MANUFACTURING OF AN OPTICAL QUALITY MIRROR SYSTEM FOR ADAPTIVE OPTICS

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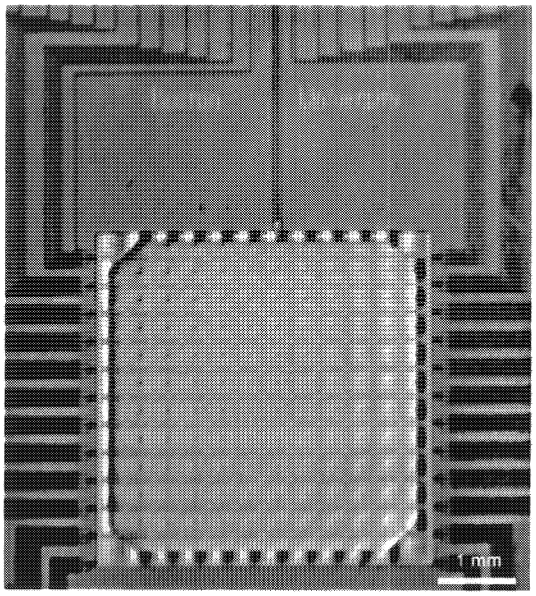
ABSTRACT

Manufacturing of optical quality micromachined deformable mirrors for use in adaptive optic (AO) correction is described. Several non-standard manufacturing techniques have been developed to improve optical quality of surface micromachined mirrors. Two challenges to manufacturing optical quality micromachined mirrors are reducing surface roughness and increasing reflectivity. A chemo-mechanical polishing process has been used to improve surface quality of the mirrors, and a gold coating process has been developed to improve the reflectivity without introducing a significant amount of stress in the mirror membrane. Surface reflectivity and topography measurements of optically flat and smooth mirrors are presented. Based on these results, a new 1024 actuator mirror has been designed and is currently being fabricated. Design considerations and performance expectations for this mirror will be presented.

Keywords – Adaptive Optics, Actuators, Aberrations, Chemo-mechanical Polishing, Evaporation, Micromachined, Mirrors, Ion machining, Optical quality, Reflectivity

1. INTRODUCTION

Surface micromachining techniques have been used to develop a μ-deformable mirror (μ-DM) for use in an Adaptive Optics system. These μ-DMs consists of an array of addressable surface normal electrostatic actuators with center posts that support a compliant optical mirror membrane. Each actuator consists of $300 \times 300 \times 3$ μm silicon membrane anchored to the substrate on two sides above a silicon electrode. A schematic and SEM of the mirrors is shown below in Figure 1.



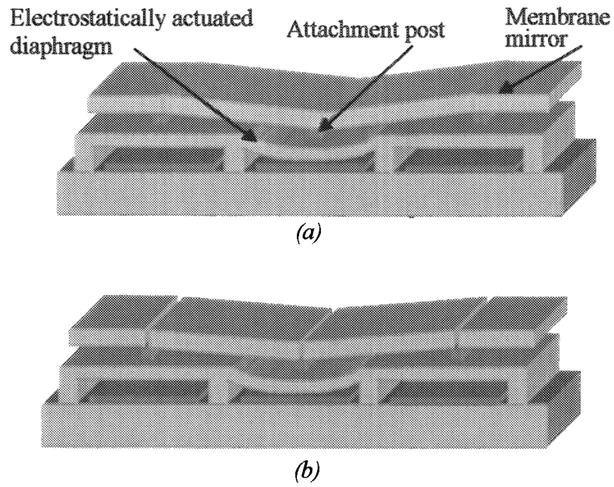


Figure 1. SEM (left) and Schematic (right) of deformable mirror array sections with (a) continuous mirrors and (b) tip- tilt mirrors.

A feasible AO system must have a mirror that optimizes the number of actuators in the DM, the motion resolution of each pixel, the control bandwidth of each actuator, and the maximum available actuator stroke[1]. μ-DM's with the following design specification have been developed: 140 electrostatic actuators (12 × 12 w/o corners), 2-μm stroke per actuator, 10-nm resolution, and a 7 kHz bandwidth as is shown in Figure 2.[3, 4, 5]

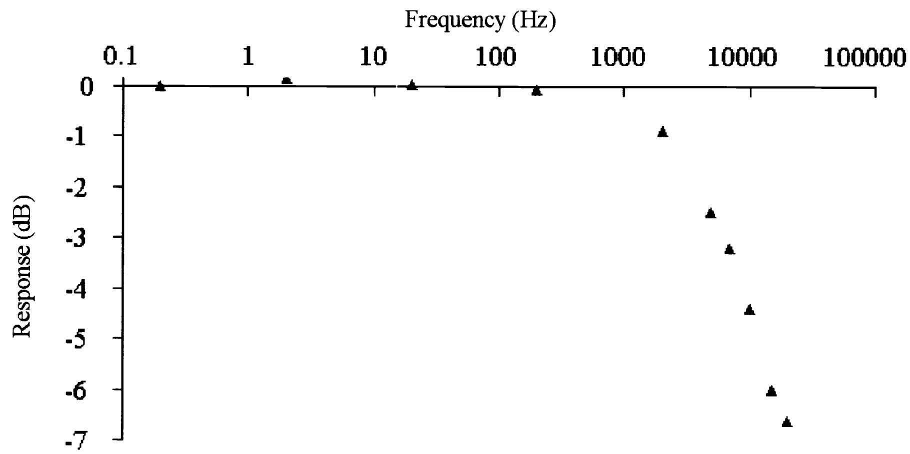


Figure 2: Frequency response for a continuous mirror membrane

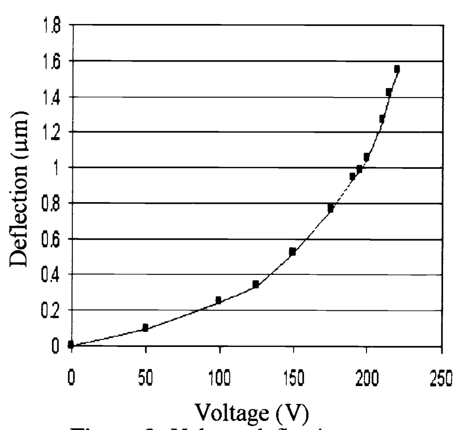


Figure 3: Voltage deflection curve

These recently fabricated mirrors also have an actuator voltage deflection characteristic that is a monotonically increasing function of applied voltage as shown in Figure 3. There is a 15% influence function (relative deflection of an unenergized actuator due to deflection to an energized adjacent actuator). By individually addressing each of the 140 actuators, appropriate shapes can be generated on the mirror membrane to correct a distorted image. The fill factor for these mirrors is above 98.6% for the segmented tip tilt mirrors and above 99.5% for the continuous membrane mirrors.

An important characteristic of a μ-DM is optical quality. A mirror used for adaptive optic (AO) correction must be flat in order to deform to the correct shape and smooth to prevent the introduction of high frequency noise onto the corrected signal. Two important measurements of optical quality are mirror curvature and surface roughness. In surface micromachining techniques optically flat smooth mirrors are difficult to achieve due to processing effects. Rough surfaces result from surface topography due to the conformal multi-layer thin film manufacturing process. Chemo-mechanical polishing was used to significantly reduce surface roughness.

2. OPTICAL PROCESSING

The measurements in Figure 4 show a comparison a mirror pre-release mirror segment before and after chemo-polishing. The 40 second chemo-mechanical polishing process reduced the surface roughness from 46 nm to 12 nm[5].

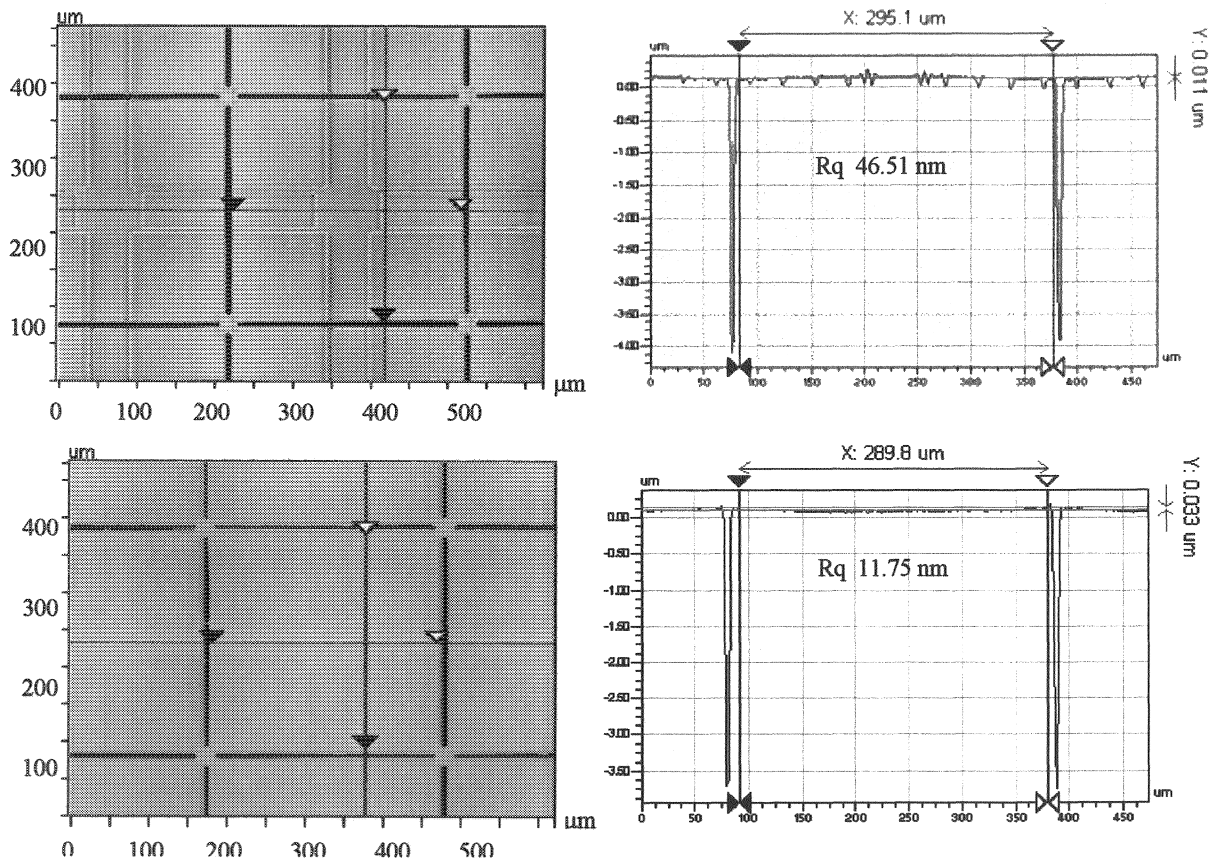


Figure 4: Interferometric surface measurement across one mirror segment before and after chemo-polish.

Figure 5 is an interferometric surface measurement and profile of an optically flat polished 12×12 µ-DM recorded with an interferometric surface microscope.

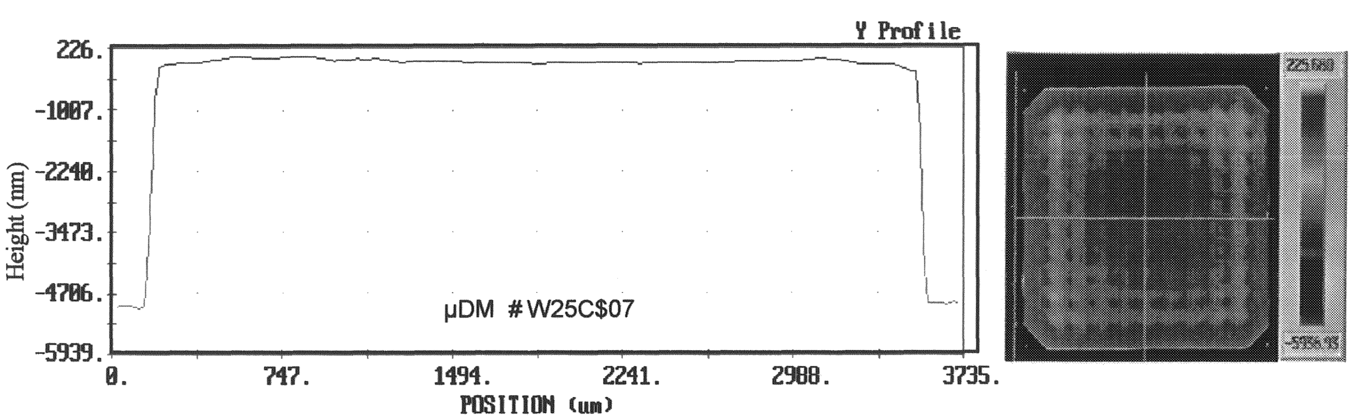


Figure 5: Profile of an optically flat 12x12 DM

Gold was deposited on the deformable mirror *after release* to achieve a highly reflective mirror surface, while avoiding the high tensile stresses that accompany pre-release coatings based on a chromium-gold composite. This technique allows mirrors to be reflective in visible and IR wavelengths, without compromising flatness. Gold was deposited by two methods: sputtering and evaporation.

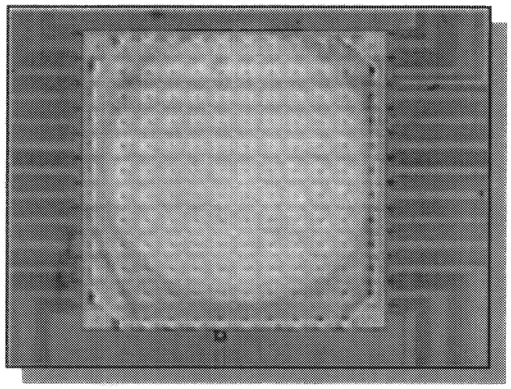


Figure 6: Mirror coated with sputtered gold

Figure 6 is a photograph of a mirror with gold sputtered through a circular aperture. A highly reflective mirror surface was produced without changing the surface roughness or the mirror flatness. Approximately 433 Å of Au was deposited on the mirror surface. As is shown in Figure 7 the process does not significantly affect surface roughness or mirror shape.

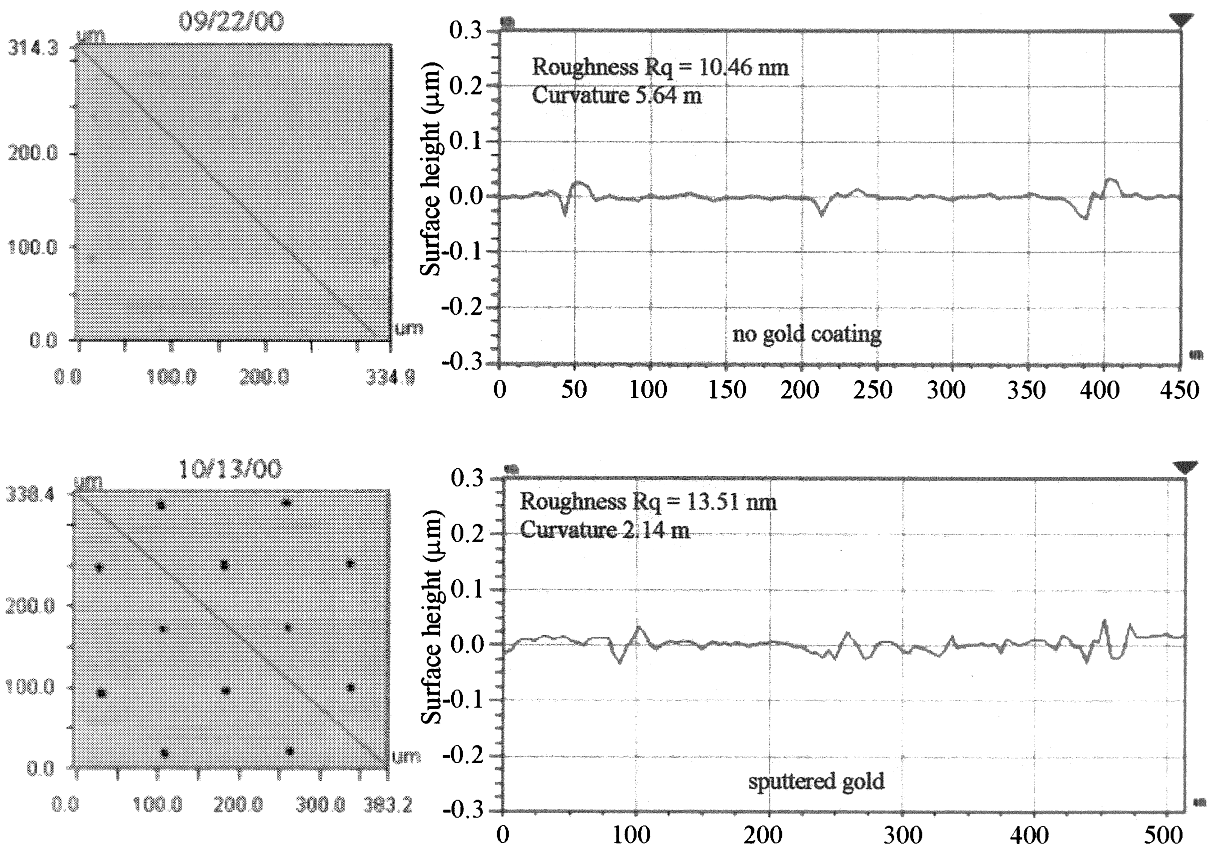


Figure 7: 2 point profile of a continuous mirror membrane over one actuator before and after gold coating

Unlike conventional MEMS metalization processes, this approach does not employ an adhesion layer such as chromium prior to gold coating, since such layers typically have a pronounced effect on the thin film stress (and curvature). Durability testing of the gold to silicon adhesion was done. One actuator was cycled over a billion times at 3.3 kHz and measured periodically to find if there was any change in the gold on the surface. Figure 8 shows the measurement of surface roughness of the gold above the actuator. The nominal roughness did not change significantly over the billion cycles.

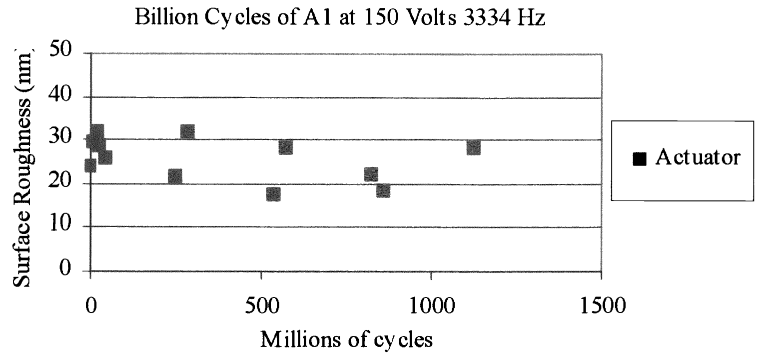


Figure 8: Surface roughness of gold on mirror

Gold coating by e-beam evaporation resulted in a much smoother gold surface. Roughness of evaporated gold on silicon was measured to be about 3 nm. Durability of the evaporated gold on silicon was evaluated under different temperature conditions. Silicon partially coated in evaporated gold was subjected to 10 minute excursions to high temperatures. After each thermal cycle the reflectivity of the bare silicon and the gold on silicon was evaluated against a front surface mirror. Measurements in Figure 9 show that there was no significant change in the reflectivity of gold up through the maximum anneal temperature of 350° C. The same piece was then evaluated for a 72 hour anneal at a temperature of 350° C without a significant change in the reflectivity as is shown in Figure 10.

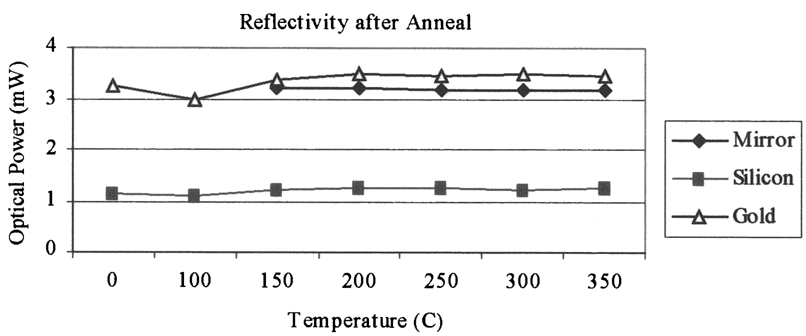


Figure 9: Reflectivity versus anneal temperature for evaporated gold on silicon

Thicker layers of evaporated gold have been shown to add appreciable curvature to the mirrors due to the tensile stress that is characteristic of a gold film deposited on silicon. This can be used to advantage if the silicon mirrors are curved due to excessive compressive stress on their upper surface, as has been shown in an experiment reported here. A mirror membrane with initial stresses that caused it to be severely curved was coated with sufficient gold to reverse the sign of the mirror's curvature. This corresponds to overcompensation of an initially compressive surface layer in the silicon by adding a tensile metal layer. This metal layer was then thinned by use of a netral ion beam until the mirror was made flat. Figure 11 (a) shows a mirror membrane with mirror segments that have a radius of curvature of –24 mm. Gold was evaporated 1500 Å thick onto the center 10×10 mirror segments using an aluminum mask as is shown in Figure 11 (b). This amount of gold fully reversed the curvature on the mirror membrane segment. Ion machining was then used to remove some of the gold in order to balance the stress in the mirror membrane as is shown in Figure 11 (c).

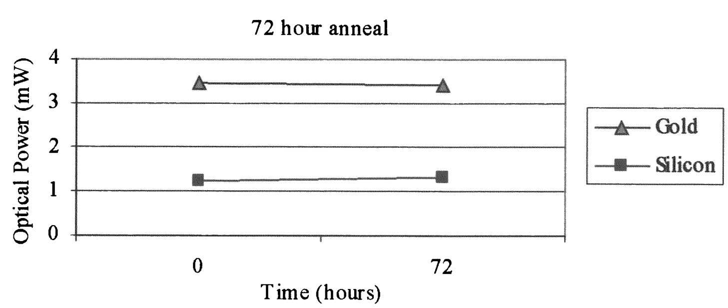


Figure 10: Effect of long anneal on reflectivity

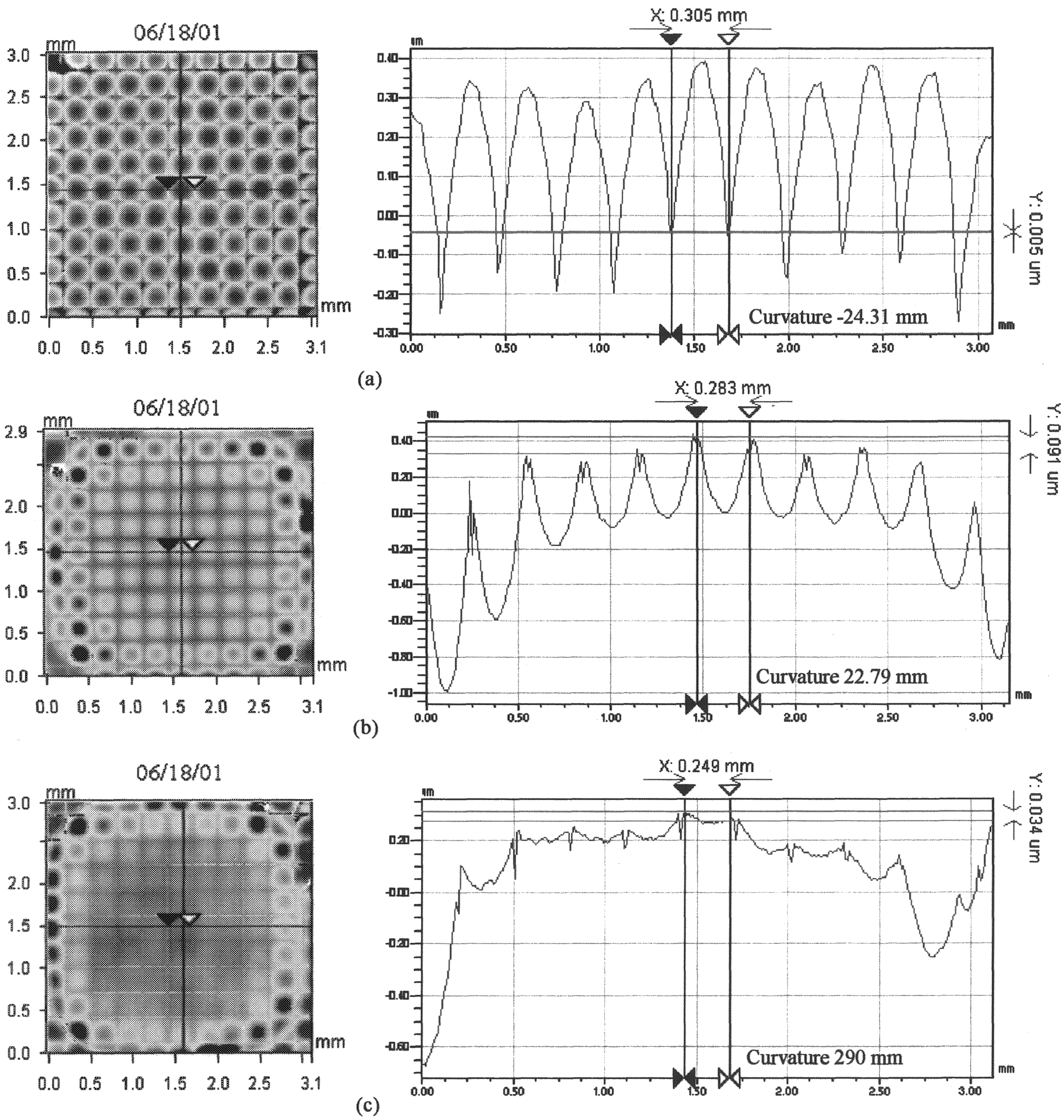


Figure 11: Comparison of a mirror membrane with (a) no gold (b) 1500 Å gold, and (c) partial removal of gold using ion machining (IM)

Gold evaporated on a membrane mirror with a thickness on the order of 500 Å can be used to improve reflectivity without significantly changing the mirror surface. A flat mirror membrane was coated with 500 Å of gold had only a nominal change in the mirror curvature as is shown in Figure 12.

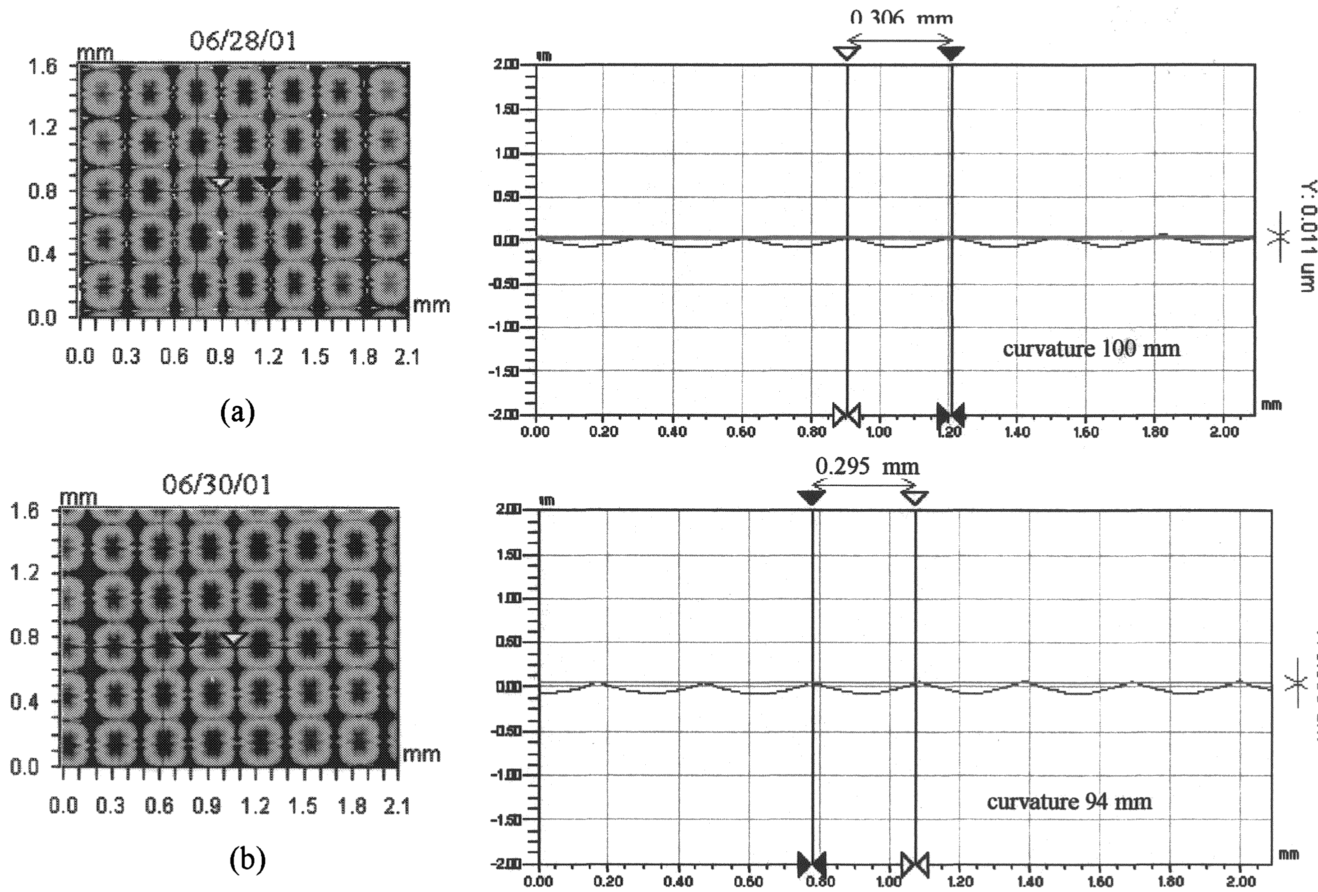


Figure 12: Comparison of a mirror membrane with (a) no gold and (b) 500 Å gold

3. FUTURE WORK

Future work will include a modified process to coat a much larger 32×32 deformable mirror actuator arrays currently in development. A mask layout drawing of the new 32×32 actuator array is shown in Figure 13.

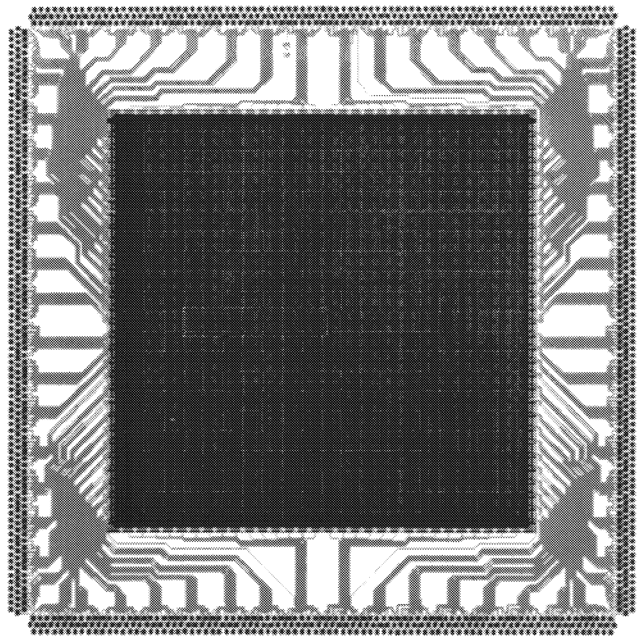


Figure 13: Cad drawing for the mask layout of new 32x32 mirror array.

4. ACKNOWLEDGMENTS

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