LARGE APERTURE DEFORMABLE MIRROR WITH A TRANSFERRED SINGLE-CRYSTAL SILICON MEMBRANE ACTUATED USING LARGE-STROKE PZT UNIMORPH ACTUATORS

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ABSTRACT

We have demonstrated a large aperture (50 mm × 50 mm) continuous membrane deformable mirror (DM) with a large-stroke piezoelectric unimorph actuator array. The DM consists of a continuous, large aperture, silicon membrane "transferred" in its entirety onto a 20 × 20 piezoelectric unimorph actuator array. A PZT unimorph actuator, 2.5 mm in diameter with optimized PZT/Si thickness and design showed a deflection of 5.7 ⌠m at 20V. An assembled DM showed an operating frequency bandwidth of 30 kHz and influence function of approximately 30%.

Keywords: Deformable mirrors, Piezoelectric unimorph actuators

INTRODUCTION

Future deployment of ultra-large, light-weight, space based telescopes is being envisioned by NASA and other defense agencies. Launching conventional rigid primary mirrors is prohibitively expensive. Therefore, the planned deployment scenario involves either a segmented aperture or a relatively flexible, monolithic primary mirror whose large surface errors are corrected by subsequent active or adaptive wavefront control [1, 2]. Both of 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 DM with a high actuator density that is scalable to large areas (Figure 1). We have already demonstrated an optical quality membrane transfer technology [3]. Other requirements for space telescope DMs include mirror actuation of > 5 μm at < 50 V (< 1 ⌠W per pixel), with a bandwidth of > 10 kHz, and influence function of < 30%. Micromachined DMs have been previously reported, however they needed high-voltage operation due to electrostatic actuation (100-700V) [4-8], had small stroke (< 2 μm) [4-6, 8], marginal surface quality [4,6], or high influence function (crosstalk) [5, 6], any of which is unacceptable for space telescope applications. In this paper, we present a novel, large-aperture, single-crystal silicon continuous membrane DM actuated using 20×20 piezoelectric unimorph actuators with large stroke actuation.

PZT UNIMORPH ACTUATOR

We have modeled, fabricated and characterized a series of PZT unimorph membrane actuators with various membrane designs in order to optimize the DM actuator geometry. Our deformable mirror concept consists essentially of a continuous membrane mirror transferred onto an underlying array of piezoelectric unimorph membrane-based microactuators. The primary benefit of the piezoelectric actuation approach is that it meets the stringent DM requirements for precise spatial control, thereby justifying the added complexity of microfabrication. The unimorph actuation principle is illustrated in Figure 2. The details are as follows: An electric field applied perpendicular to the membrane-mounted piezoelectric thin film induces a contraction in the lateral direction, converted by the membrane geometry to a large out-of-plane deflection. The vertical deflection acts on the portion of the mirror membrane mounted over the microactuator. Compared to the conventional piezoelectric stack actuators that are widely employed in commercial DMs, our actuation mechanism requires far less voltage and power to produce the same extent of mirror deflection.

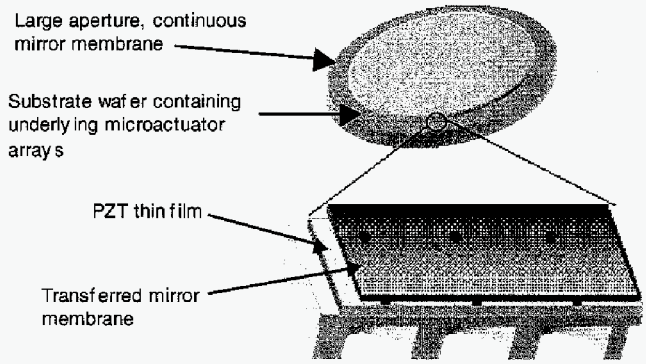

Figure 1. Conceptual schematic diagram of the large-area continuous membrane deformable mirror (DM). For minimizing the effect of "print-through", the silicon mirror membrane is required at least 10μm thick. The mirror membrane is transferred in its entirety from another substrate (carrier wafer) in order to preserve an optical quality surface, and is backed by an array of piezoelectric unimorph microactuators.

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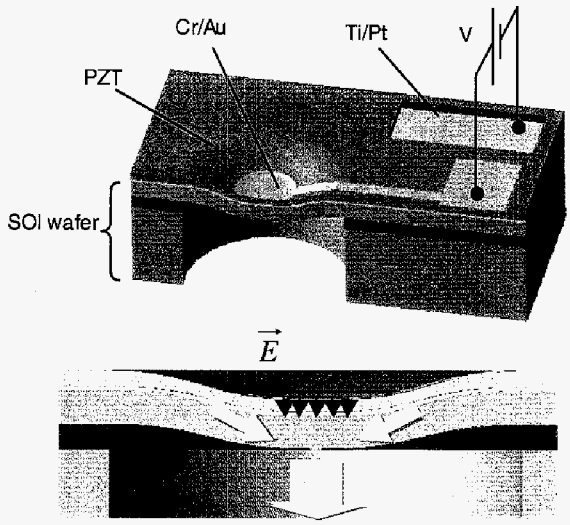

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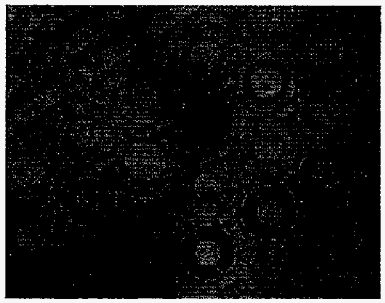

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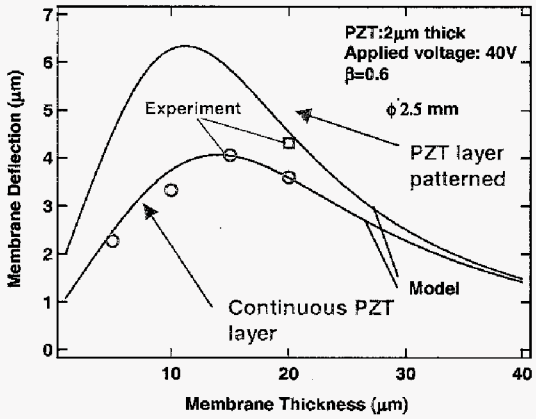

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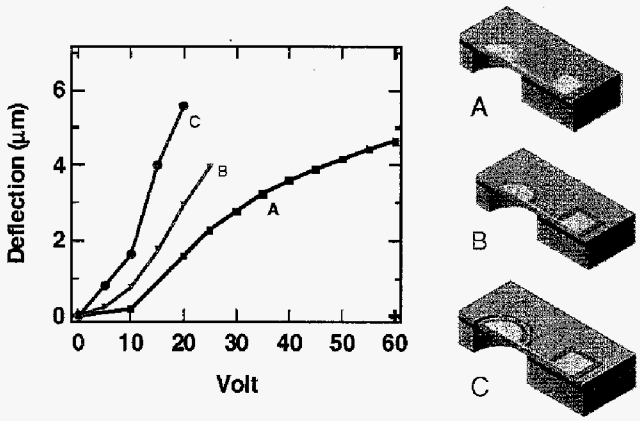

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DEFORMABLE MIRROR

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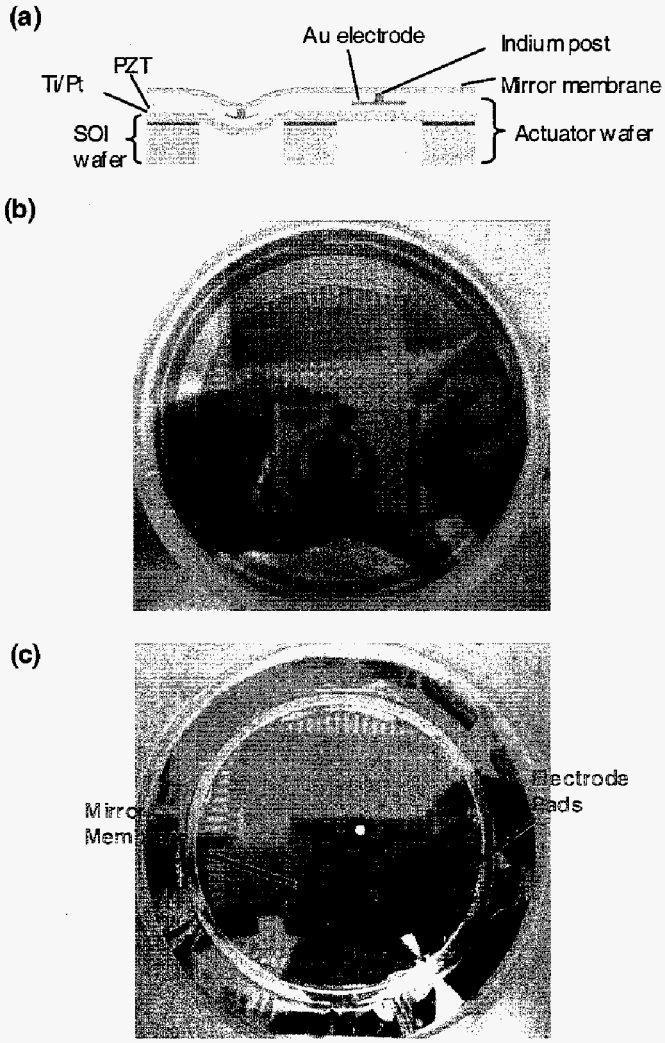

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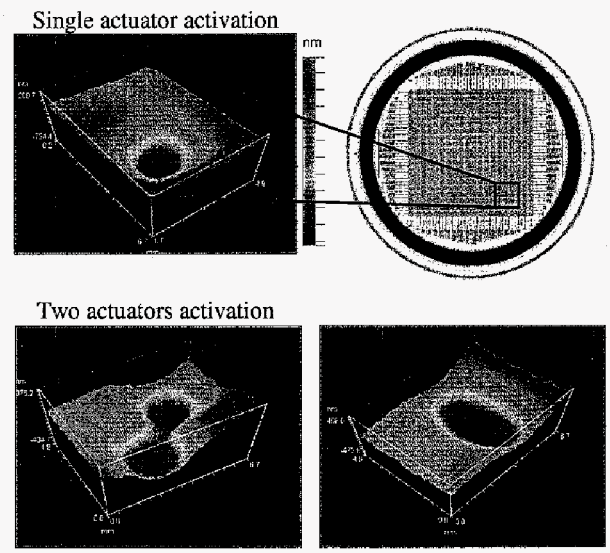

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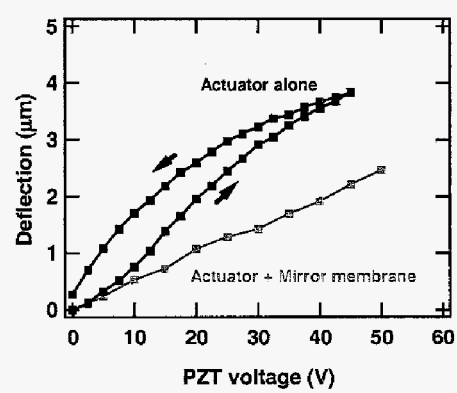

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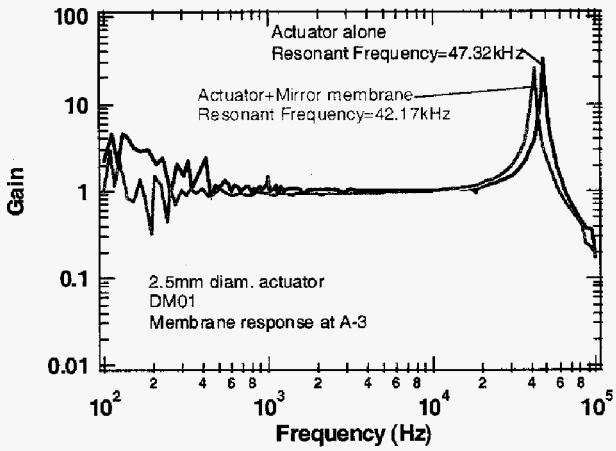

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CONCLUSIONS

We have successfully fabricated, assembled and characterized a large aperture DM composed of a continuous single-crystal silicon membrane supported by piezoelectric unimorph actuator arrays. Our improved piezoelectric unimorph actuators with patterned PZT film designed with optimized PZT/Si thicknesses can produce large strokes at low voltages. DMs consisting of 20 μm thick single-crystal silicon membranes supported by 20×20 actuator arrays were fabricated and optically characterized. Further work is underway to infuse this DM into applications for future ultra-large space telescope.

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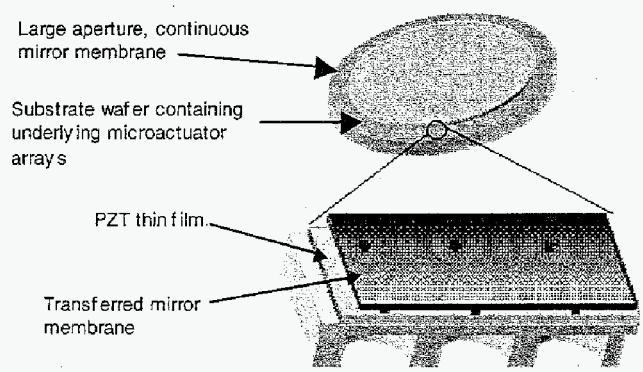

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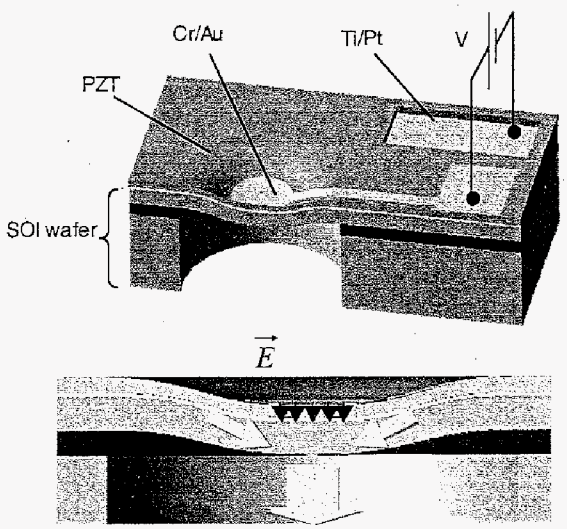

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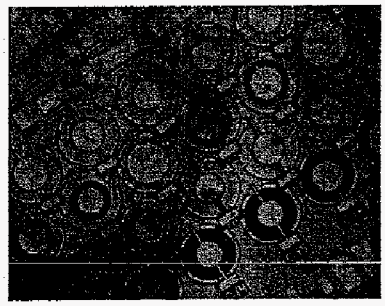

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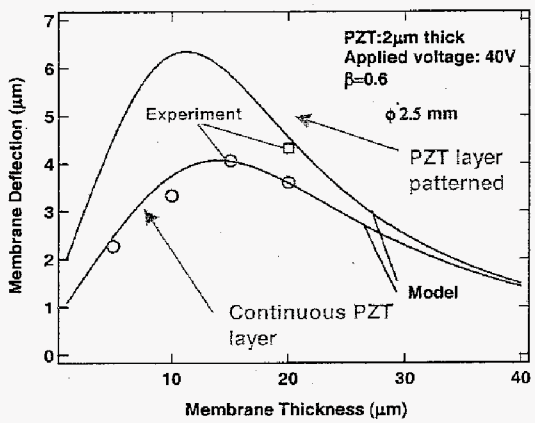

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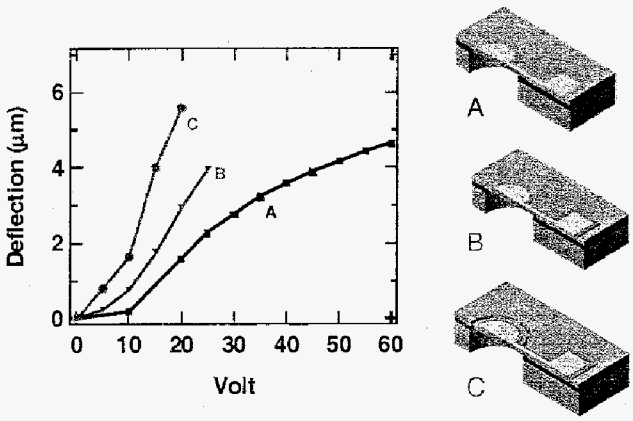

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DEFORMABLE MIRROR

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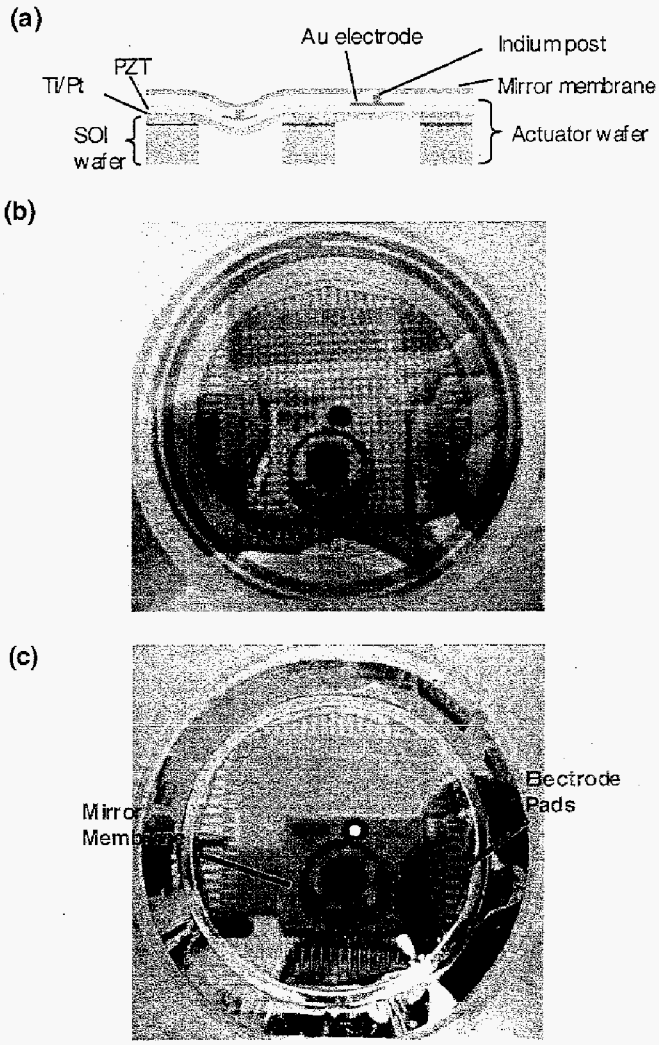

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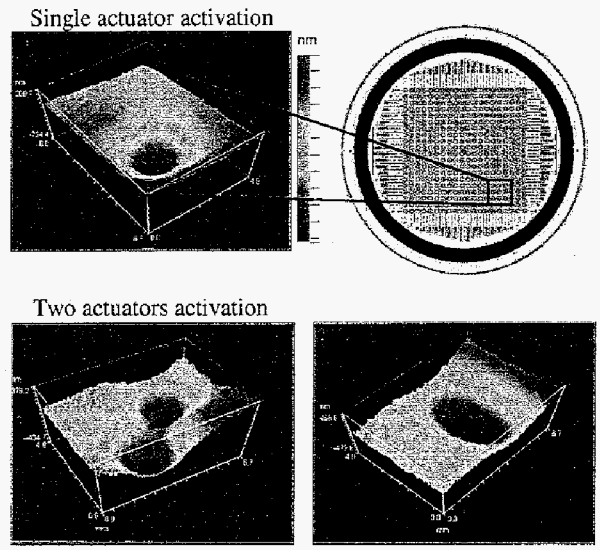

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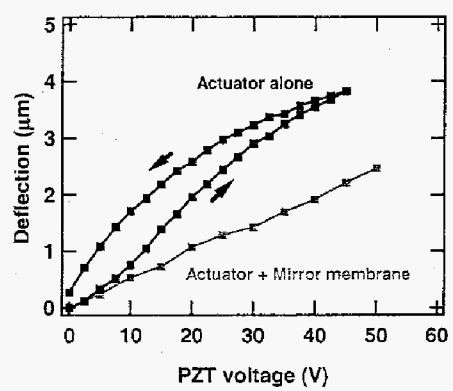

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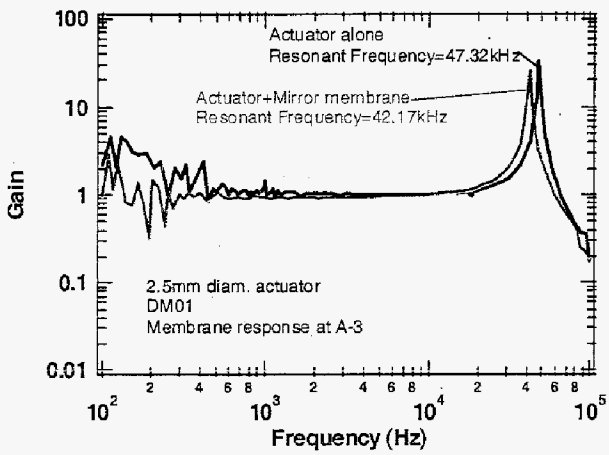

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