# A Wafer Transfer Technology *for* MEMS Adaptive Optics

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  - ✓ Conventional Deformable Mirrors
  - ✓ MEMS-based Deformable Mirrors
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- ❑ Wafer Transfer Technology
- ❑ Surface Profile
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# MEMS Deformable Mirror Applications

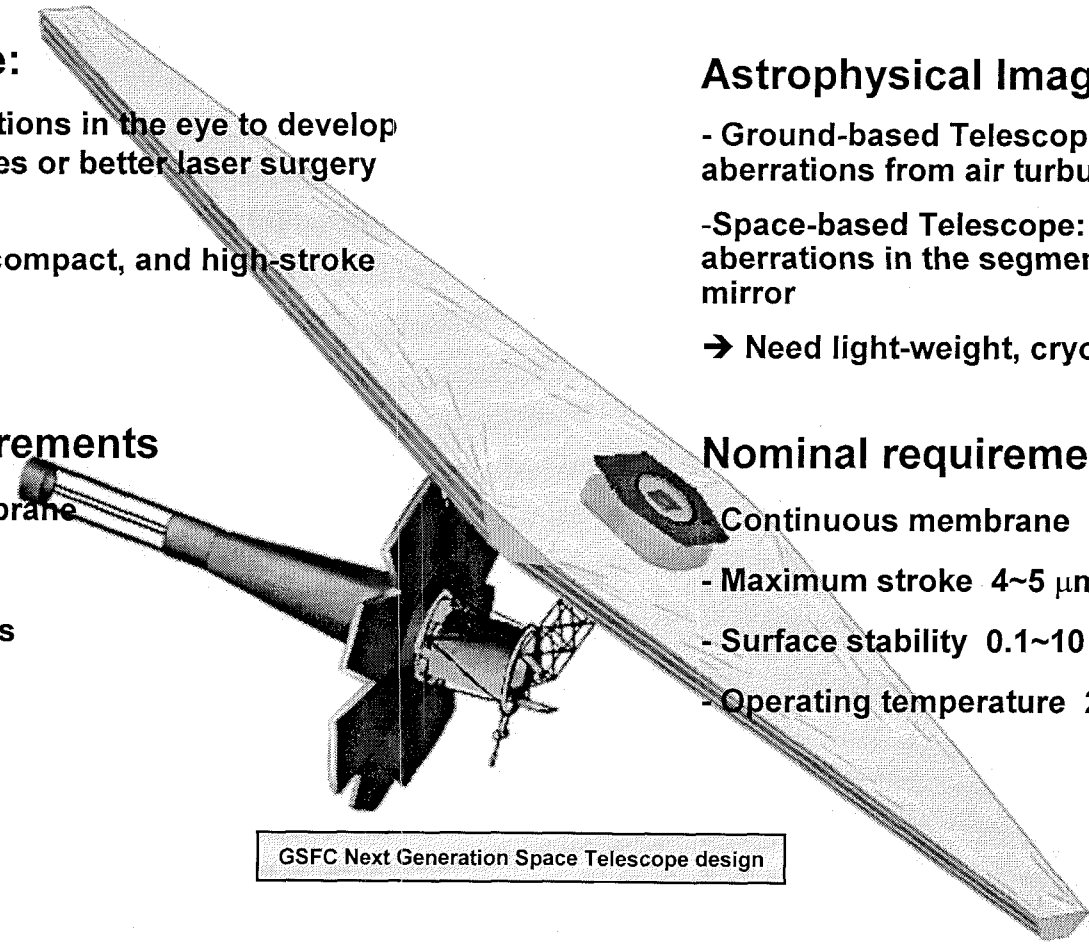
## Visual Science:

- Measuring aberrations in the eye to develop better contact lenses or better laser surgery procedures

→ Need low cost, compact, and high-stroke device

## Nominal requirements

- Continuous membrane
- 8 mm diameter
- 100 - 200 actuators
- +/- 6 μm stroke



GSFC Next Generation Space Telescope design

## Astrophysical Imaging

- Ground-based Telescope: to compensate aberrations from air turbulence

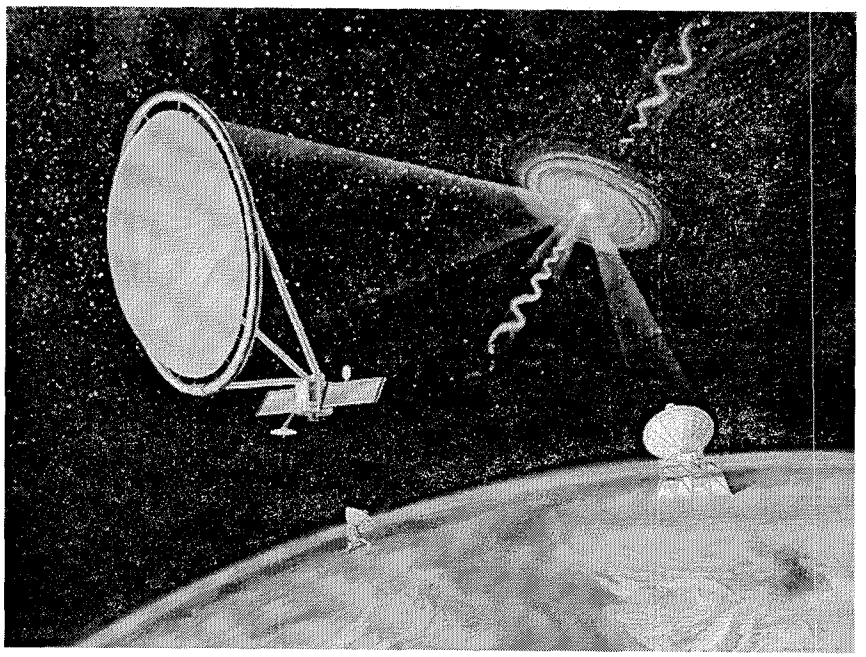
-Space-based Telescope: to compensate aberrations in the segmented primary mirror

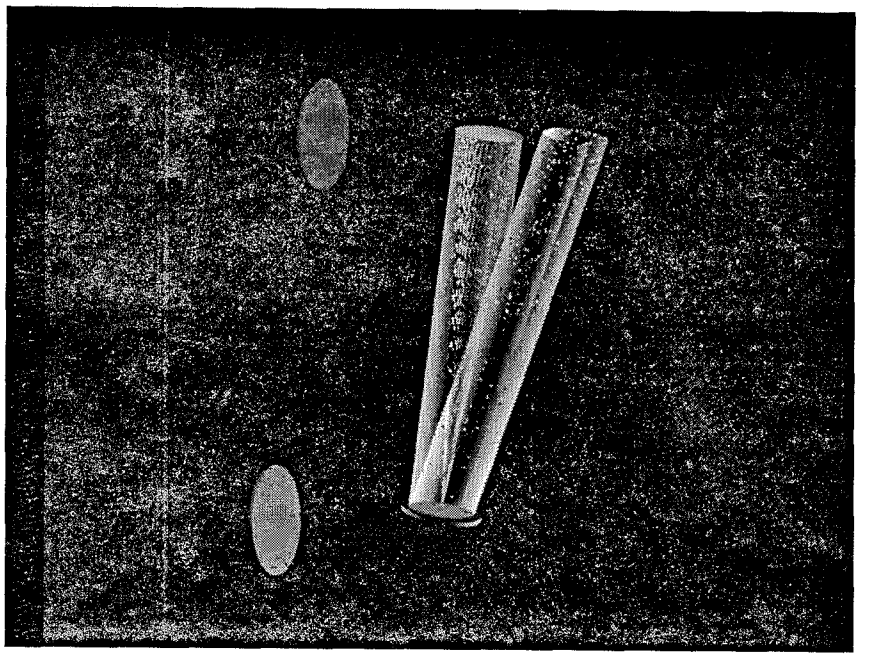
→ Need light-weight, cryogenic device

## Nominal requirements

- Continuous membrane
- Maximum stroke 4~5 μm
- Surface stability 0.1~10 nm/sec
- Operating temperature 20~55 $^{o}$K

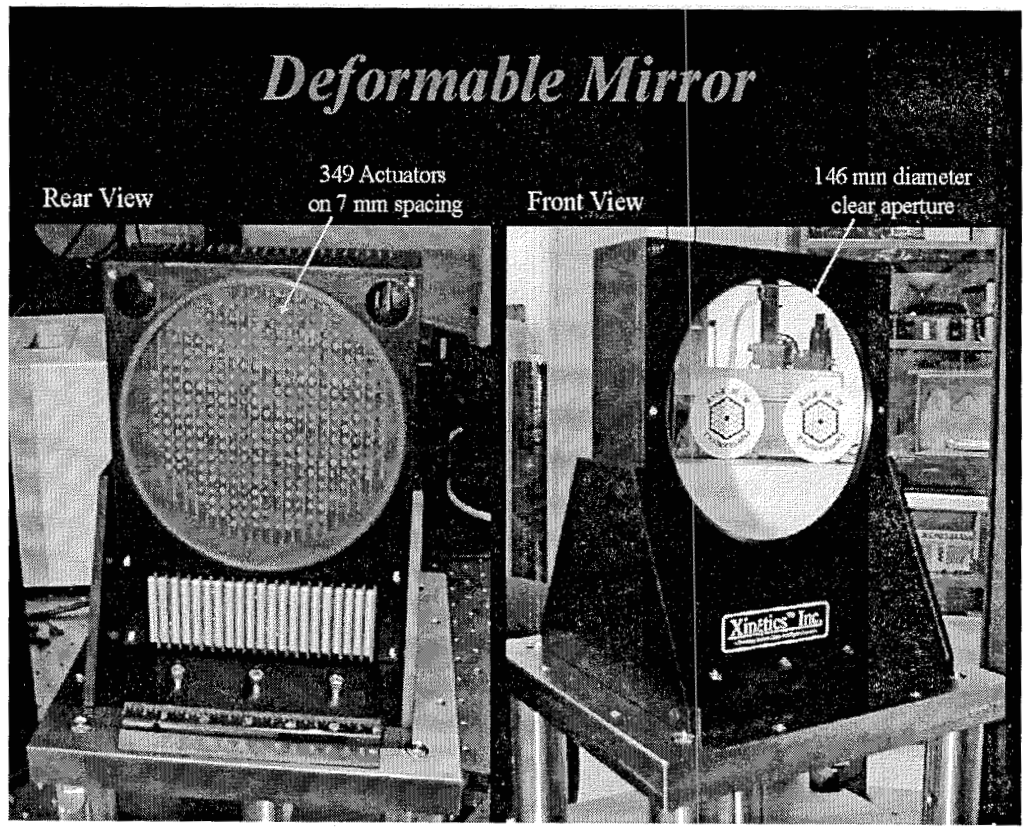
# Gossamer Apertures





Spacecraft formation flying geometry. Starlight entering from the top-right is collected by a Schmidt corrector mirror (bottom) then focused by the F/10 primary mirror (top). Also shown are two large sunshades (at left), which may be inflatable.

# Conventional Deformable Mirrors




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

**Piezo ceramic or electrostrictive deformable mirrors**

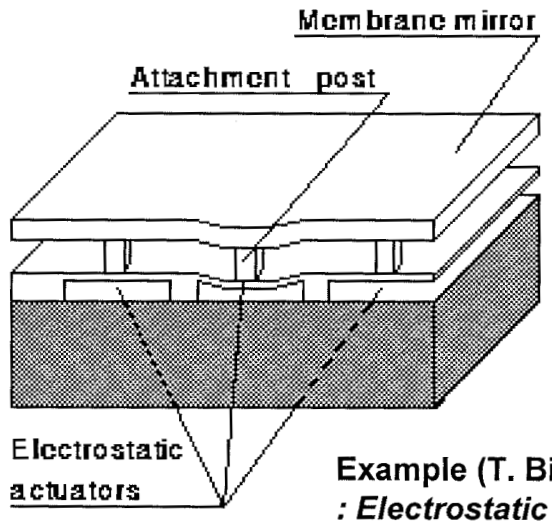
**<Compensating aberrations from air turbulence for Ground-based telescopes>**

- ***Precise, Optical quality***
- ***Temperature limitation***
- ***Stroke/size limitation***

# Continuous Membrane MEMS Deformable Mirrors

## Continuous membrane mirror

- No diffraction of the reflected beam
  - Ensuring smooth and continuous phase variations across the mirror




Example (T. Bifano *et al.*)
*: Electrostatic MEMS-DM*

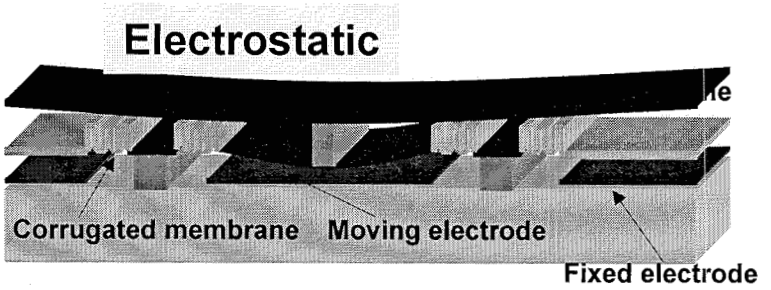
## MEMS-based deformable mirror

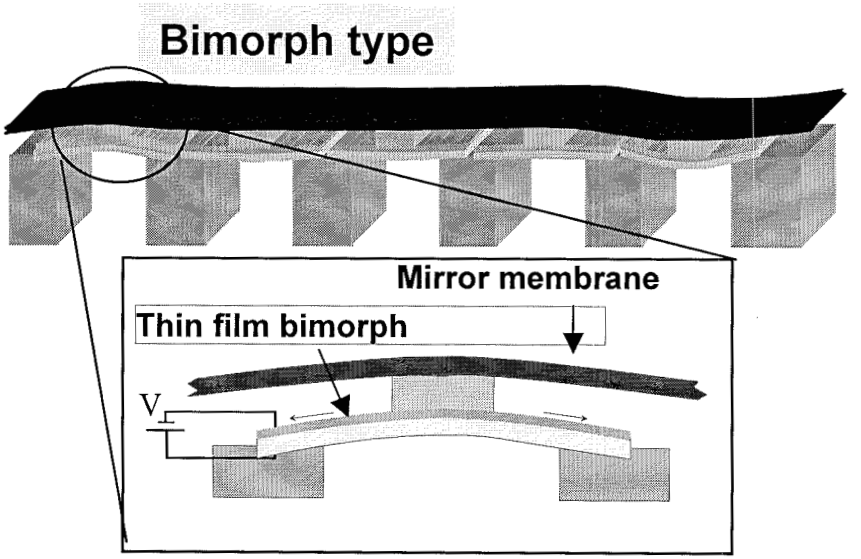
*- Compact, low power, lower cost*

*- Mirror quality*

*- Stroke limitation*

# Quality MEMS Deformable Mirror Concepts



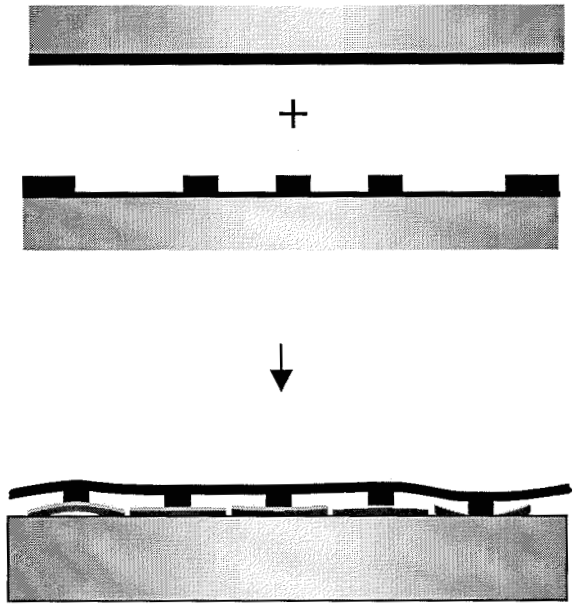

Transferred mirror membranes for optical quality deformable mirrors

- Electrostatic actuation for precision operation

- Bimorph actuation for large stroke actuation

- Large stroke actuators are essential for high order wavefront compensation for segmented telescopes and inflatable reflectors.

# Wafer Transfer Process*



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

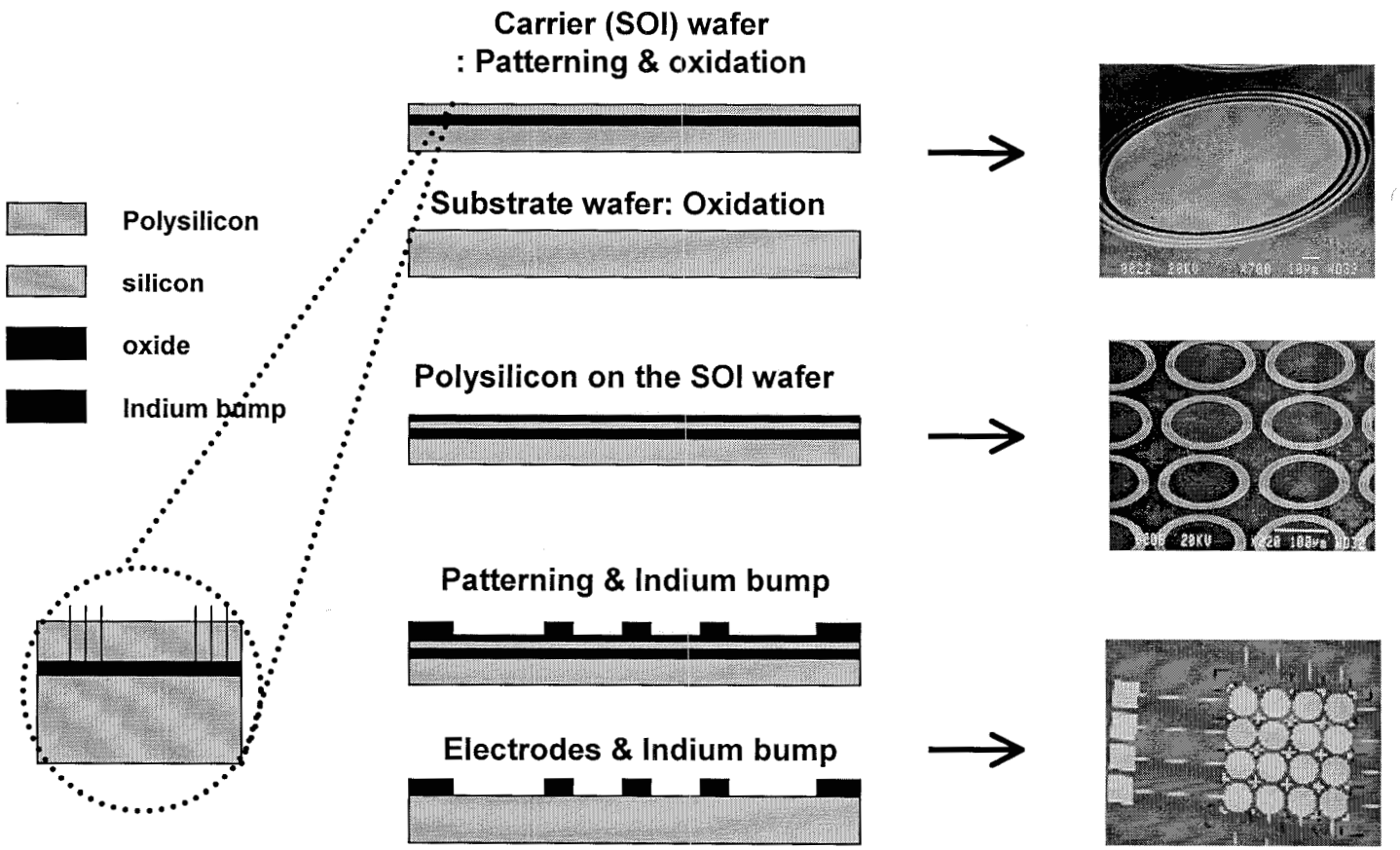
- Surface quality: Transferred membrane is a replica of the carrier wafer.

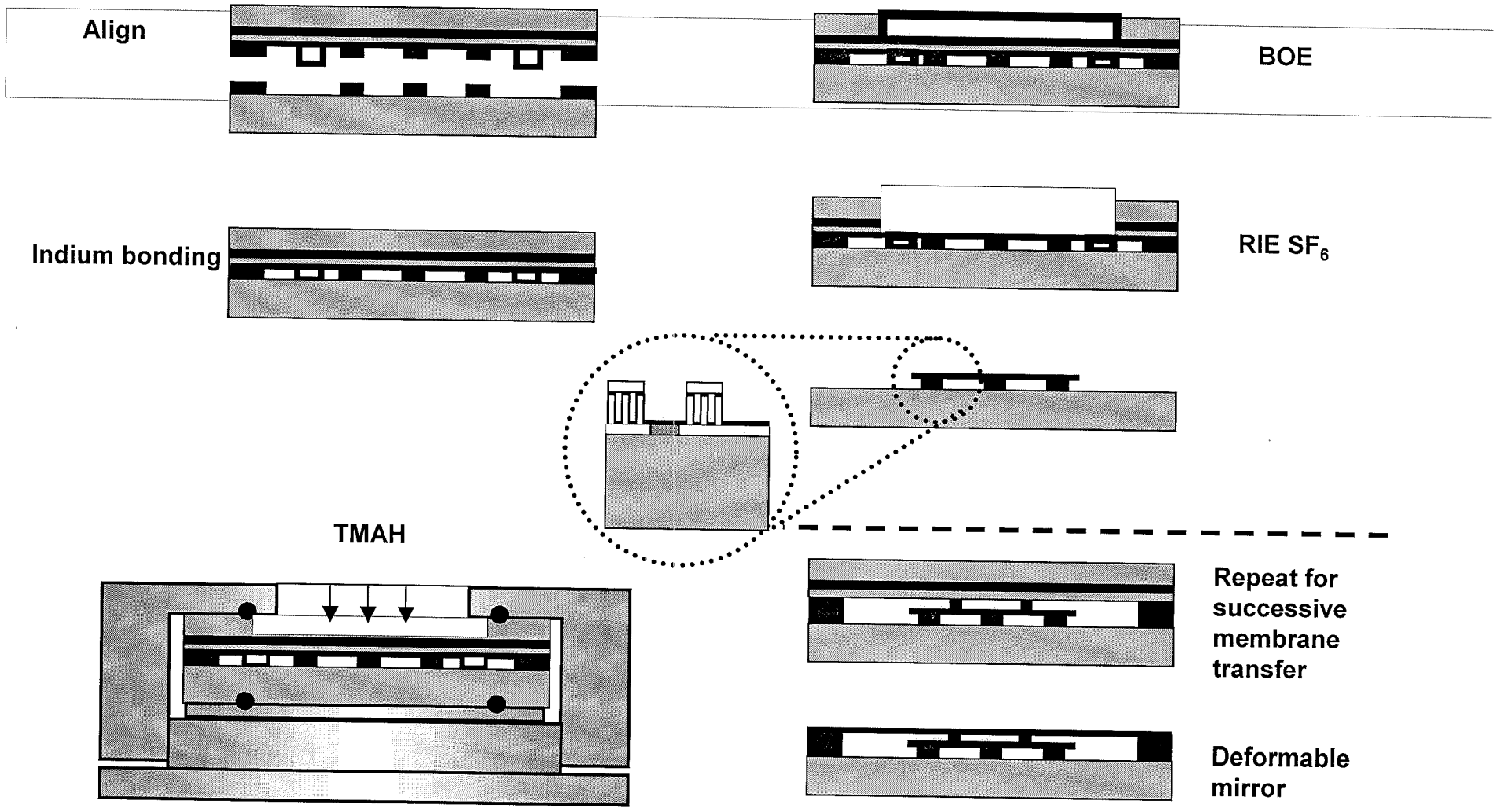
- Several optical materials can be transferred.



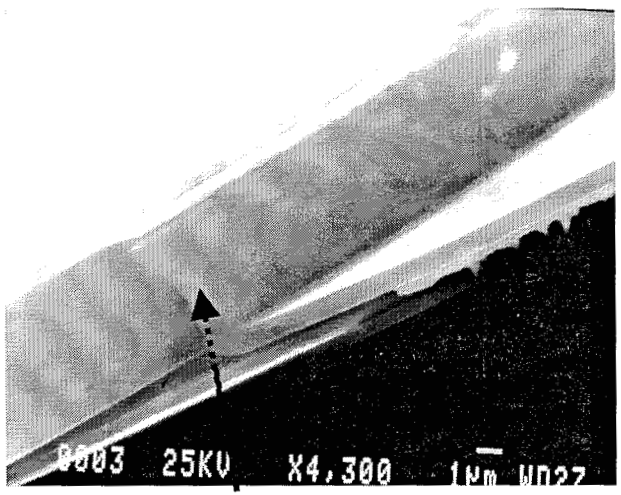
*Patent pending

# Transfer of a 1 μm thick Corrugated Poly-Si Membrane

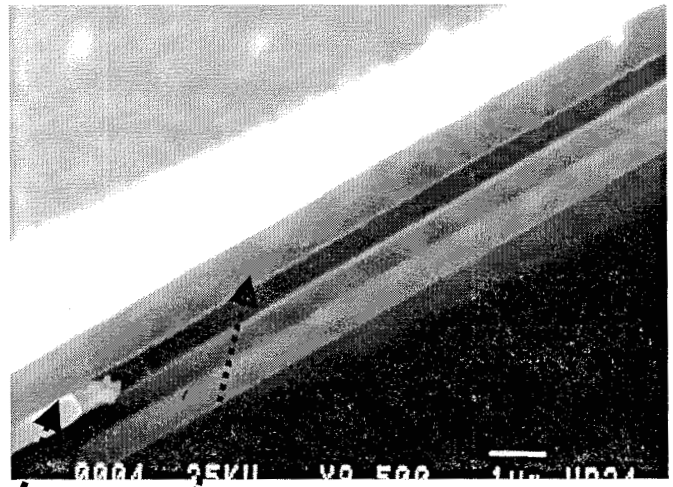



Align
BOE
Indium bonding
RIE $SF_6$
TMAH
Repeat for successive membrane transfer
Deformable mirror

# Transferred Interface



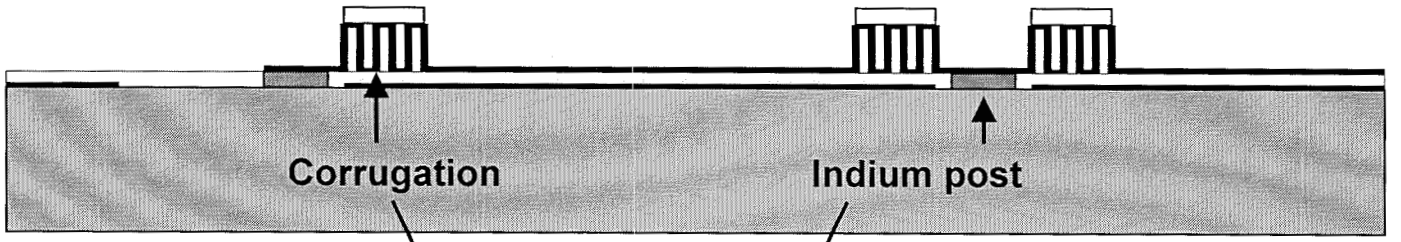

Corrugated polysilicon



Indium post

Transferred polysilicon membrane

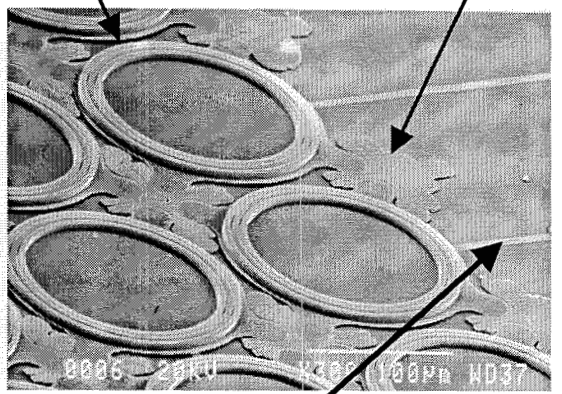
# Transferred Corrugated Membrane Actuators

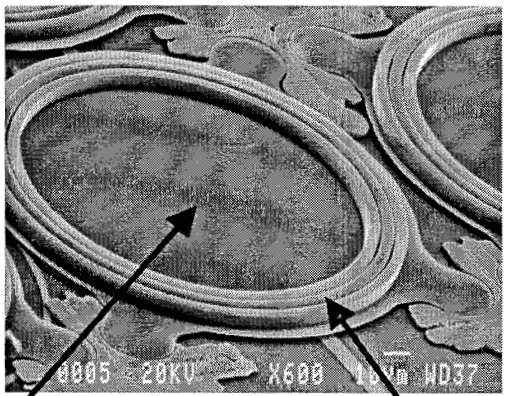



Electrode gaps: 0.7~4 μm

Pixel-to-pixel spacing: 200 μm

Thickness of the polysilicon membrane: 1 μm



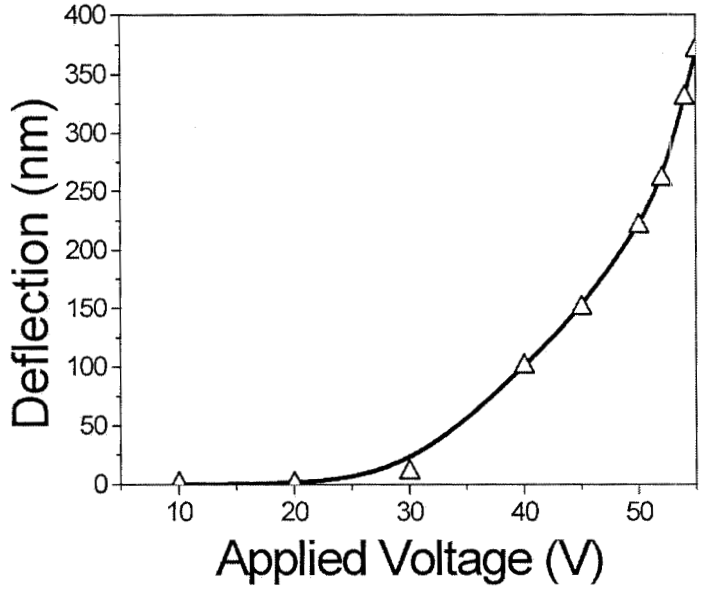


Au line

Membrane (poly-Si)

corrugation

# Electrostatic Actuation of a Transferred Membrane




**Polysilicon actuator membrane**

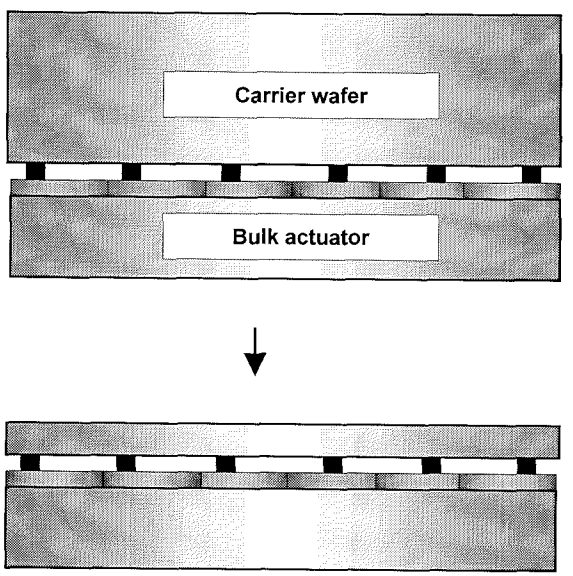
**Electrode gaps: 1.5 μm**

**Pixel-to-pixel spacing: 200 μm**

**Membrane thickness: 1 μm**

**Deflection at 55 V: 0.4 μm**

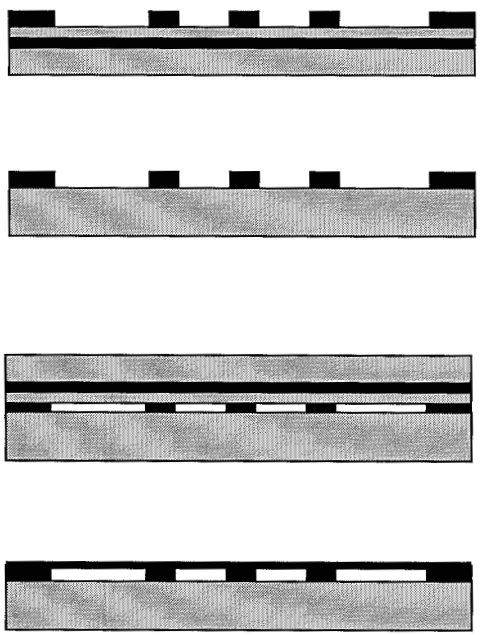
# Transferred Single Crystal Silicon Deformable Mirror Concept

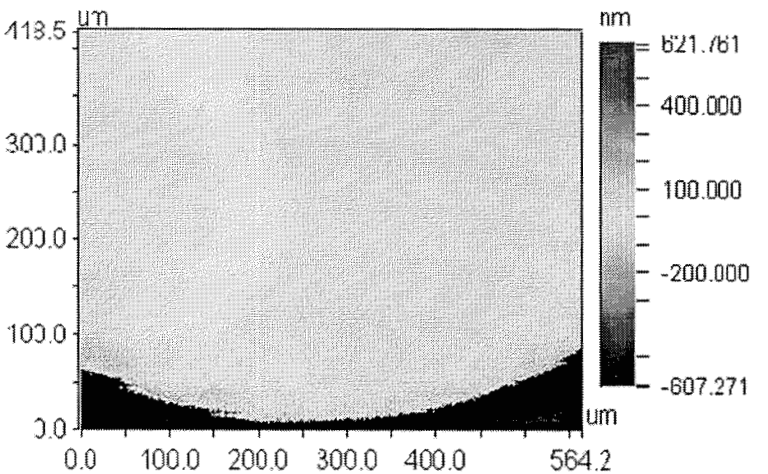



- SCS mirror transfer directly to robust actuator columns to provide high quality deformable mirror

-Further miniaturization possible by incorporating thinner mirror plate

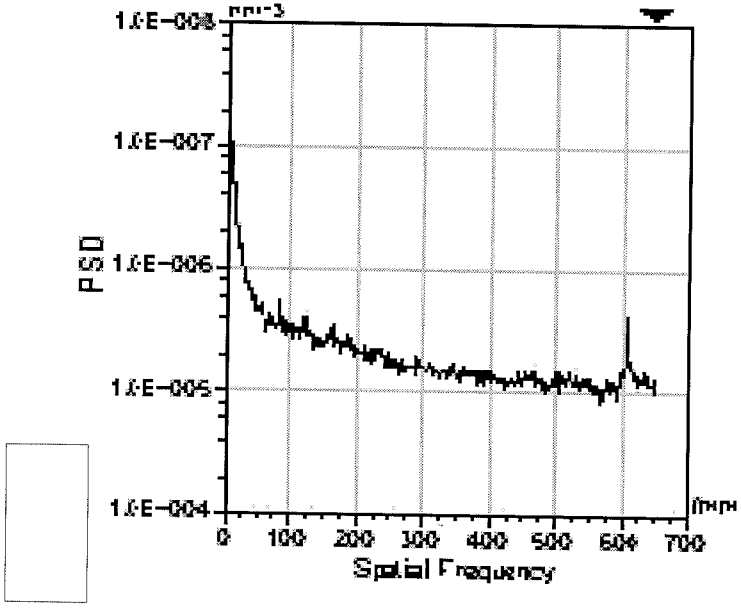
# Transfer of a SCS Membrane



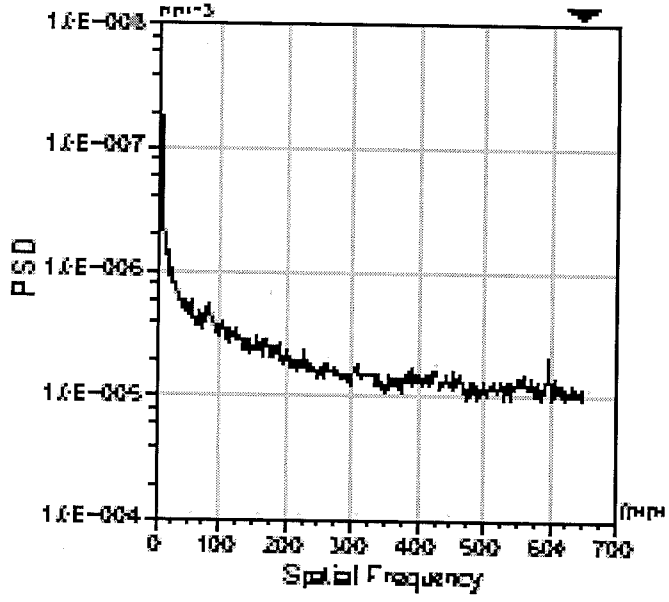



**Surface quality measured by using WYKO interferometer**

# X Average PSD Plots of Silicon Surfaces

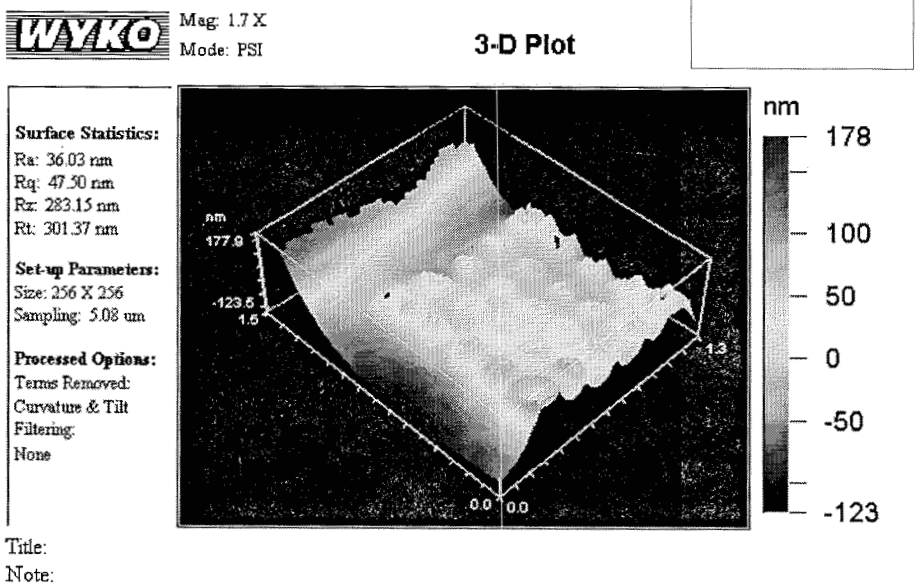



A transferred SCS membrane




A typical silicon wafer

# 3-D Profile of a 1 μm thick Transferred Membrane



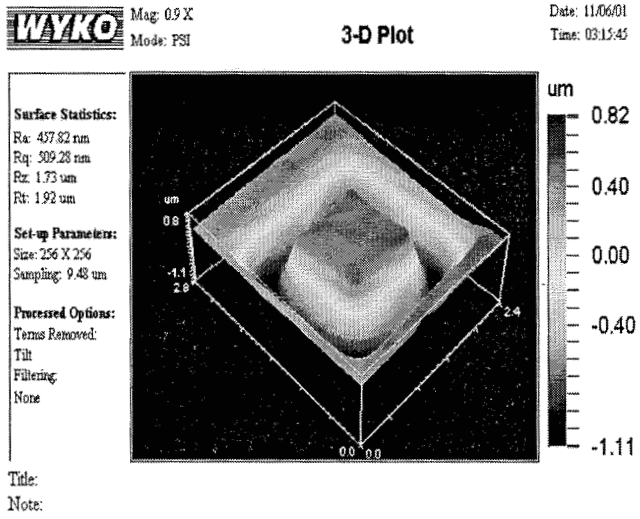

**Thin membrane**

**(<= 1 μm)**

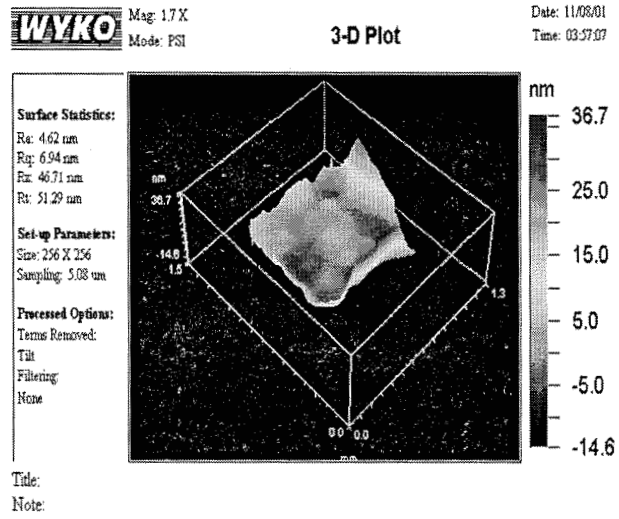
***- Tensile stressed membrane needed for better surface figure***

**Hermetically sealed 1 μm thick Si*x*N*y* membrane**

# 3-D Profile of a 16 μm thick Transferred SCS Membrane

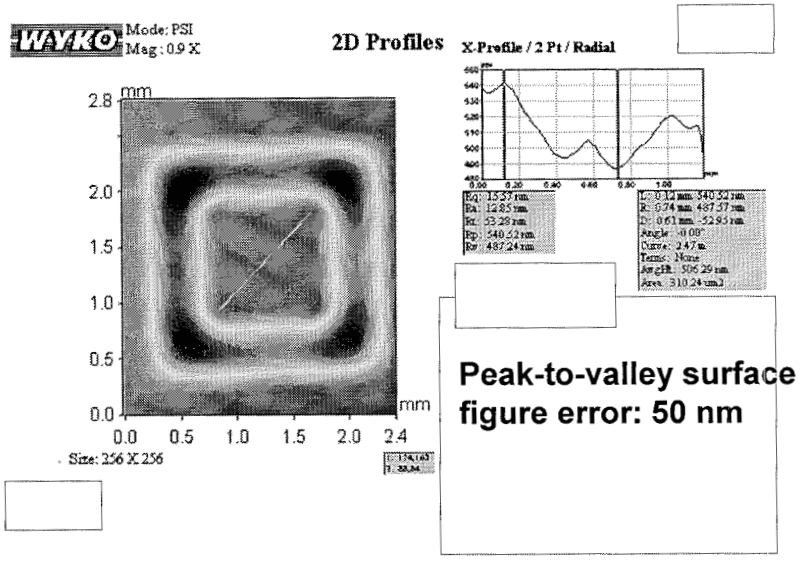



Hermetically sealed 16 μm thick SCS membrane



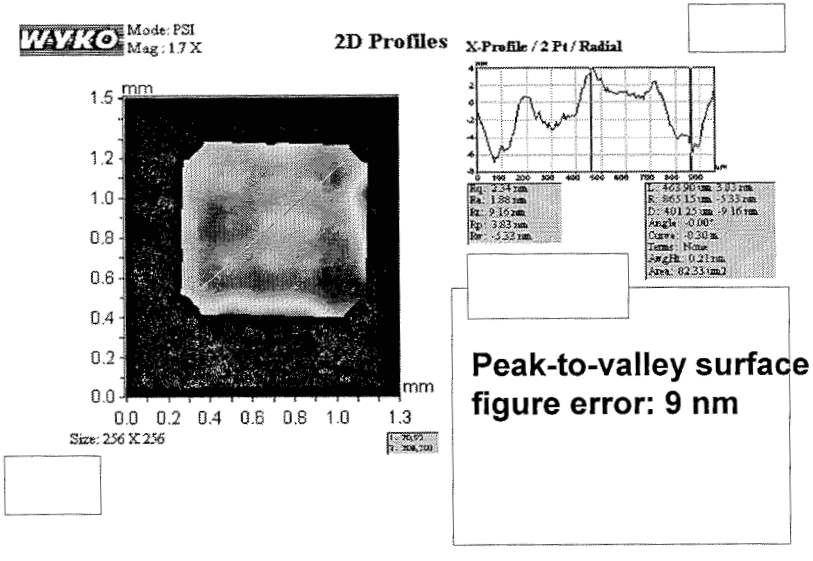

A 16 μm thick SCS membrane after patterning

# Surface Profile of a 16 μm thick Transferred SCS Membrane




Peak-to-valley surface figure error: 50 nm

Hermetically sealed 16 μm thick SCS membrane

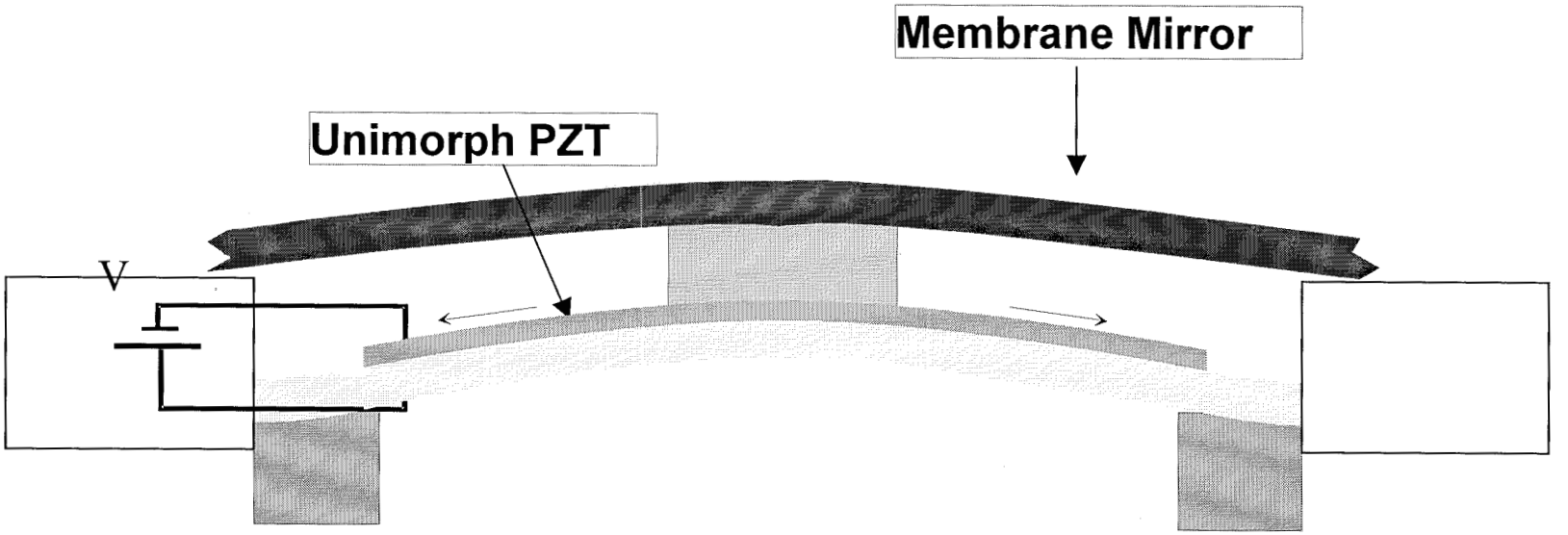



Peak-to-valley surface figure error: 9 nm

A 16 μm thick SCS membrane after patterning

# Bimorph (or Unimorph)

## Bimorph type ept



# Summary

- Transferred membrane optical quality deformable mirror concepts have been presented.
- Electrostatic actuators have been fabricated by the wafer transfer technique to demonstrate the process.
- Transferred 16 μm thick, 1.5 mm x 1.5 mm single crystal membranes showed surface figure error of 9 nm.
- Various thickness, different materials including optical quality thin films can be transferred by using the transfer technology