# A MEMBRANE TRANSFER TECHNOLOGY FOR A CONTINUOUS MEMBRANE MEMS DEFORMABLE MIRROR

Final Report

JPL Task 1016

Eui-Hyeok Yang, In Situ Technology and Experiments Systems Section (384)
Dean Wiberg, In Situ Technology and Experiments Systems Section (384)

## A. OBJECTIVES

The objective of this work was to develop a wafer-scale membrane-transfer technology for the fabrication of large-area, optical-quality, continuous face-sheet deformable mirrors.

Our ultimate goal is to develop deformable mirrors by a membrane-transfer process. The membrane-transfer technique will provide a critical technology complement for a deformable mirror meeting the requirements for the surface figure and the mechanical compliance for large-area deformable mirrors.

## B. PROGRESS AND RESULTS

This report describes a new fabrication technique developed for the construction of large-area mirror membranes via the transfer of wafer-scale continuous membranes from one substrate to another. Using this technique, wafer-scale silicon mirror membranes have been successfully transferred without the use of sacrificial layers such as adhesives or polymers. This transfer technique has also been applied to the fabrication and transfer of 1 μm-thick corrugated membrane actuators. These membrane actuators consist of several concentric-ring-type corrugations constructed within a polysilicon membrane. A typical polysilicon actuator membrane with an electrode gap of 1.5 μm, fabricated using the wafer-scale transfer technique, shows a vertical deflection of 0.4 μm at 55 V. The mirror membranes are constructed from single-crystal silicon, 100-mm in diameter, and have been successfully transferred in their entirety. Using a white-light interferometer, the measured average peak-to-valley surface figure error for the transferred single-crystal silicon mirror membranes is approximately 9 nm as measured over a 1 $mm^2$ membrane area. The wafer-scale membrane-transfer technique demonstrated in this paper has the following benefits over previously reported transfer techniques: 1) No post-assembly release process to remove sacrificial polymers is required. 2) The bonded interface is completely isolated from any acid, etchant, or solvent during the transfer process, ensuring a clean and uniform membrane surface. 3) Our technique is capable of transferring large, continuous membranes onto substrates.

We have demonstrated a wafer-scale membrane-transfer-process technique by transferring a 10 μm-thick single-crystal silicon membrane as a whole from a separate silicon substrate. Specifically, under the proposed effort, the following was accomplished:

- Transfer of a single-crystal silicon membrane, 100-mm in diameter, from one substrate to another to demonstrate the process.
- Determined a technique for transferring a wafer-scale membrane for a full-aperture surface figure.

## C. SIGNIFICANCE OF RESULTS

Space-based astronomical imaging systems are inherently challenged by the need to achieve near-diffraction-limited performance with lightweight optical components. For many future space-based systems, such diffraction-limited performance will require the use of deformable mirrors as wavefront correctors. NASA is planning ultra-large, lightweight space telescopes for the scientifically critical UV-visible (0.1µm -1µm), mid-infrared (3-30µm) and far-infrared (30-300µm) wavelength regimes. Missions being considered include SUVO, a 4-8m UV-visible telescope, SAFIR, an 8-10m far-IR telescope, and Planet Imager, a 30m telescope. Launching conventional rigid primary mirrors is prohibitively expensive, so it is planned to deploy either a segmented aperture, as with the James Webb Space Telescope (JWST), or relatively flexible monolithic primary mirrors whose large surface errors are corrected by subsequent active or adaptive wavefront control. These concepts potentially involve wavefront errors much greater than several wavelengths. The key optical component needed for effective wavefront compensation is a large-stroke, continuous-membrane deformable mirror with high actuator density that is scalable to large areas (high actuator count).

Our ultimate goal is to develop deformable mirrors by a membrane-transfer process. The membrane-transfer technique will provide a critical technology complement for a deformable mirror, meeting the requirements for the optical surface figure and the mechanical compliance for large-area deformable mirrors. The specific advantage of the proposed technology is that an optical-quality membrane can be transferred onto various substrates/actuators with different volume and mass. Therefore the development of a MEMS-based deformable mirror in combination with various actuator technologies would be the next step to provide a wide range of applications within the Space Science and Earth Science Enterprises.

## D. FINANCIAL STATUS

The total funding for this task was $125,000, all of which has been expended.

## E. PERSONNEL

Yoshikazu Hishinuma (384) has contributed to the demonstration of the concept.

## F. PUBLICATIONS

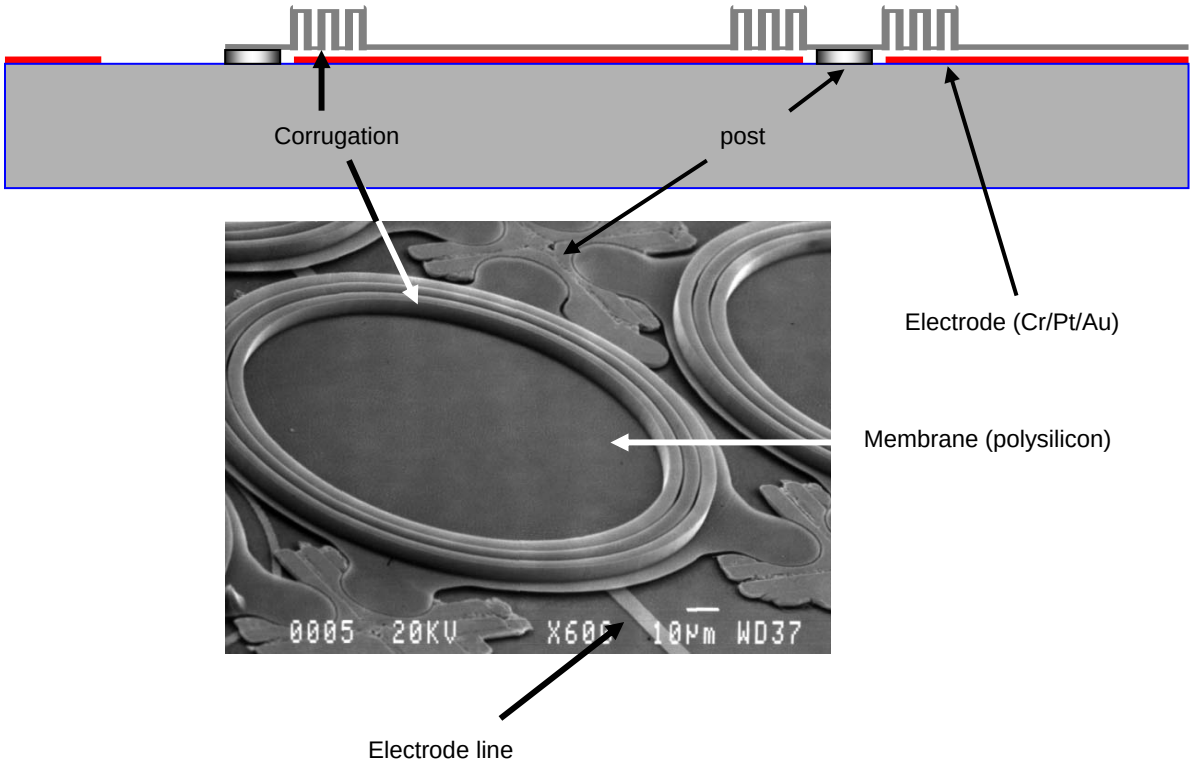
[1] **E. H. Yang** and D. Wiberg, "A wafer-level transfer of membranes in semiconductor processing, 10/005,765 US Patent Pending

[2] **E. H. Yang** and D. V. Wiberg "A wafer-scale membrane transfer process for the fabrication of optical quality, large continuous membranes," *IEEE/ASME Journal of Microelectromechanical System*s Oct. 2003. To be published.

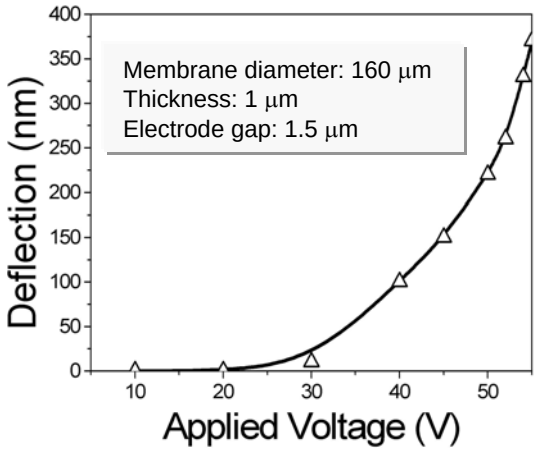
## G. REFERENCES

[1] R. Dekany, S. Padin, E. H. Yang and M. Troy, "Advanced Segmented Silicon Space Telescopes (ASSiST)," SPIE International symposium on Astronomical Telescopes and Instrumentation, Adaptive Optical System Technologies II, 22-28 August 2002, Waikoloa, Hawaii, USA.

[2] M. A. Ealey and J. F. Washeba, “Continuous face sheet low voltage deformable mirrors,” Optical Eng., (29) p.1191, Oct. 1990.




(a)




(b)

Figure 1: Wafer-scale transfer-fabricated corrugated polysilicon membrane actuator. (a) Cross-sectional schematic and corresponding SEM micrograph of the electrostatic actuator configuration for the corrugated membrane. (b) Deflection characteristics of a single membrane actuator.

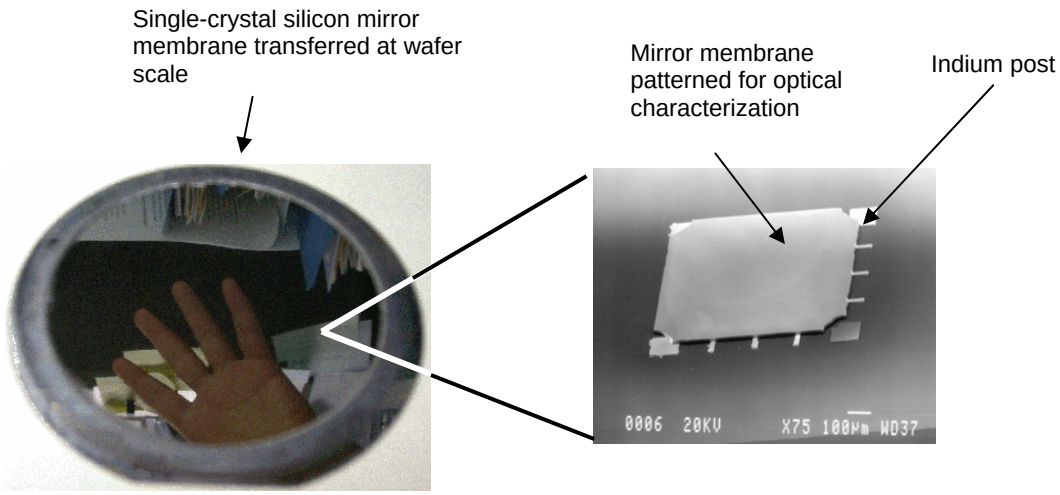



Figure 2: A 10-cm-diameter silicon mirror membrane was successfully transferred from an SOI carrier wafer to a substrate wafer. (a) Photograph of the wafer-scale transferred silicon mirror membrane. (b) Patterned sector of the silicon mirror membrane for high-order "local" surface figure characterization.

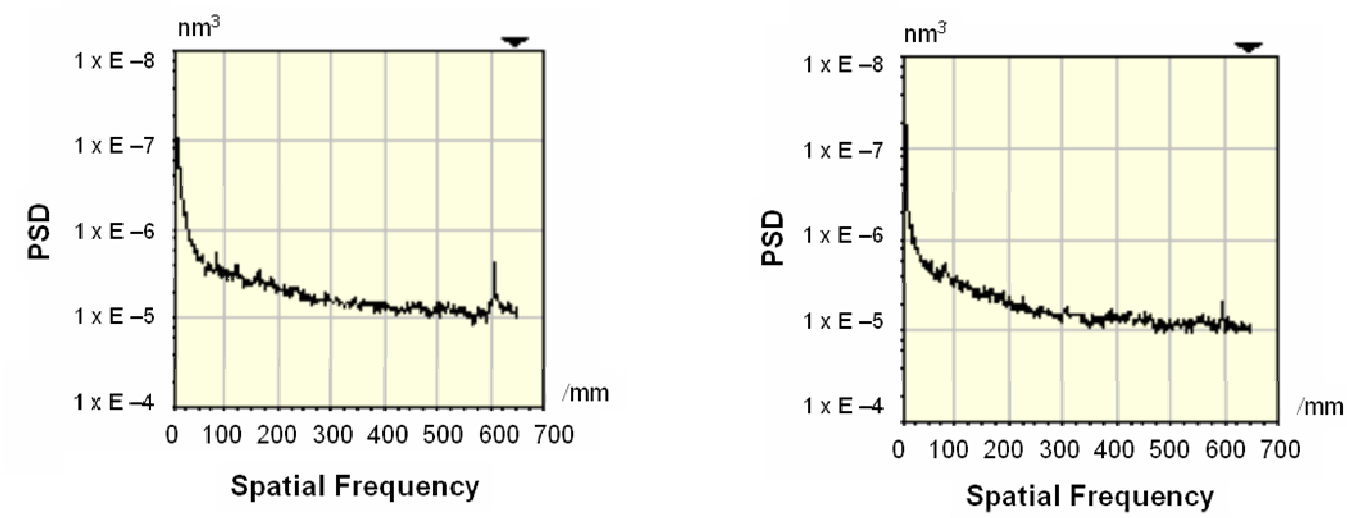



Figure 3: Average power spectral density (PSD) plots. The PSD plot obtained from the transferred membrane is almost identical to that from a typical silicon wafer, showing excellent surface quality. The transferred mirror membrane is essentially a replica of the carrier wafer in terms of surface quality. (a) PSD plot for a transferred silicon membrane. (b) PSD plot for a polished typical silicon wafer.