

Actuation of Deformable Mirrors Using Laser Controlled Pistons

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ABSTRACT

Current deformable mirrors used for adaptive optics employ many actuators to adjust the mirror in order to compensate for optical irregularities. These mechanical actuators, which can number in the hundreds for a given mirror, require a significant amount of electrical wires in order to be controlled.

The objective of this research is to implement a different type of actuator that can be controlled without the use of wires. The actuator developed employs a laser to quickly heat and expand the air in a closed "cell". When the air expands, it pushes a membrane that causes the mirror to move. Creating an array of these cells, and scanning them with a laser can control a deformable mirror.

Testing showed that a single cell with a 5 mm diameter and 10mm in length can deflect a membrane of aluminized Mylar in excess of our minimum requirement of 20 microns.

These cells can now be assembled in a 5 x 5 matrix and attached to many small mirrors. An electro-mechanical scanning assembly can be used to aim the laser directly onto individual cells causing the mirror at that location to move.

1. BACKGROUND

The design of the laser-controlled actuator is modeled after a device invented by Marcel Golay¹ in 1949 to detect changes in temperature. Figure 1 shows the mechanics of the Golay cell. It is a fairly simple concept—air is heated in an enclosed volume. This volume is allowed to expand at one end causing a piston-like action. A light source is directed at a mirror attached to the piston. As the piston moves, it reflects the light onto a photo-detector. The output of the circuit is a voltage that changes with respect to the change in light on the photo-detector.

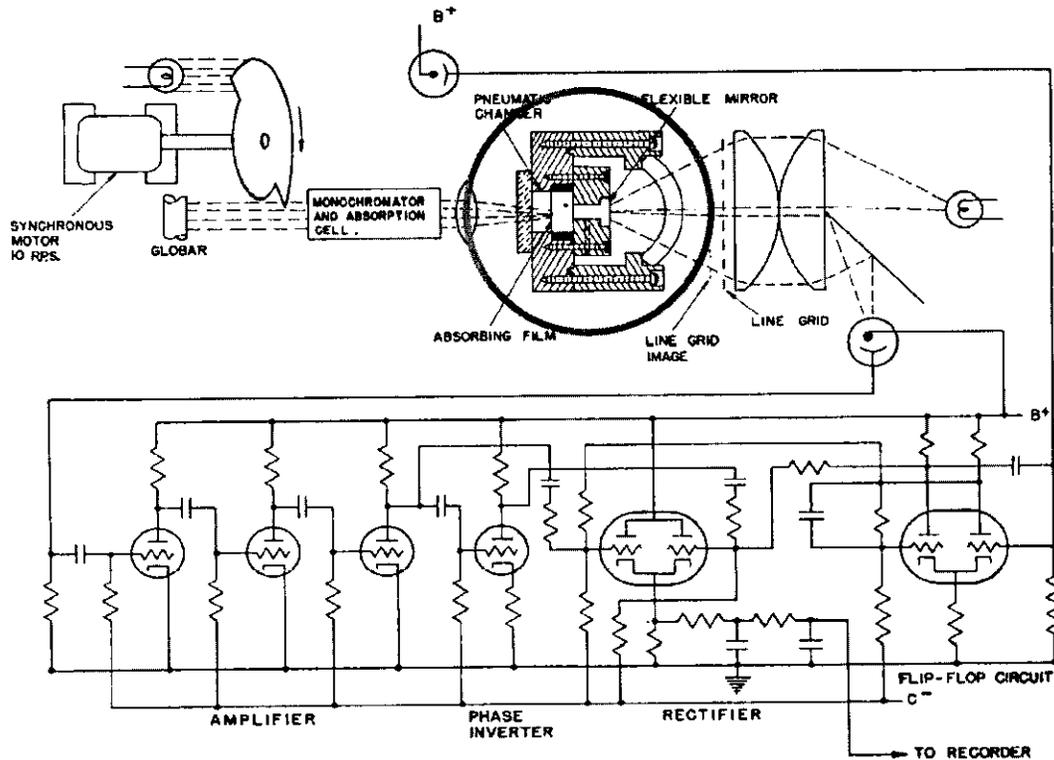


Figure 1: Golay Cell working drawing by Marcel Golay

The following research, performed by Charles Scott and Adam Lint, centered on implementing the first stage of the Golay cell (the portion in the green circle in Fig. 1) as an actuator for a deformable mirror. Very little information can be found on Golay cells and the mechanical drawing in Figure 1 is all there was to work with since there is no documentation to be found on how to actually build a cell. The first goal was to build a single working cell, and after that was accomplished, the construction of an array of cells that could be used in conjunction with a deformable mirror.

2. METHODS AND RESULTS

2.1 Individual Actuator Assembly and Testing

Research began by building and testing cells varying in length, hole diameter, material type, and membrane thickness. The design of the various cells generally stayed the same. A glass window was attached to one end of the cell. The glass is a microscope slide cover plate attached with rigid 5-minute epoxy. The movable end was made by attaching an aluminized Mylar membrane to the cell body with a flexible 24-hour epoxy. Figure 2 shows various copper, aluminum, and stainless steel cells used in testing.

These cells range in diameter from $\frac{3}{32}$ " to $\frac{1}{2}$ " and in length from $\frac{1}{2}$ " to $1\frac{1}{4}$ ". The Mylar was $\frac{1}{2}$ to 1 mil in thickness.

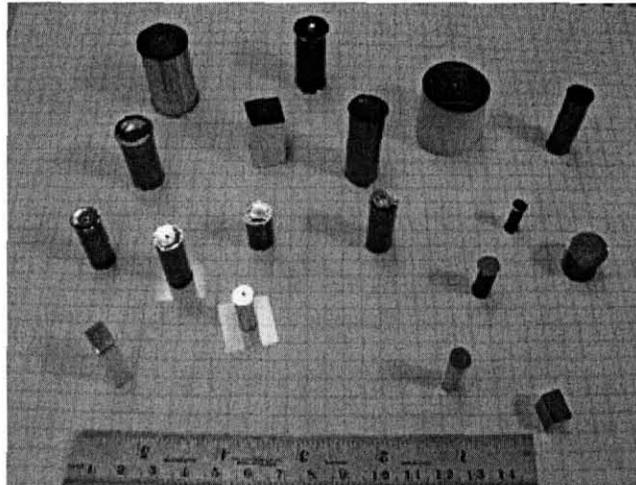


Figure 2: Assortment of cells tested for performance

Since a deformable mirror will have better resolution with more actuators per unit area, the hole of the cell (which is the size of the actuator) was kept small enough to get a decent resolution, but large enough to work with. After testing, it was found that an aluminum cell with a 5mm diameter hole and a length of 10mm worked well (See Figure 3).

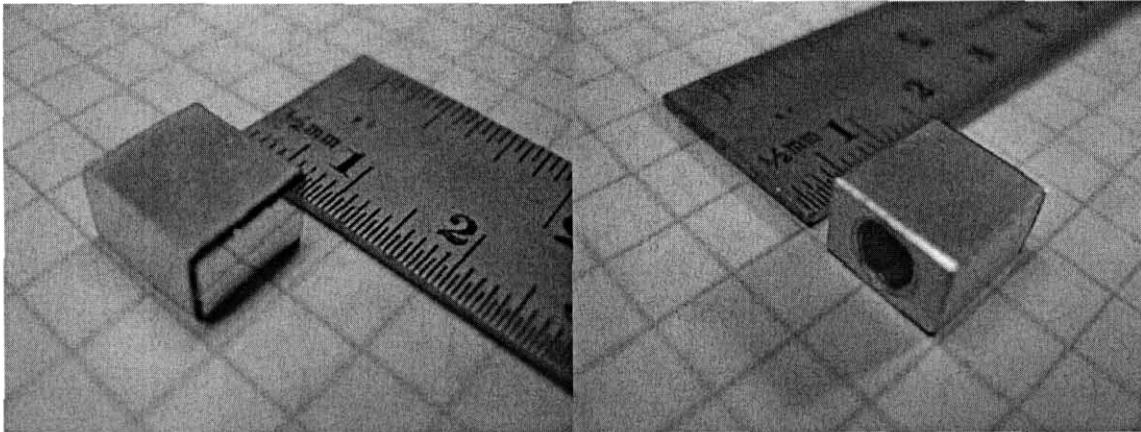


Figure 3: Final design of a single actuator

The plan for the first generation cell was to direct a 808nm variable power Diode laser into the window and heat the air inside the tube which would then expand and push the Mylar membrane outward. It was quickly evident that the laser could not simply be shot into an empty cavity and expand the air. There needed to be a mechanism for transferring the energy of the laser to heat energy. This was accomplished by placing a small metal absorber plate inside the cell (Figure 4). The plate was a 3.54mm square made out of 0.08mm thick copper which was painted black in order to absorb the laser. It was attached in the middle of the cell with 5-minute epoxy. Care was taken to attach the plate such that there were gaps between the walls of the cell and the sides of the plate so airflow would not be restricted.

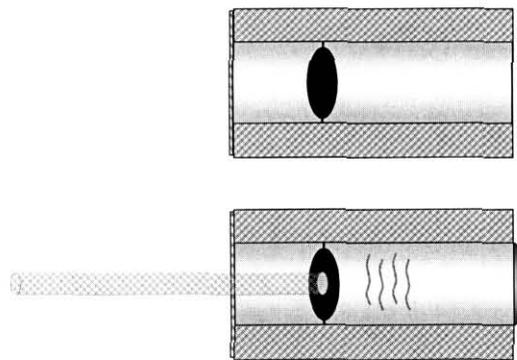
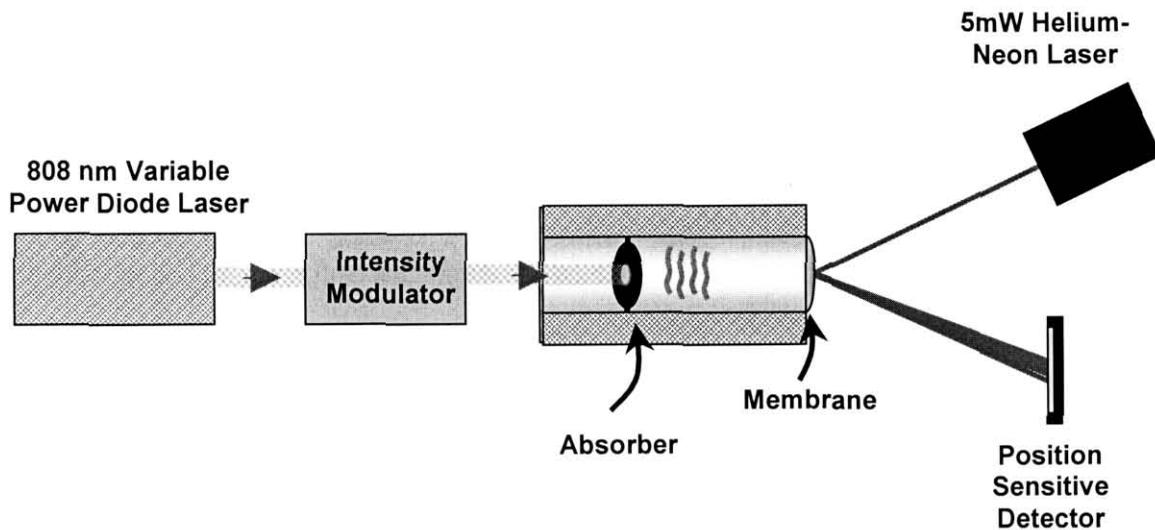


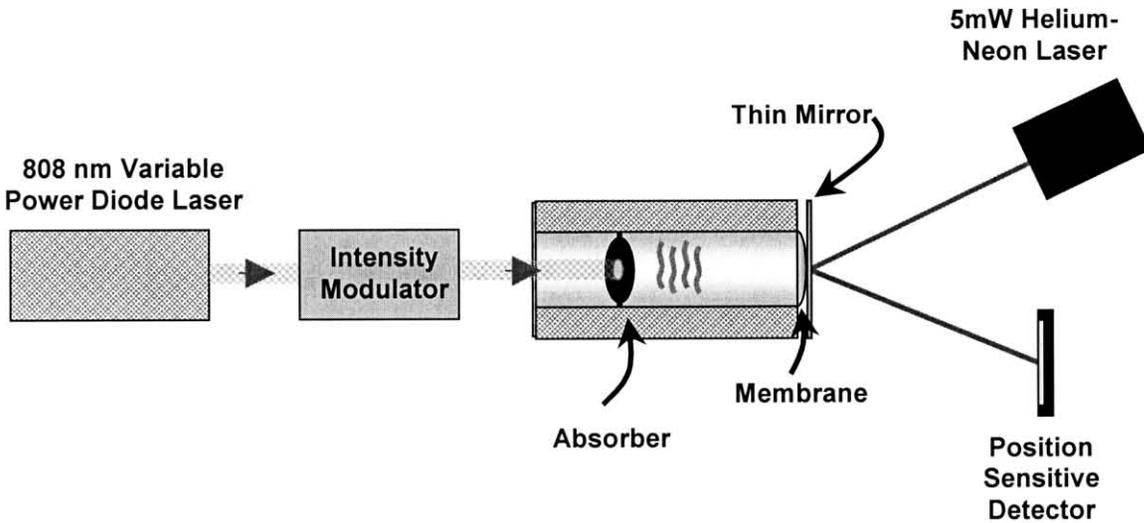
Figure 4: Actuator with and without deflected membrane

2.2 Position Sensitive Detector

Two methods were employed to determine if, and how much, the membrane could move. The first method used a Position-Sensitive Detector (PSD), which is a semiconductor device capable of detecting a light spot on its surface. The output of this device is a voltage that changes as the light spot moves across the surface and has a resolution better than a few microns. The light spot can be detected in both the X and the Y-axis. By reflecting a 5mW Helium-Neon (HeNe) laser off the aluminized Mylar membrane and onto the PSD as shown in Figure 5(a), the amount of deflection in the membrane could be determined. This method did not work because the curvature of the expanded Mylar caused the HeNe beam to diverge.



(a)



(b)

Figure 5: PSD with beam reflecting off of (a) Mylar and (b) mirror

By mounting a small gold-coated silicon wafer (0.3mm thick) to the membrane to act as a mirror, a reasonable surface for reflecting the laser was achieved (Figure 5(b)). A major difficulty was mounting the mirror such that it would move in only one axis when the pressure inside the tube expanded the Mylar. If the mirror was not centered perfectly on the Mylar, it would tip and tilt instead of having a smooth piston action. In the course of the experiments, this happened several times, which led to erroneous measurements. In order to test the mirror for even movement, the laser had to be carefully aimed at different locations on the mirror and the deflection checked. When the deflection values were the same regardless of where the laser was pointed on the mirror, the mirror was only moving in one axis.

In order to verify the deflection, a chopper was set between the Diode laser and the cell, causing the cell to heat and cool. Figure 6 shows the experiment on the light table. An oscilloscope recorded the output voltage from the PSD. The results of one such test are shown in Figure 7(a), which is a screenshot of voltage as a function of time. In this particular experiment, the cycle time of the chopper was set at 1Hz. Movement of the light dot on the PSD converts to 1 V/cm or $1 \text{ mV}/\mu\text{m}$. The sawtooth signal shows that the mirror attached to the actuator is moving forward as the Diode laser heats the cell,

and moves the opposite direction as the cell cools down when the laser is no longer in contact with the absorbing plate.

A heat-sink with a cooling fan was attached to the cell in order to dissipate any heat buildup after extensive use. Without the heat-sink, the cell would rise in temperature and eventually saturate. A thermal-electric (TE) cooler was attached to the cell in an attempt to regulate the temperature further, but this proved to be problematic because it would cool the cell to the point where the pressure in the cell was much lower than the outside pressure. The mirror did not respond rapidly enough, so the TE cooler was abandoned.

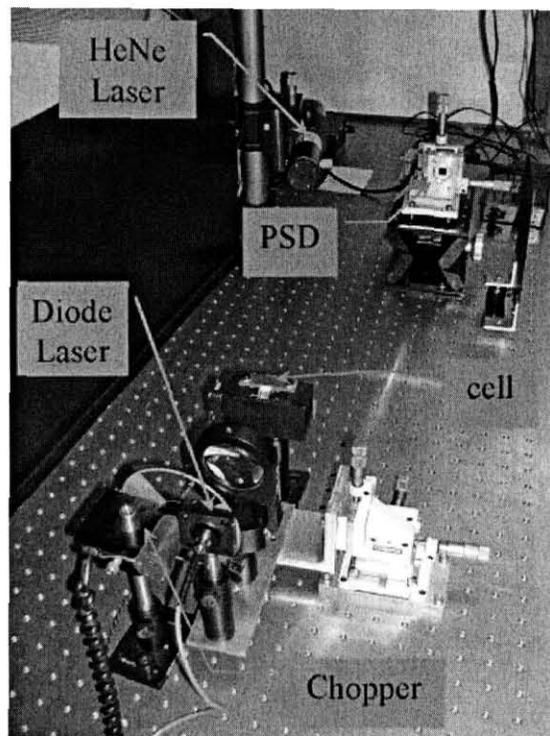
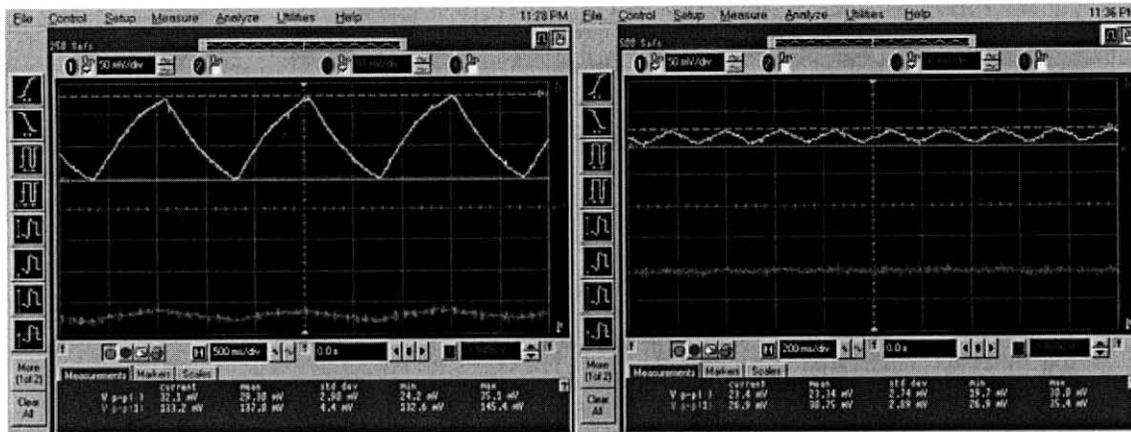


Figure 6: Light table configuration for deflection testing using PSD



(a)

(b)

Figure 7: Oscilloscope screenshots of PSD voltage (a) 1Hz at 230mW and (b) 5Hz at 230mW

The peak-to-peak voltage of channel 1 (the yellow line) is 140mV, which converts to 140 μm movement on the X-axis. A little trigonometry is used to calculate the piston-action movement to be 373 μm (see Appendix A for calculations). Also plotted on this screenshot (the violet line) is the movement on the Y-axis. This line shows that the mirror is tilting slightly causing the reflected beam to move 32 μm on the detector. Ideally, there would be zero movement on the Y-axis, but this seemed an acceptable amount for these preliminary designs.

The frequency at which the cell can be cycled is limited to the desired amount of deflection. The longer the Diode laser is incident upon the cell, the greater the deflection. Figure 7(b) is a screenshot of the same cell cycled at 5Hz. This shows a peak-to-peak value of 31mV, which translates to 83 μm deflection. There is also movement in the Y-axis, most of which looks like noise. Table 1 shows measurements taken using the 5 x 10mm cell at 1Hz and 5Hz.

Power (mW)	Output (mV)	Deflection (μm)
110	62	165
170	100	266
230	140	373
290	185	493
350	220	586

(a)

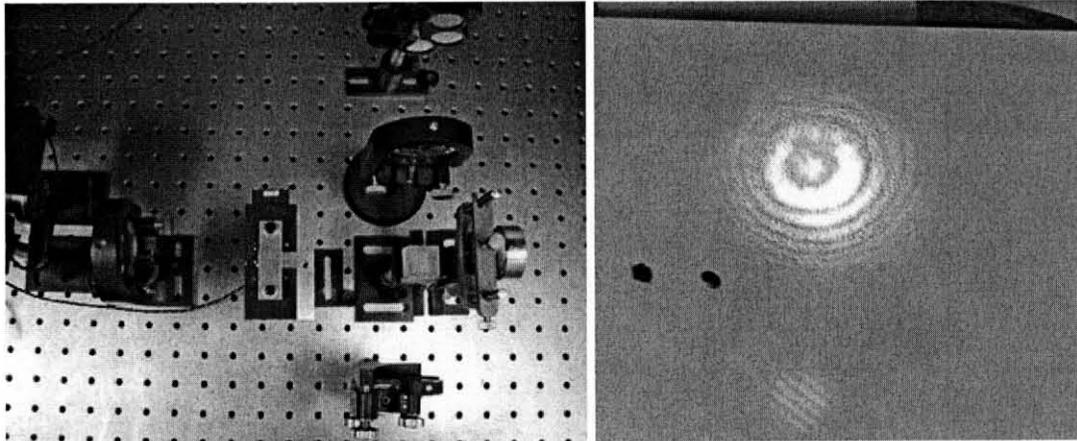
Power (mW)	Output (mV)	Deflection (μm)
110	20	53
170	25	67
230	31	83
290	33	88
350	40	107

(b)

Table 1: Mirror deflection based on different power levels at (a) 1Hz and (b) 5Hz

2.3 Michelson Interferometer

A second method utilized to show deflection was with a Michelson interferometer. The apparatus for this is shown in Figure 8(a). While this was used for a second verification of movement, it was not used to measure the actual amount of deflection. Figure 8(b) shows the fringe lines of the interferometer. A CCD and a frame-grabber were used to capture the changing fringe pattern and make it into a video.



8(a)

8(b)

Figure 8: (a) Michelson interferometer setup (b) fringe pattern

2.4 Actuator Array

After testing the various cells and determining the optimal dimensions, a 5 x 5 array of cells was designed. Each one of the cells in the array controls an individual mirror. Carlos Esproles machined the array out of a solid block of aluminum 10mm thick. 5mm holes were drilled with 1.25mm spacing between them. Colin Petersen drew up the plans to get the part machined (see Appendix B). Unfortunately, there was not much time to work with the array once it was finished being machined. The array was constructed similar to the way the individual test cells were made with the same type of absorber plate and $\frac{1}{2}$ mil aluminized Mylar. The finished product is shown in Figure 9.

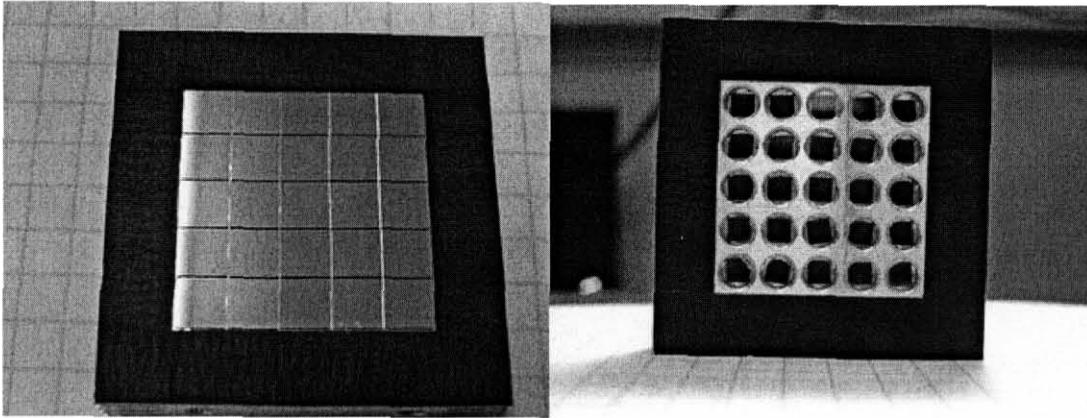


Figure 9: Finished array of cells

2.5 Laser Scanning

In order to use a laser to control each one of the cells in the array, the beam needed to be moved to the individual absorber plates. Rather than moving the laser itself, the beam was moved with two scanning mirrors. These scanning mirrors were cannibalized from some old pieces of equipment. This equipment consisted of two mirrors each attached to a different motor—one for movement in the X-axis, and the other for movement in the Y-axis. Using the Internet, the documentation for the control electronics for each motor was located (see Appendix C). A computer with LabView and an I/O interface board was used to control the motors. Scanning the actuators was simply a matter of moving the X and Y mirrors so the beam would hit the appropriate point. The method of scanning the array is done using a raster pattern shown in Figure 10. Using this method, the cells can be scanned by the laser very rapidly. A more complete apparatus would require a shutter to turn the laser on and off when appropriate so the cells could be turned on and off. A working system would also require a feedback loop for the adaptive optics to orchestrate the precise timing of the shutter to activate the movement of specific mirrors in the array.

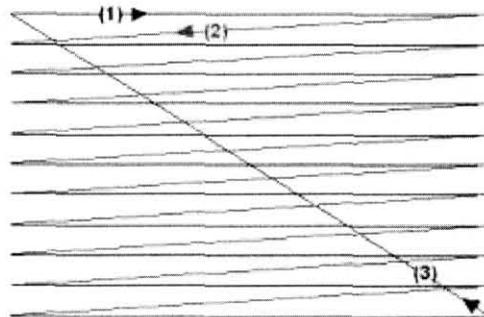


Figure 10: Raster Scan Pattern

Testing on the array showed that the group of cells performed the same as an individual cell. One concern is that adjacent cells would interfere with each other, but no interference was detected in the testing. The performance of individual cells in the array was not uniform due to the tolerances available during assembly.

3. CONCLUSION AND RECOMMENDATIONS

The experiments performed in this study show that the laser controlled piston method could be a feasible way of controlling deformable mirrors. The actuators described in this report achieved greater than 20 μ m deflection at 5Hz. Future versions would require greater tolerances in assembly, which would be difficult to do by hand. Better accuracy would be necessary in order to eliminate the amount of tip/tilt found in these actuators. The cells are also very sensitive to temperature and atmospheric conditions. Results from tests were different from day to day depending on the temperature of the room and barometric pressure. Care must be taken in future designs to account for this.

4. REFERENCES

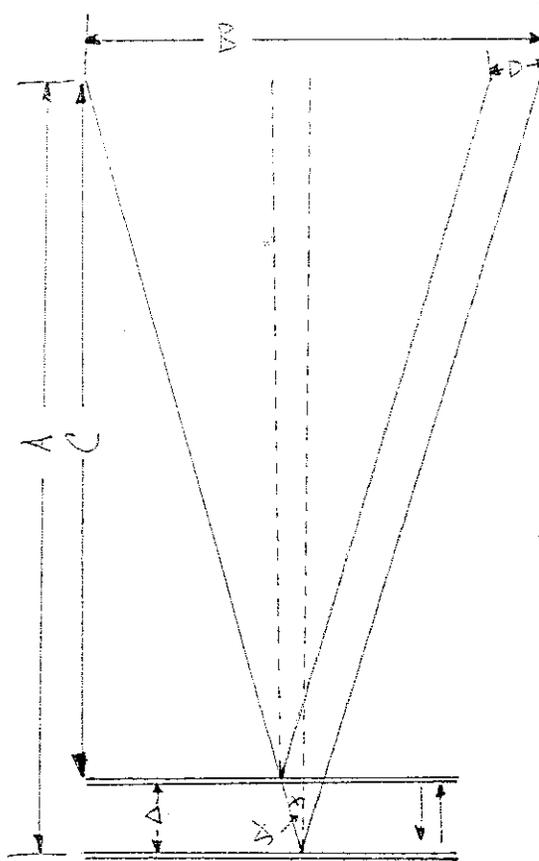
1. Golay, Marcel J. E. The Theoretical and Practical Sensitivity of the Pneumatic Infra-Red Detector. *The Review of Scientific Instruments* Vol. 20, Number 11 (1949)

5. ACKNOWLEDGEMENTS

I would like to thank the Idaho Space Grant Consortium for sponsoring me as a summer intern—I feel I have greatly benefited from my experiences at the Jet Propulsion Laboratory. I would also like to thank the Optical Communications Group and Hamid Hemmati for choosing me to work on this project.

APPENDIX A

Deflection Calculations



$$\Delta = \tan\left(\frac{1}{2} \frac{B}{A}\right)$$

$$\Delta = \tan\left(\frac{B-D}{2}\right)$$

$$\frac{B}{2A} = \frac{B-D}{2C}$$

$$C = A - \frac{AD}{B}$$

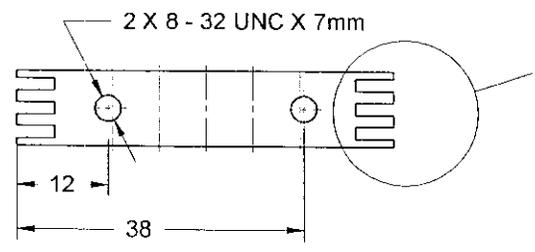
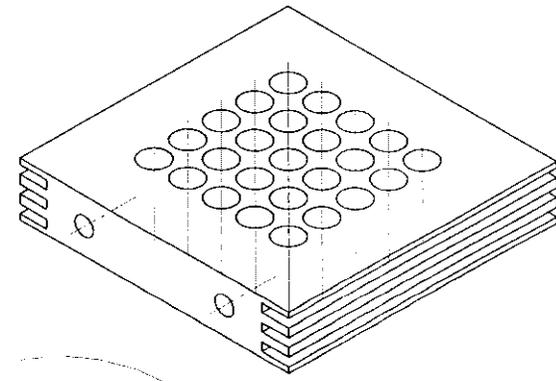
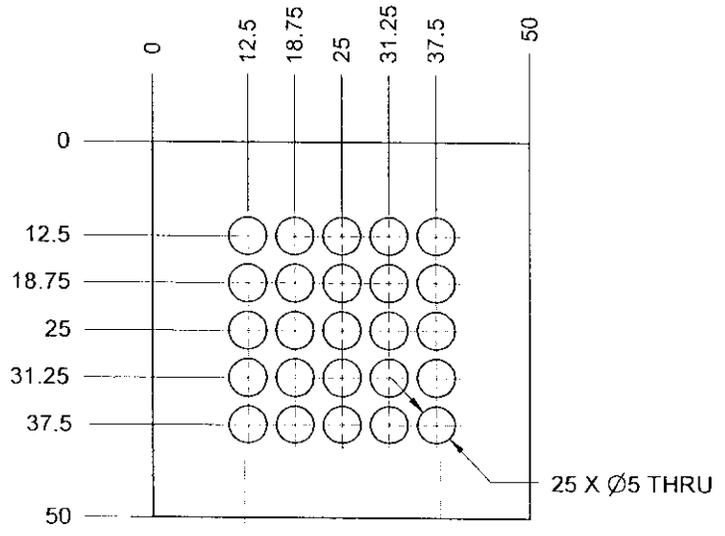
$$D = A \cdot C = A - \left(A \cdot \frac{AD}{B}\right) = \frac{A^2}{B}$$

A = 47.78 cm
B = 17.99 cm

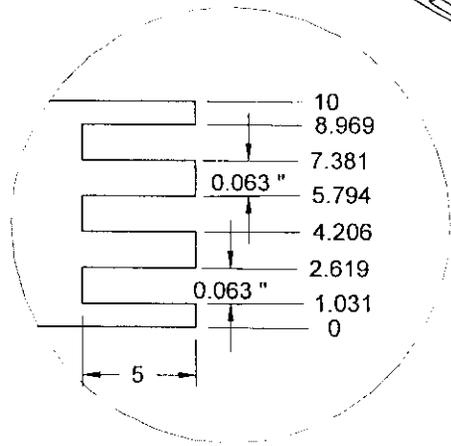
D = 6.2 × 10 ⁻³ cm	Δ = 165 mm
1 × 10 ⁻² cm	266 mm
1.4 × 10 ⁻² cm	373 mm
1.85 × 10 ⁻² cm	493 mm
2.2 × 10 ⁻² cm	586 mm

APPENDIX B

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



A



Detail A SCALE: 3:1

ALUMINUM

SI

SIZE A	FSCM NO.	DWG NO.	REV
SCALE 1:1	GOLAY ARRAY		SHEET

APPENDIX C

Table 1: Power Connector

Pin	Function
1	Reserved
2	Supply + (+15 to +24 V)
3	Supply Ground
4	Supply - (-15 to -24 V)

Mating Connector*: Panduit: CE100F22-4-D
Strain Relief*: Panduit: SCC100F-4-D
Assembly Tool*: Panduit: MRT-100F
Specified Wire Size: AWG #22 (Also available in #24, #26, #28)

**Contact your local GSI Lumonics Sales Representative for sample.*

4.2 Control Signal Interface

The control signal interface is provided on connector J2 located on the baseboard. System I/O including command input, position output, status feedback, and enable are located on this connector. The signal connector pin functions are provided in Table 2:

Table 2: Signal Interface Connector

Pin	Function
1	Command +
2	Command -
3	Ground
4	Temperature Status
5	Servo Enable
6	Servo Ready
7	Scanner Position +
8*	Scanner Position -

* Differential output- do not ground.

Mating Connector: Panduit CE100F22-8-D
Strain Relief: Panduit SCC100F-8-D
Assembly Tool: Panduit: MRT-100F
Specified Wire Size: AWG #22 (Also available in #24, #26, #28)