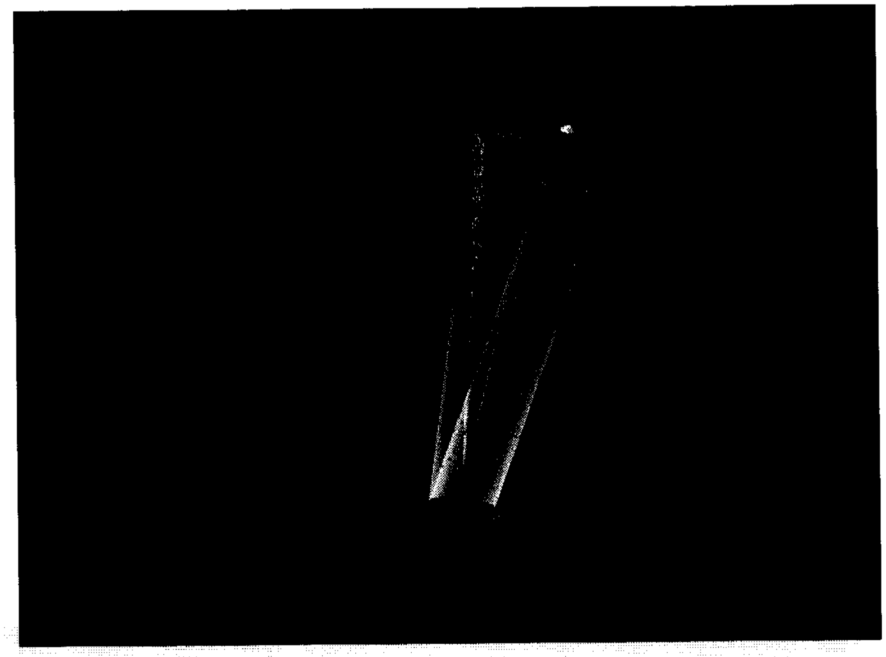






Adaptive Optics for Gossamer Apertures





Gossamer primary mirror structures:

Would require tertiary adaptive optics to compensate for large wavefront errors.

Need "very" high stroke deformable mirrors:
- Continuous membrane
- Stroke: > 10 μm

Adaptive Optics for Visual Science

- The AO technology for telescopes and vision science are surprisingly similar.

- In retinal imaging, the limits to microscopic imaging of the human eye are the monochromatic aberrations of the cornea, the lens, ocular medium in front of the retina.

- High resolution imaging of the live human retina gives clues and has the potential to help in the early detection and treatment of diseases, thereby helping in the prevention of vision loss.

- Studying basic properties of photoreceptors at high spatial and temporal resolution has the potential to revolutionize our understanding of human vision with potential application in fields such as robotic vision.

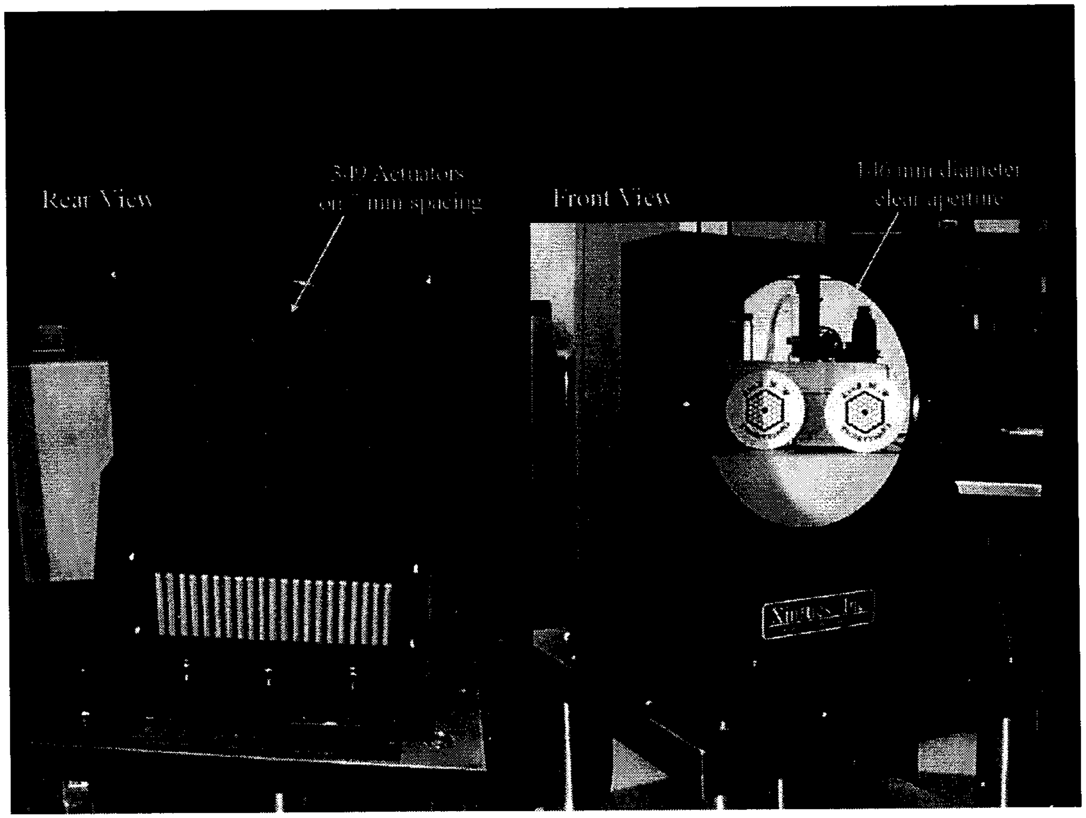
Adaptive Optics for Visual Science

Requirements of a deformable mirror for retinal imaging

Mirror membrane	High fill factor	Continuous membrane (100% fill factor)
Actuator spacing (μm)	-	800
Mirror diameter (mm)	10	10
Number of actuators	100-200	140
Stroke (μm)	+/- 6	12 (Goal)
Drive voltage (V)	-	20
Influence function (%)	-	10

Without Adaptive Optics | With Adaptive Optics

PZT/PMN Deformable Mirrors



http://www2.keck.hawaii.edu:3636/realpublic/inst/ao/about/slides/dmirror.html

Advantage

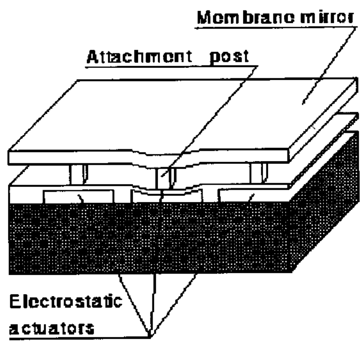
-Precise, Optical quality

Disadvantage

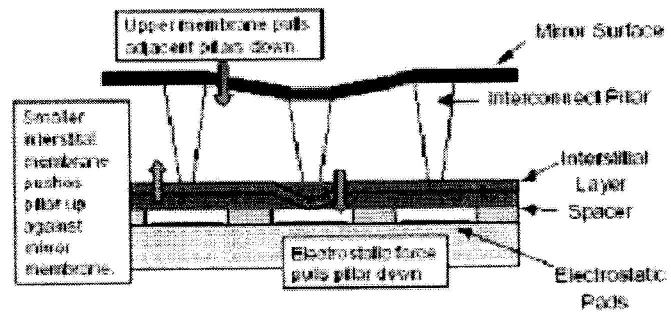
- Stroke/size limitation

  ➔ ~~> 10μm~~

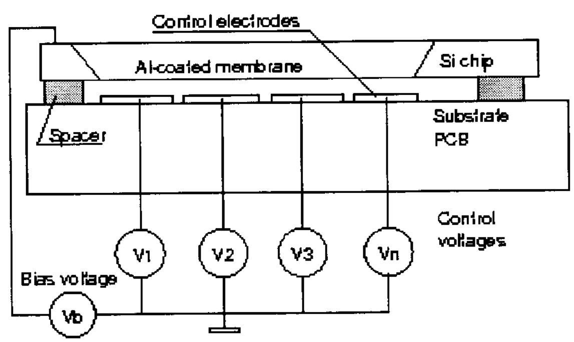
Micromachined Deformable Mirrors



BU MEMS-DM



Stanford MEMS-DM



DU MEMS-DM

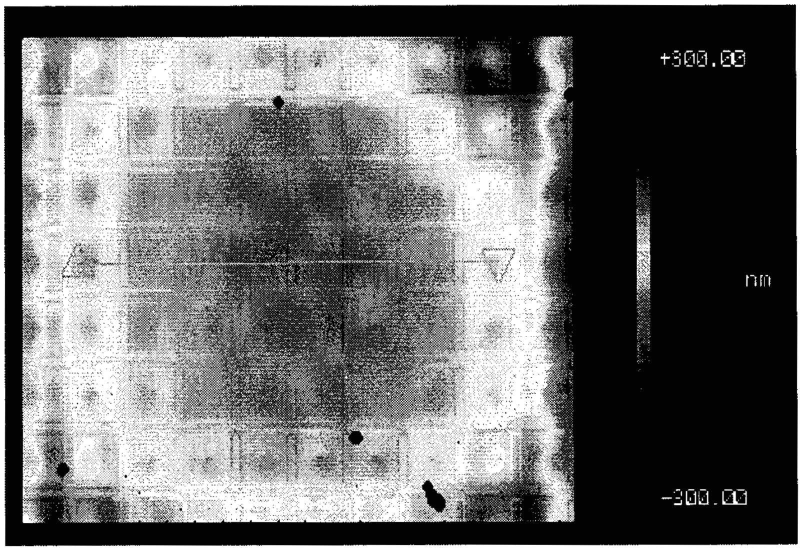
Advantage

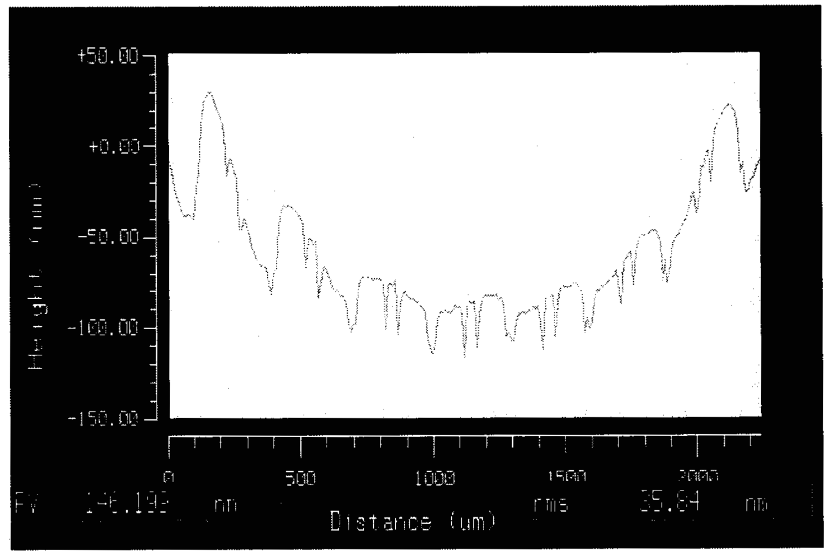
- Compact, low power, low cost

Disadvantage

- Marginal mirror quality
- Stroke limitation

Surface Figure of a Micromachined Deformable Mirror (BU)





Line Scan ~ 8 actuators: rms: 35.84 nm

Challenge and Benchmark

Develop a continuous membrane, large-stroke, optical quality deformable mirror

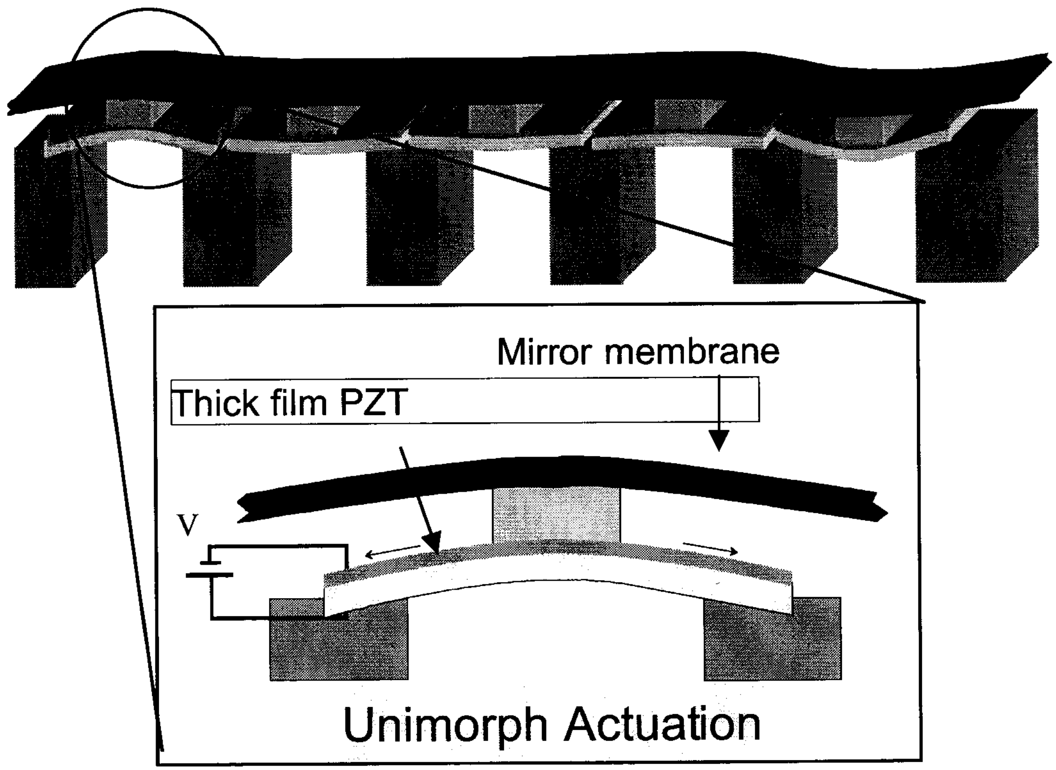
- Competitive approaches

- Marginal mirror quality and/or limited stroke

- JPL deformable mirror provides

- Large-stroke mirror: Unimorph actuation ➔ Transfer wafer-scale membrane onto the high stroke actuator array
- Optical quality continuous mirror: Transfer optical quality membrane

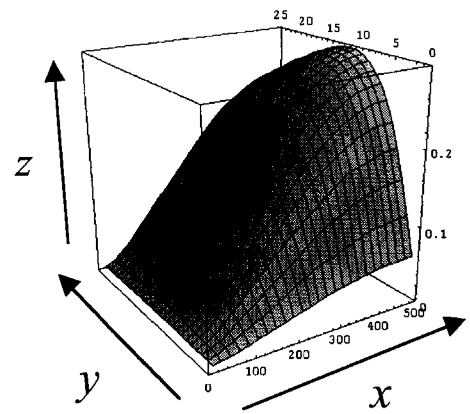
PZT Unimorph Deformable Mirror Concept



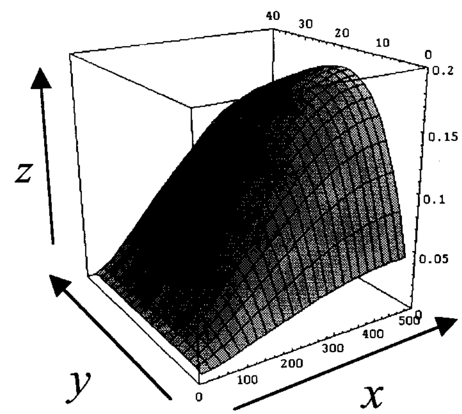
-Transfer of a mirror membrane

- Unimorph actuation for high stroke actuation: small strain obtainable from a piezoelectric material is translated into large vertical displacement

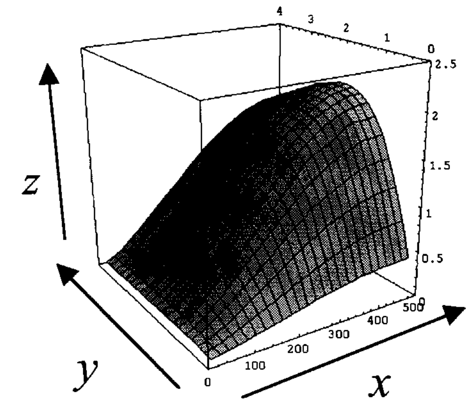
Modeling Results: Optimization



Base: 16 μm Si

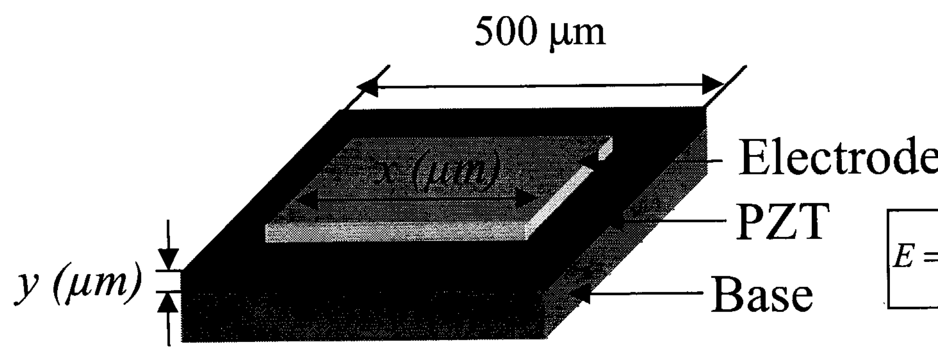


26 μm Si



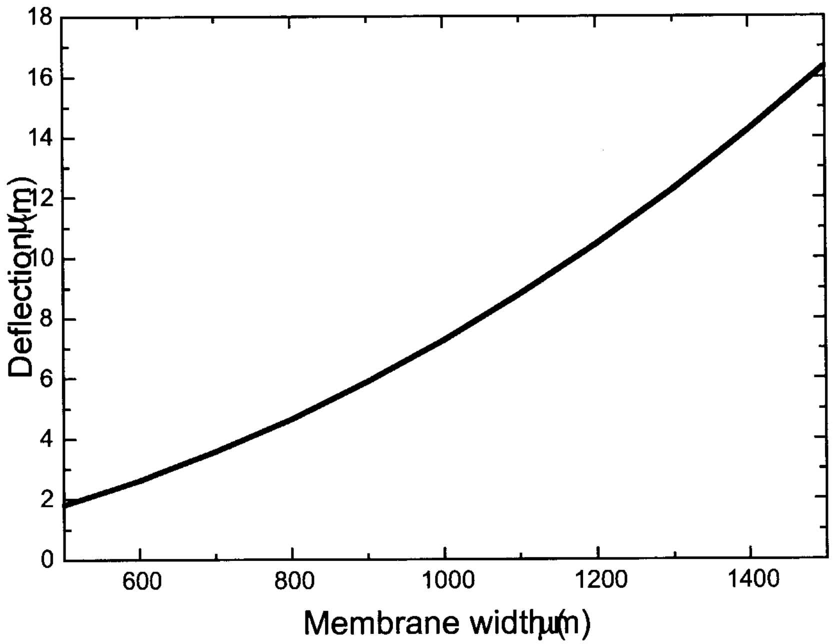
2 μm Si_xN_y

x: Electrode Length
y: PZT Thickness
z: Center Deflection

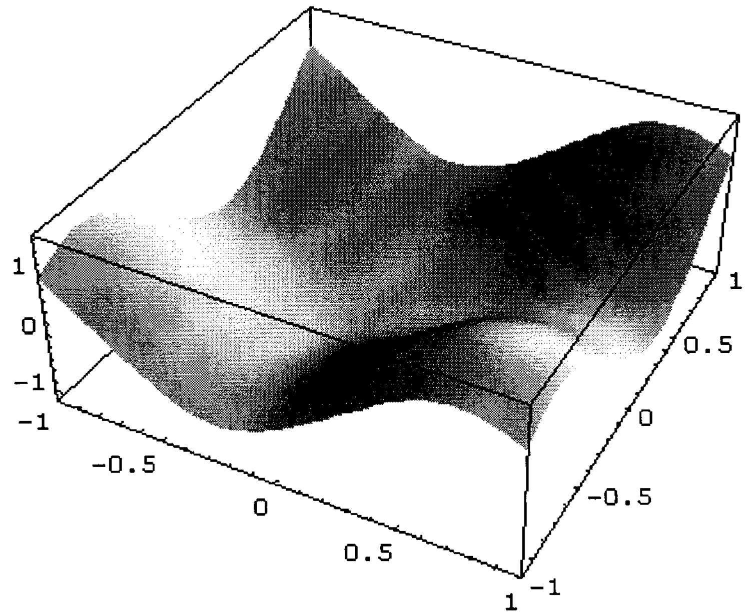


$$E = 1\frac{V}{\mu m}$$

Modeling Results: Estimation of Performance

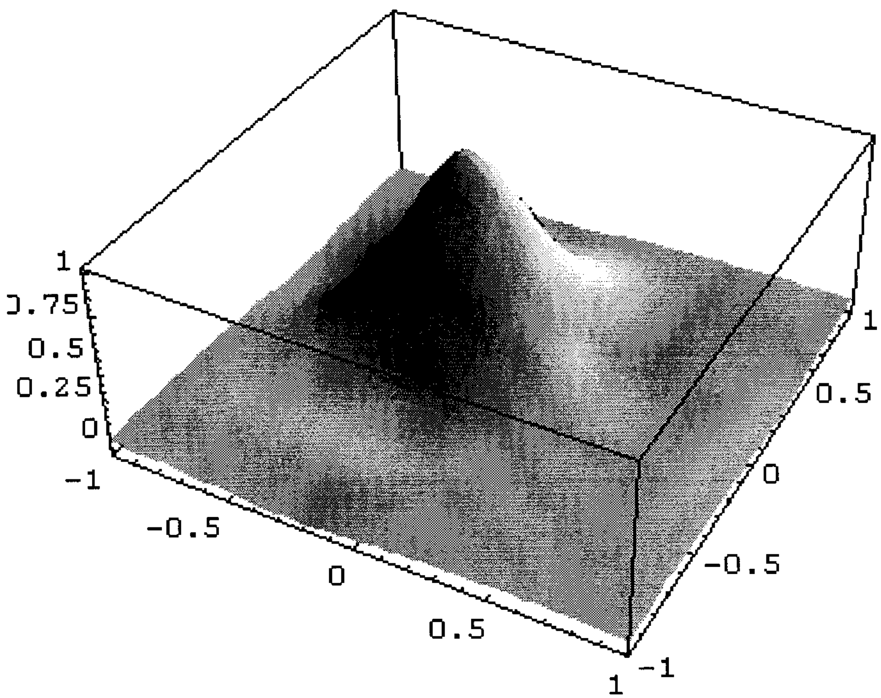


Actuator displacement at constant field vs. actuator size.



Membrane profile with one actuator at 1 V/μm, all others at 0 V/μm.
(Vertical scale is in microns, lateral in mm)

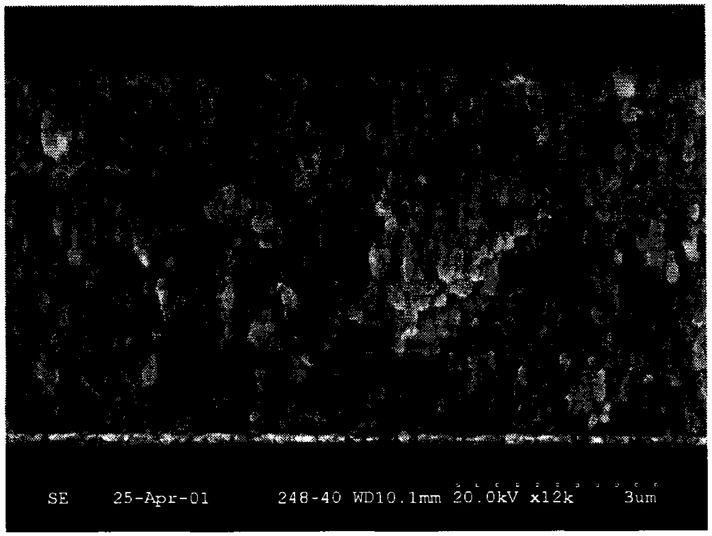
Modeling Results: Estimation of Performance

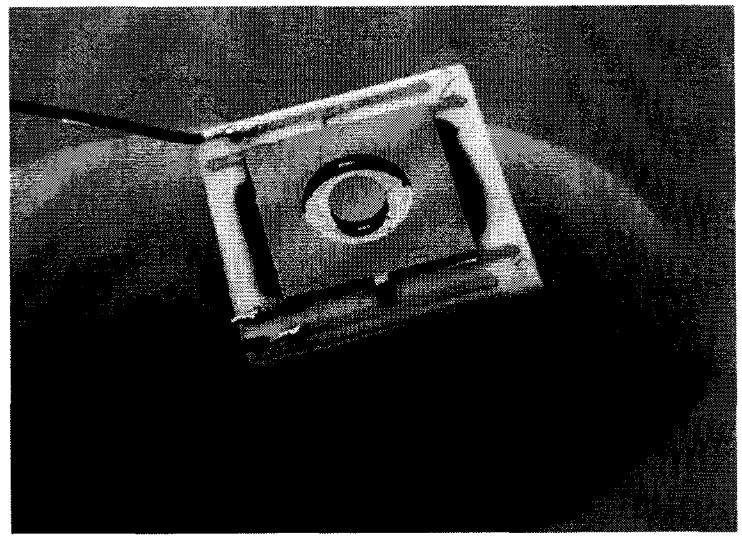


0.075	0.047	-0.752	0.047
0.296	-0.752	1.458	-0.752
0.075	0.047	-0.752	0.047
-0.020	0.075	0.296	0.075

Mirror membrane profile with a single actuator required to be at 1 μm (V/μm = 1.458), while all other actuators are set at zero displacement. The electric field values in V/μm required to achieve this membrane displacement profile are shown in the accompanying table.

Thick-Film PZT Actuator Technology

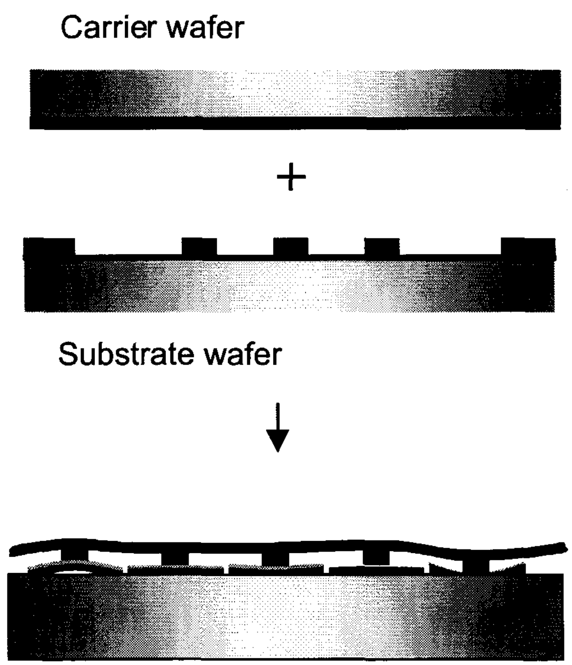




On existing diaphragm structures with diameters of 500 μm, center deflections of >3 μm have been achieved using comparatively thin PZT films (~1.5 μm).

➔ Currently we are trying 7 μm thick PZT with PSU.

Wafer-Level Membrane Transfer Technique

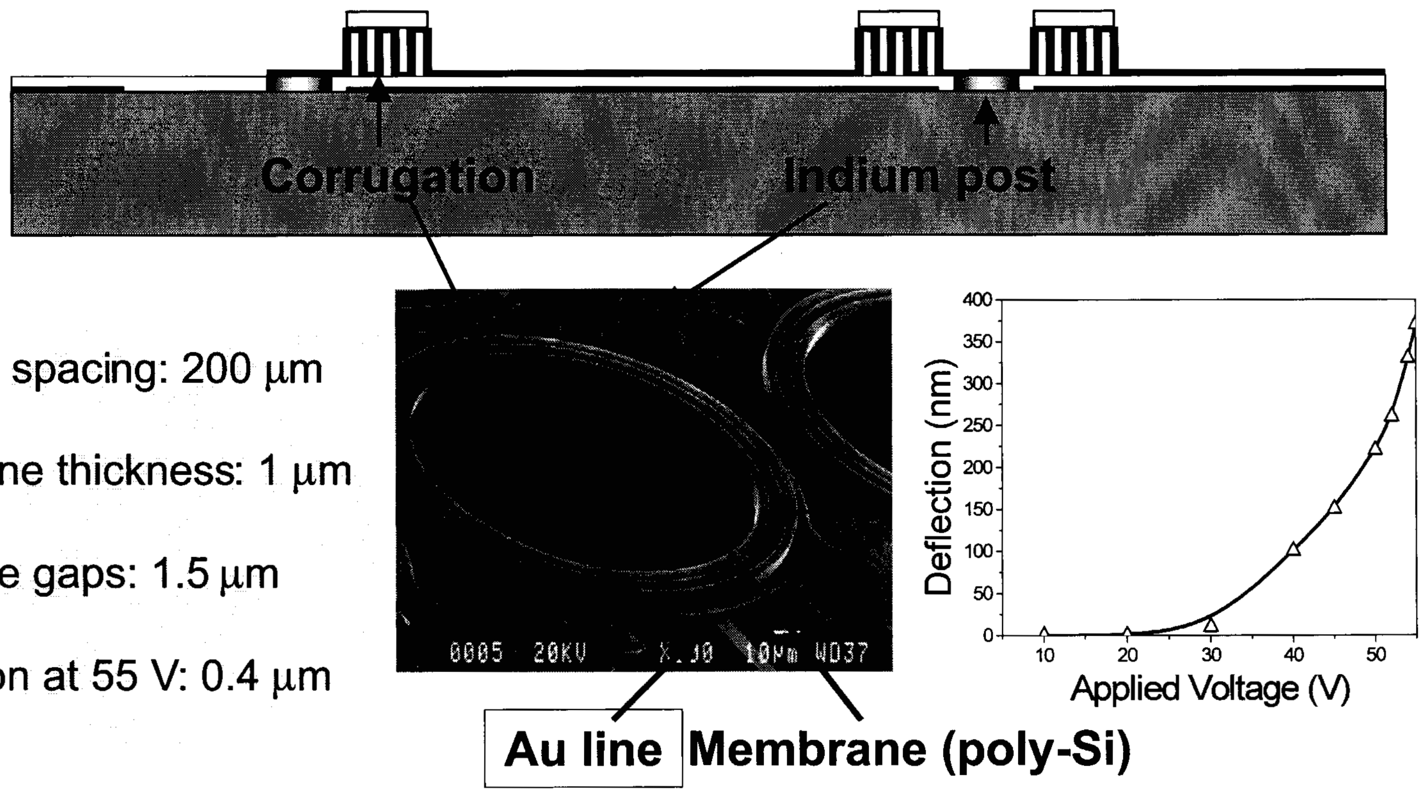


- Transfer of an optical quality mirror membrane from one wafer to another

- Surface quality: Transferred membrane is a replica of the carrier wafer.

- Various optical materials can be transferred onto various substrates.

Transferred Corrugated Membrane Actuators



Actuator spacing: 200 µm

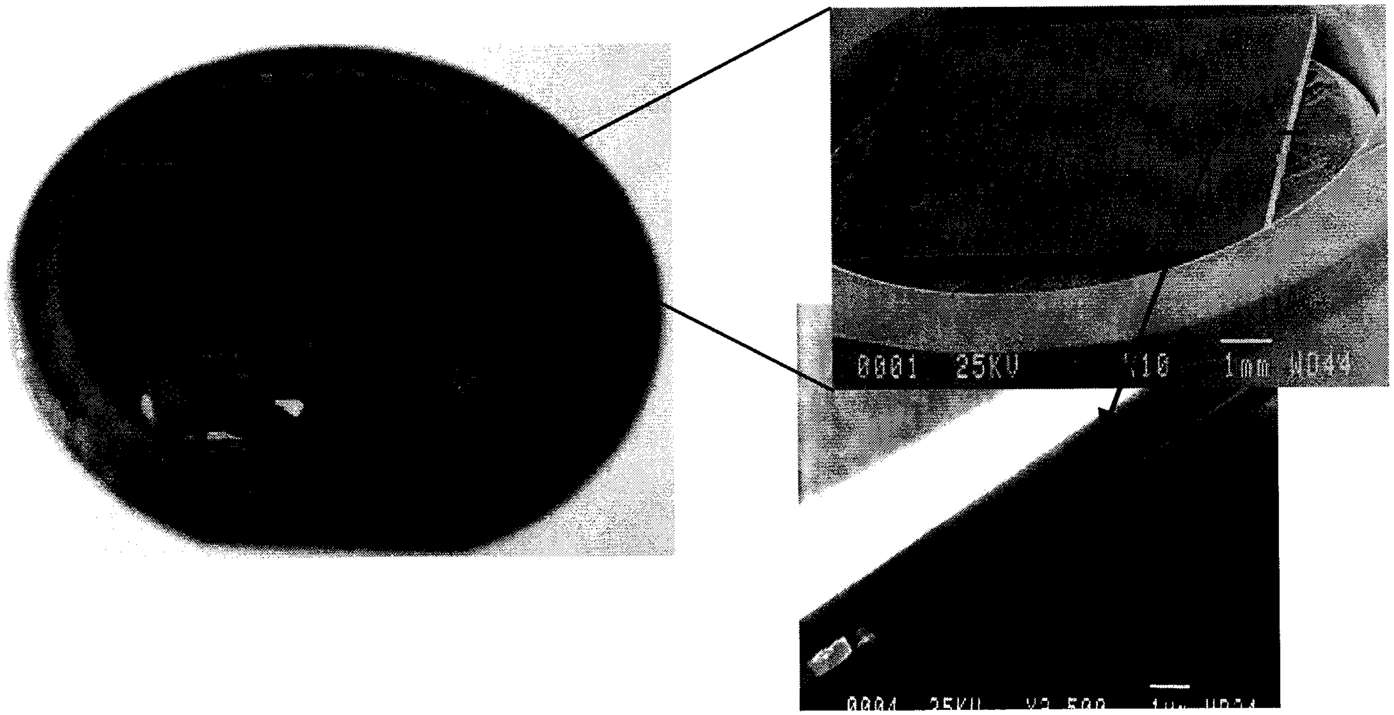
Membrane thickness: 1 µm

Electrode gaps: 1.5 µm

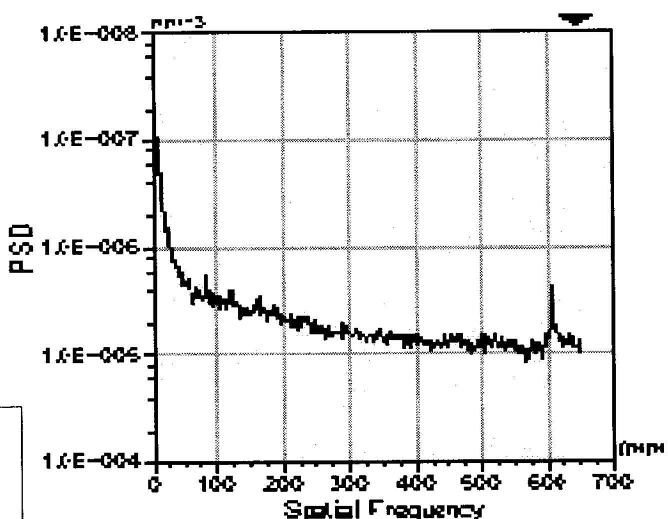
Deflection at 55 V: 0.4 µm

Successful transfer of a free-standing membrane

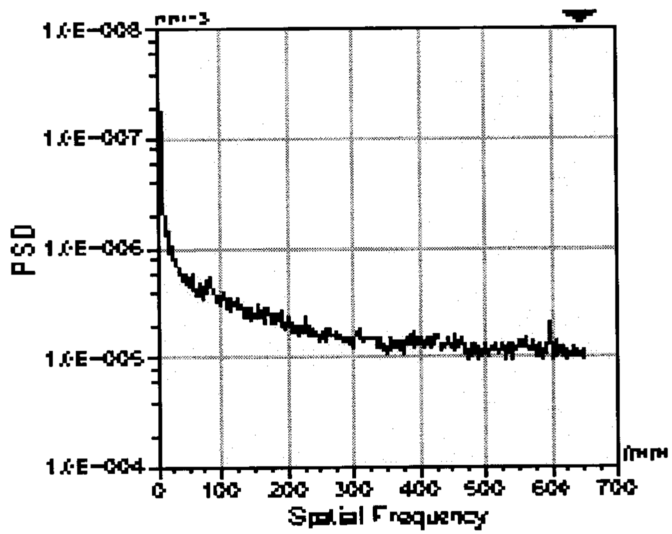
Wafer-Level Transferred Membrane



X Average PSD Plots

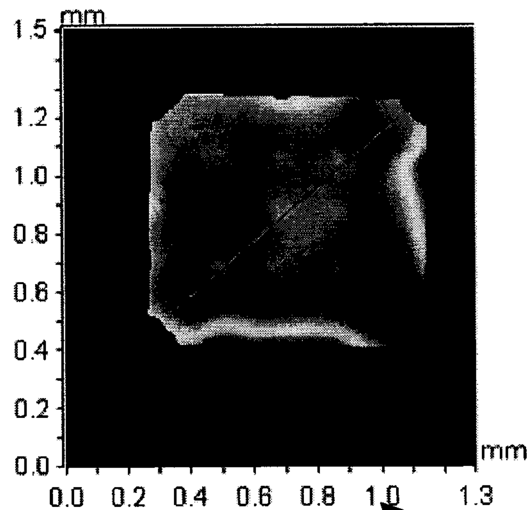


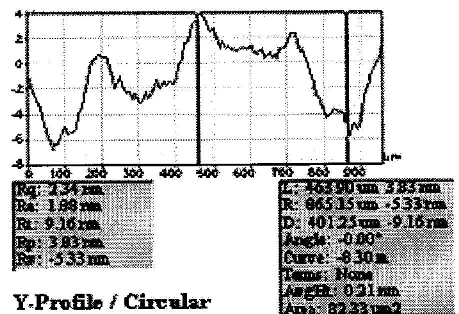
A transferred silicon membrane

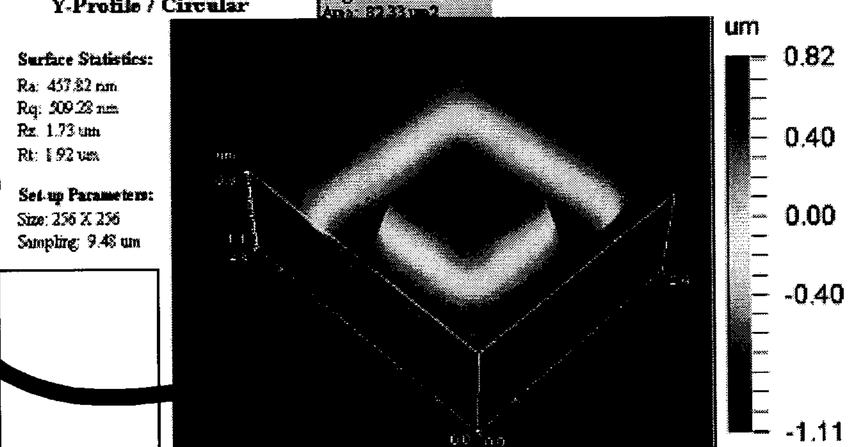


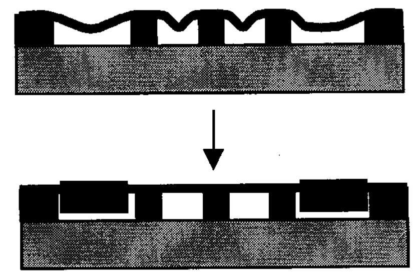
A typical silicon wafer

Surface Figure of a Transferred Membrane



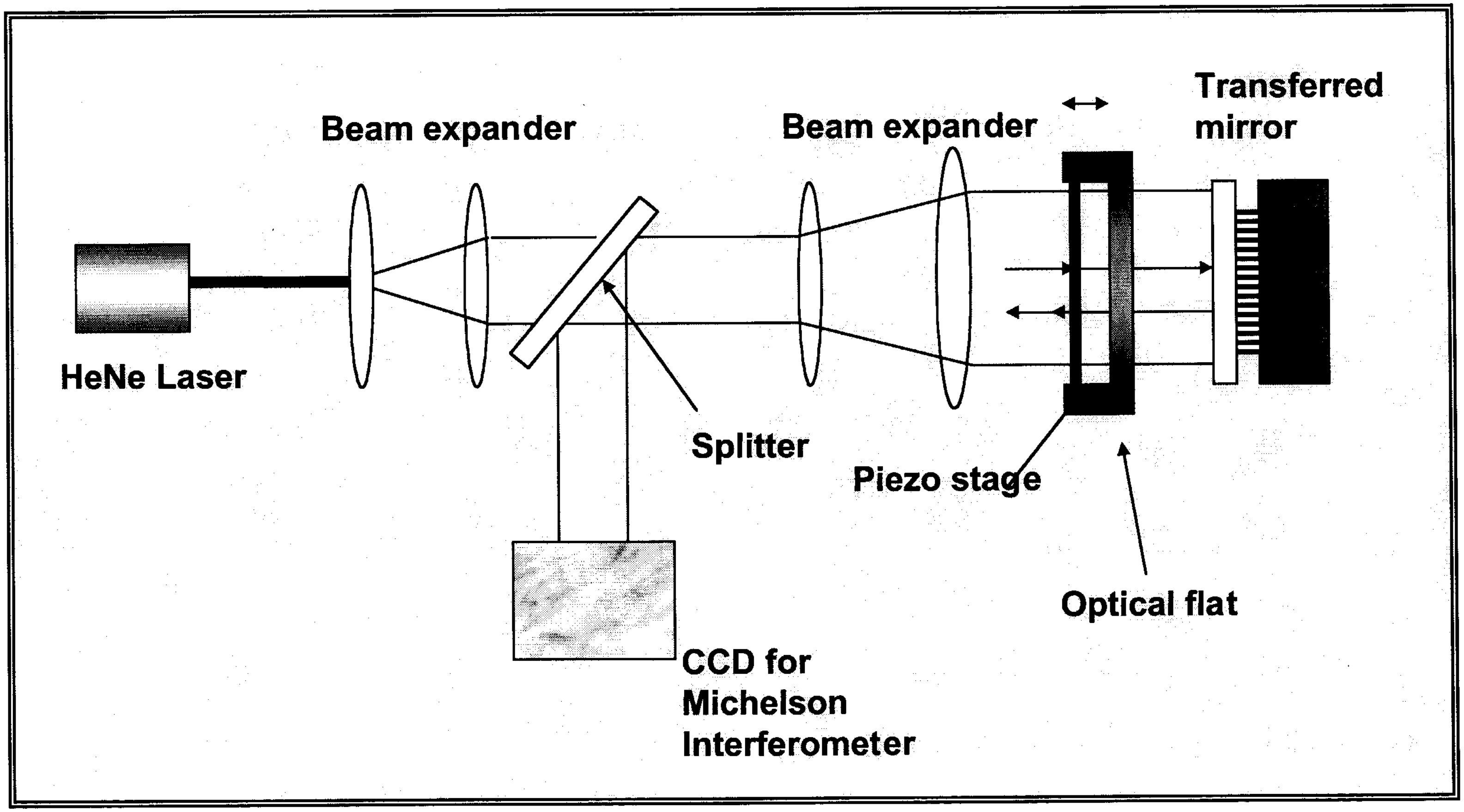






Surface figure error:
0.2 nm rms, 0.9 nm p-v
➔ << λ/20

Full Scale Surface Figure Measurement



R & D Status

- **Achieved**
  - *Developed a membrane transfer process technology for the fabrication of optical quality mirror membrane.*
  - *Developed the design and process technologies for the fabrication of the large-stroke unimorph PZT actuator array.*
- **Remaining**
  - *Full-aperture optical characterization*
  - *Development of a reliable deformable mirror device by combining the mirror transfer technology with the PZT actuator technology.*

Intellectual Property

- **Patent Applications**
- **E.H. Yang** and D. Wiberg, "A wafer-level transfer of membranes in semiconductor processing, CIT-3325-PCT, US Patent Pending
- **Public Disclosures**
- **NASA Tech Briefs:**
  - E.H. Yang and D. Wiberg, "A wafer-level membrane-transfer process for fabricating MEMS" (NPO-21088)
- **Publications:**
  - E. H. Yang, "A Wafer Transfer Technology for MEMS Adaptive Optics," *CfAO MEMS Workshop*, CfAO, UC Berkeley, Feb. 2002.
  - E. H. Yang and Dean V. Wiberg, "A Wafer Transfer Technology for MEMS Adaptive Optics," *ASME International Mechanical Engineering Congress and Exposition, Novel Micromachining Processes and Packaging for MEMS,* New York, New York, November 2001.
  - E. H. Yang and Dean V. Wiberg, "A New Wafer-Level Membrane Transfer Technique for MEMS Deformable Mirrors," *IEEE International Conference on Microelectromechanical Systems (MEMS '01) Conference*, Interlaken, Switzerland, Jan. 2000, pp. 80-83
  - E. H. Yang, Dean V. Wiberg, and Richard G Dekany, "Design and Fabrication of Electrostatic Actuators with Corrugated Membranes for MEMS Deformable Mirror in Space," *SPIE Int'l Symp. Optical Science and Technology, Vol. 4091*, San Diego, July 30 - Aug. 4, 2000, pp. 83-89.