Metrology of Prototype Nanolaminate Deformable Mirrors

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Optics with small areal densities will have broad applications in lightweight deployable optical systems such as large aperture space telescopes. Integrated actuation of nanolaminate optical surfaces can provide stand-alone membrane optics that can reach areal densities as low as 1kg/m^2. The objective of the project I am involved with is to evaluate the performance of these deformable mirrors (DM). The DM consists of a base layer upon which electrodes lay then a spring layer and finally a mirror layer on top; each layer is connected by posts. I used a laser profilometer to measure the relative displacement of the mirror layer in the rest position and then while actuated (by applying an electrical potential). I am presenting the results from two different prototype designs. The measurements I obtained show the prototype deformable mirrors had an average mechanical stroke of 2.75 microns.

Introduction

➢New lightweight, active optics technology will enable a new class of large aperture space telescopes. The current technology consists of deformable mirrors (DM) which are made of thin sheets of glass or silicon a few inches in diameter with actuators attached to the back which bend the mirror locally to correct for wavefront aberration.

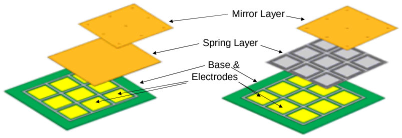
➢The DOE NA-22 project objective is to demonstrate and evaluate integrated actuation of meter-class nanolaminate (NL) optics suitable for space applications. The enabling technologies are:

The Nanolaminate

• Produced by sputtering alternating layers of two metals onto a pre-formed mandrel.

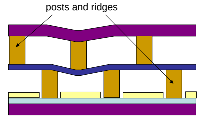
• Mirrors can be fabricated in less than a week and can be ~ 1 micron thick.

Integrated Actuation



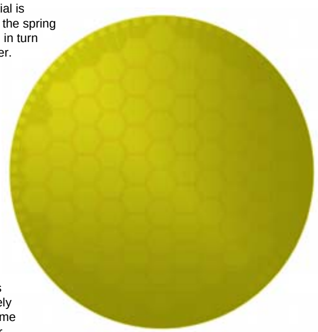
• Here are two 3x3 pixel prototype DM with 1 cm spacing, on the left the spring layer is a continuous sheet of NL while on the right it is an etched invar foil and both are surmounted by a NL mirror layer.

Mirror Displacement



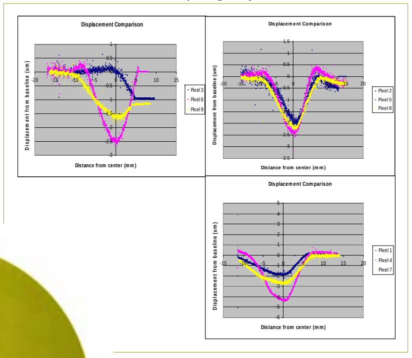
• As an electrical potential is applied to the electrode the spring layer is displaced which in turn displaces the mirror layer.

➢My project was to evaluate the performance of two 1st generation 3x3 pixel prototype DM with a glass base layer, rolled invar spring and mirror layers, and SU-8 posts and ridges. One DM had a continuous invar spring layer and the other an etched invar spring layer.



Results

Continuous Spring Layer Data



Pixel Reference

9	8	7
6	5	4
3	2	1

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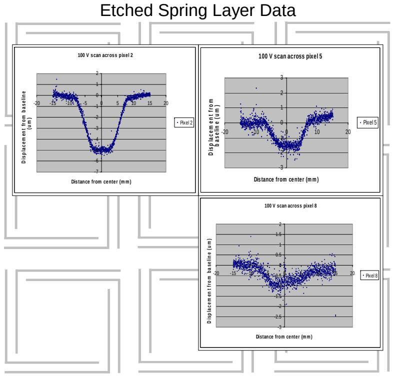
Etched Spring Layer Data



Methods

➢ I used a UBM laser profilometer to take measurements of the prototype DM.

➢ The UBM uses infrared light from a semiconductor laser which is focused to a spot by an objective lens. The light reflected by the object surface is directed by a beam splitter, through a prism and is imaged as a pair of spots onto an arrangement of photodiodes. When the objective lens is precisely it's focal distance from the surface both diodes are illuminated equally. If the distance between object surface and objective lens then changes by some amount the imaged focus point is shifted and the illumination of the photodiodes becomes unequal. This unequal illumination generates a focus error signal. A control circuit monitors the focus error signal and moves the objective lens accordingly.

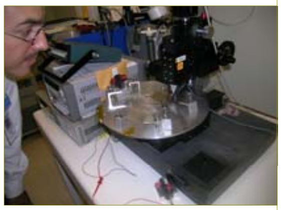
9	8	7
6	5	4
3	2	1

➢ I aligned the edges of each prototype to the UBM grid and measured the vertical center and horizontal center of each pixel. The UBM scanned from right to left and each pixels surface profile was individually measured (50 points per mm) first at rest then with a 100 V potential applied. The difference of the two measurements was calculated and plotted with respect to horizontal distance.

➢ I also measured a reference standard with the UBM and compared the measurements to those taken by a calibrated profilometer so I could get the absolute displacement.

Aligning the DM to the UBM grid

Referencing lab book data



Checking the objective lens height

Discussion

➢ Continuous spring layer: Pixel 3 data represents the invar mirror layer becoming disconnected from the spring layer and not responding to actuation. Pixels 3,6, and 9's deflections run flat because the UBM's vertical range is 100 μm so when the mirror layer's curvature ranges more than 100 μm the difference between rest and actuation is 0. This causes the graph to flatten when the range is exceeded.

➢ Etched spring layer: The deflection curves are flatter on the bottom presumably due to the mechanics of the etched spring layer. Pixel 2 has a very large displacement not characteristic of any other pixels on either DM.

➢ The reference standard measurements by the calibrated profilometer were averaged and the value was 7.16 μm. The reference standard measurements by the UBM were averaged and the value was 6.25 μm. These measurements calculate a 13% difference. Below are tables showing the absolute measured displacement.

Continuous Spring Layer

Pixel #	Relative Displacement (μm)	Absolute Measurement (μm)
1	1.84	2.08
2	1.87	2.11
3		
4	4.27	4.83
5	2.39	2.70
6	2.49	2.81
7	2.69	3.04
8	2.2	2.49
9	1.59	1.80

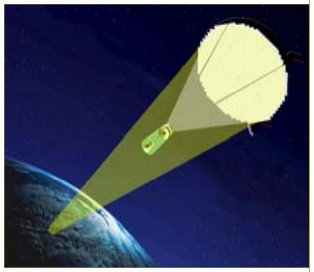
Average Displacement ~ 2.73 μm

Etched Spring Layer

Pixel #	Relative Displacement (μm)	Absolute Measurement (μm)
2	4.99	5.64
5	1.54	1.74
8	0.82	0.93

Average Displacement ~ 2.77 μm

➢ The success of these 1st generation prototypes and subsequent 2nd and 3rd generation prototypes will allow for scaling to meter size DM suitable for space applications such as the picture to the right.



Lightweight space telescopes are an integral part of future surveillance and nanolaminate foils, developed at LLNL, are making the lightweight optics for these telescopes a reality.

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