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

Interim Report

JPL Task 1016

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## A. OBJECTIVES

Future ultra-large, lightweight space telescopes envisioned by NASA have either segmented or inflatable primary mirrors [1]. Due to the optically imperfect surface figure of these mirrors, the primary optics would require an active compensation of large wavefront errors. A large-stroke deformable mirror is a key component for the wavefront compensation system for an astrophysical imaging instrument. 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.

Specifically under the proposed effort, the following was to be accomplished:

1) Transfer a compliant membrane with an area of 2500 mm$^2$ from one substrate to another to demonstrate the process.
2) Determine the surface quality of the transferred membrane.

The objective of this work is <u>to develop a membrane transfer technology</u> for the fabrication of a compact, low-cost, high-compliance, optical-quality continuous face-sheet deformable mirror for astrophysical imaging.

## B. PROGRESS AND RESULTS

Wafer-scale single-crystal silicon membranes have been successfully transferred without using sacrificial layers such as adhesives or polymers.

A 10 µm thick single-crystal silicon membrane (4 in. diameter) was transferred in wafer-scale. The transfer process sequence is as follows: A Silicon-On-Insulator (SOI) wafer and a silicon wafer are used as the carrier and electrode wafers, respectively. A 0.5 µm thick oxide is thermally grown on both sides of the wafers. Then Ti/Pt/Au metal layers are deposited and patterned to form electrode arrays on the electrode wafer. The Cr/Pt/Au metal layers are deposited subsequently over the photoresist patterns on both wafers for the lift-off process. A 1 µm thick indium layer is then deposited on both wafers. Since the indium layer uniformly wets the Au layer, the Au acts as a "substrate" for hermetic bonding. This hermetic bonding process is a critical step for subsequent etch processes. Indium instantly oxidizes in air, and the oxidized indium does not provide hermetic bonding. Thus, the indium deposition process is followed by the deposition of a 0.01 μm thick Au layer to prevent the indium surface from oxidizing. The deposited metal layers for bonding are patterned using a lift-off process. The carrier wafer is subsequently bonded to the electrode wafer. An Electronic Vision aligner and a thermo-compression bonder is used to align and bond two patterned wafers, respectively. The bonder chamber is pumped down to $1\times10^{-5}$ Torr before bonding two wafers. A piston pressure of 4 kPa is applied at 156°C in a vacuum chamber to provide a complete hermetic sealing. The substrate of the SOI wafer is etched in a 25 wt % Tetramethylammonium hydroxide (TMAH) bath at 80°C until the buried oxide is exposed. A Teflon fixture is used to protect the backside of the bonded wafers as well as their bonded interface. The exposed oxide is then removed by using dilute hydrofluoric acid (49% HF) droplets after an $O_2$ plasma ashing. The wafer-scale silicon membrane transfer is completed at this stage.

Fig. 1 shows a photograph image of a transferred single-crystal silicon membrane. The surface profile of a transferred single-crystal silicon membrane was measured and compared with that of a typical silicon wafer.

Fig. 2 shows the surface figure of a wafer-scale transferred 10 μm thick single- crystal silicon membrane. The membrane was subsequently patterned and etched in order to remove the hermetic sealing for the surface figure measurement of a "standing" membrane. The peak-to-valley surface figure error of a membrane (area 1 $mm^2$) with indium posts spacing of 200 μm was 9 nm. This number (9 nm p-v) shows the "optical" surface quality of the transferred membrane, since the commercially available deformable mirrors provide $\lambda/20$ at $\lambda = 633$ nm [2].

The wafer-scale 4-inch diameter surface figure measurement has not been performed yet. The full aperture measurement of surface figure will be performed by using a Michelson Interferometer.

The wafer transfer technique demonstrated in this paper has the following benefits over those previously reported: 1) No post-assembly release process is required. (e.g. No sacrificial layer is used for the transfer purpose.) 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) It offers the capability of transferring multi-layer wafer-scale membranes onto actuators.

## C. SIGNIFICANCE OF EXPECTED RESULTS

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.

The membrane transfer technique, if successfully developed, will provide the critical technology complement for a compact deformable mirror technology meeting the requirements for the optical surface figure and the mechanical compliance. 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 in order 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, of which $16,000 has been expended. The remaining funding will be expended for further transfer and test experiments. Several membranes with different thickness will be transferred and tested. The transferred membranes will be characterized with a full aperture measurement, which allows for either interferometry or a wavefront sensing measurement.

## E. PERSONNEL

No other personnel were involved.

## F. PUBLICATIONS

E. H. Yang, "A Wafer Transfer Technology for MEMS Adaptive Optics," CfAO MEMS Workshop, CfAO, UC Berkeley, Feb. 2002.
(Other task results will be written up for publication soon.)

## 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.

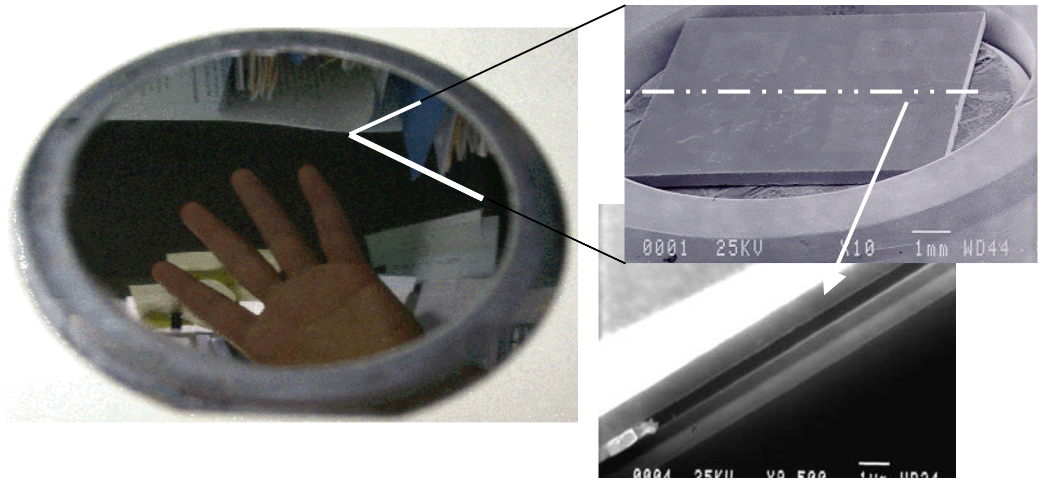


*Fig.1 Transferred membrane with 4 inches in diameter.*

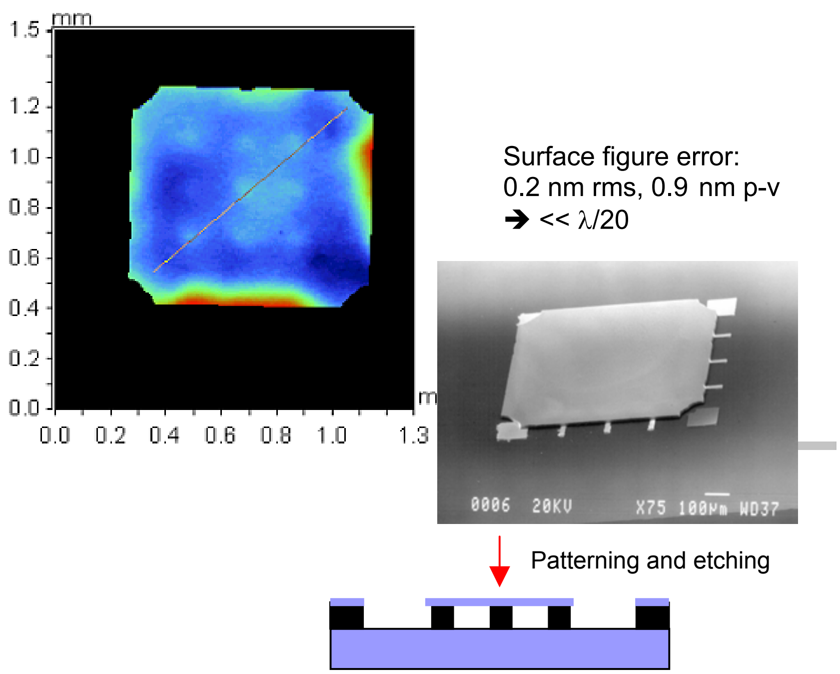


*Fig. 2 Surface figure of a patterned single crystal silicon membrane (wafer-scale transferred and patterned). The surface figure error was 9 nm P-V for this sample.*