Fabrication of Micro Actuators for a MEMS deformable mirror by Membrane Transfer

Eui-Hyeok (EH) Yang, Dean V. Wiberg and Richard G. Dekany
Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109
Eui-Hyeok.Yang@jpl.nasa.gov ph: +1-818-354-7059 fx: +1-818-393-6047

Novelty: (1) A deformable mirror concept for large, light weight, segmented space telescopes is proposed. (2) describes a novel technique for the fabrication of the deformable mirror by transferring an entire wafer-level membrane from one substrate to another.

Background: In order for a telescope to approach it's diffraction limit, it is necessary to correct the wavefront of the light to remove distortions that deviate the system from the ideal. This can be done by incorporating a deformable mirror: i.e. a reflecting element that has on it's backside an array of actuators that push and pull at the mirror to compensate for wavefront distortions. In a space based system, where energy and size considerations are paramount, it is highly advantageous to make this system small, compact, robust and energy efficient. A surface micromachined polysilicon deformable mirror has previously been demonstrated [1]. However, this polysilicon mirror has a marginal surface quality, which limits its applicability. Therefore, a continuous membrane optical quality deformable mirror concept has been proposed (Fig. 1). The device consists of a continuous membrane mirror supported by micro actuators with a pixel-to-pixel spacing as small as 200 μm. In order to realize this concept, a sheet of optical quality membrane (with surface area > 1cm^2) is transferred onto deformable membrane actuators. Batch transfer techniques have been previously demonstrated for localized devices [2-5]. Wafer level transfer techniques have also been developed, which involved adhesives and/or molding materials [6,7]. However, these techniques are not suitable for multi-layer transfer because adhesives often produce residues over the transferred membrane surface, hindering successive layer transfer. Thus, a wafer-level membrane transfer technique [8] has been developed for the fabrication of deformable mirrors.

Fabrication: A 1 μm thick polysilicon membrane has been transferred onto an electrode wafer to fabricate electrostatic actuators array. An SOI wafer and a silicon wafer are used as the carrier and electrode wafers, respectively. After oxidation, both wafers are patterned and etched to define a membrane profile and electrode array, respectively. The polysilicon layer is deposited on the SOI wafer (Fig. 2 (a)). The carrier wafer is bonded to the electrode wafer by using evaporated indium bumps. The piston pressure of 4 KPa is applied at 156 °C in a vacuum chamber to provide hermetic sealing (Fig. 2 (b)). The substrate of the SOI wafer is etched in a 25 wt % TMAH bath at 80 °C (Fig. 2 (c)). The exposed buried oxide is then removed by using 49 % HF droplets (Fig. 2 (d)). The SOI top silicon layer is etched away by using an SF_6 plasma to define the membrane profile, followed by the HF droplet etching of the remaining oxide. The wafer-level silicon membrane transfer is completed at this stage (Fig. 2 (e)). The SF_6 plasma with a shadow mask selectively etches the polysilicon membrane to fabricate actuator patterns (Fig. 2 (f)). Electrostatic actuators with various electrode gaps have been fabricated and characterized. Fig. 3 shows SEM photographs of a 1 μm thick polysilicon membrane, which has been successfully transferred onto the electrode wafer. The gap between the transferred membrane and electrode substrate is very uniform (+/- 0.1 μm across a wafer diameter of 100 mm, provided by optimizing the bonding control). A WYKO RST Plus optical profiler has been used to measure the static deflection of the membranes. The fabricated actuator membrane with an electrode gap of 1.5 μm shows a vertical deflection of 0.37 μm at 55 V (Fig. 4).

Summary: A new wafer-level silicon membrane transfer technique has been demonstrated by fabricating and testing an electrostatic actuator array for deformable mirror. A 1 μm thick silicon membrane, 100 mm in diameter, has been successfully transferred without using adhesives or polymers (i.e. wax, epoxy, or photoresist). Smaller or larger diameters can also be transferred using this technique. The complete characterization of successive single crystal silicon membrane transfers onto a deformable membrane actuator array (Fig. 2 (g, h)) will be included in the final paper. The proposed technique has the following benefits over those previously reported: 1) no post-assembly release process (e.g. using HF) is required and no wax, photoresist, or epoxy is used for the transfer purpose 2) The bonded interface is completely isolated from any acid, etchant and solvent, which ensures a clean and flat membrane surface. 3) offers the capability of transferring wafer-level membranes over deformable actuators.

References
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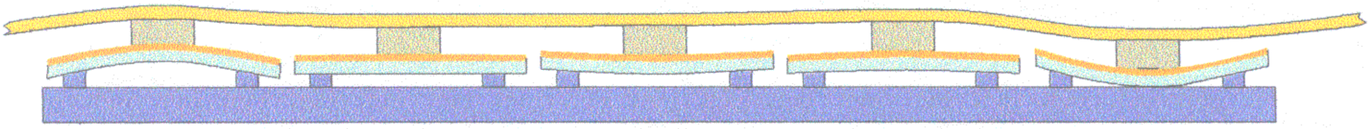


Fig. 1 The concept of the double layered MEMS deformable mirror with a continuous silicon nitride mirror membrane [1].

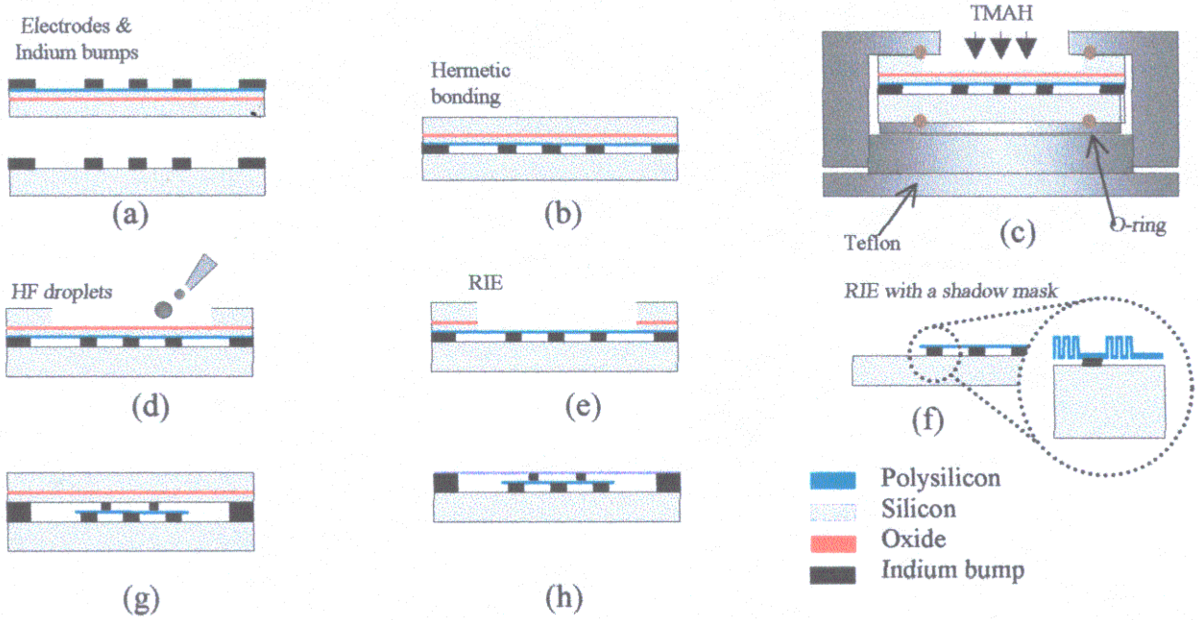
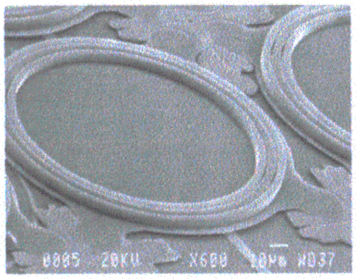
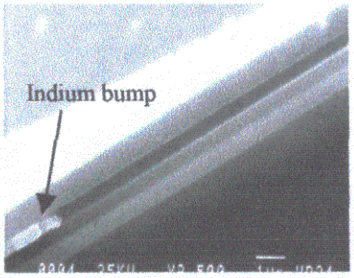


Fig. 2 The membrane transfer process. The successive layer transfer process is identical with the first layer transfer process except for the use of a shadow mask to place Indium bumps over deformable actuators. (a) Polysilicon deposition, electrode definition & Indium evaporation. (b, c, d, e) Bonding & etching. (f) Defining actuator membrane. (g, h) Successive layer transfer: a continuous single crystal silicon membrane is transferred to form a deformable mirror.



(a)



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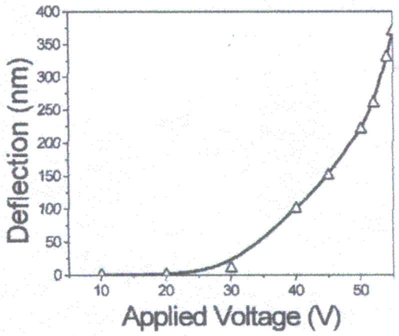

Fig. 3 The SEM photographs of the transferred membrane actuator.
(a) The transferred membrane corrugated deformable actuator.
(b) The cross sectional view of an actuator.

Fig. 4 The deflection characteristic of a transferred membrane actuator.