Large-Scale Polysilicon Surface Micro-Machined Spatial Light Modulator

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ABSTRACT

A large-scale, high speed, high resolution, phase-only microelectromechanical system (MEMS) spatial light modulator (SLM) has been fabricated. Using polysilicon thin film technology, the micro mirror array offers significant improvement in SLM speed in comparison to alternative modulator technologies. Pixel opto-electromechanical characterization has been quantified experimentally on large scale arrays of micro mirrors and results are reported.

Keywords : spatial light modulators, micro mirrors, actuator frequency response

DESIGN

Applications for large scale µSLMs exist in various fields such as astronomical and medical imaging, holographic encryption for telecommunications, and optical correlation. Such dynamic optical applications require µSLMs to have low signal loss, high reflectivity, high phase resolution, and a fast response. The primary function of an SLM is to alter the local phase of reflected light, which can be accomplished by deflecting mirror pixels by half the wavelength of the light source. The advantages of µSLMs using MEMS technology are a fast response, high fill factor, and zero polarization effects. Another advantage to MEMS electrostatic actuators is no hysteresis thus facilitating driver control [2].
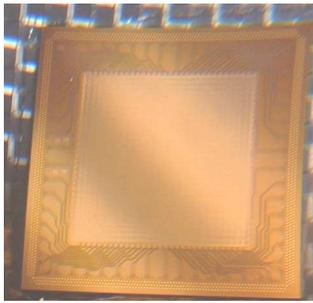

Figure 1. 1024 element
µSLM with bond pads

The design of the µSLM (depicted in Figure 1) is based on previously developed devices by Boston Micromachines Corporation (BMC) and Boston University, with MEMS fabrication performed by Cronos / JDS Uniphase. The structure consists of a double cantilever membrane actuator with an overlying mirror attached (seen in Figure 2). Earlier µSLMs of 144 elements have demonstrated advantageous opto-mechanical properties, such as good optical quality (high reflectivity, > 98% fill factor, λ/50 flatness), high frequency
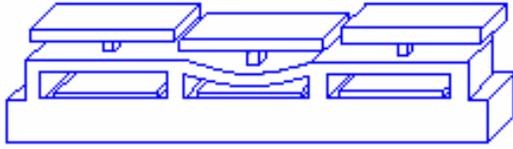
Figure 2. Cross section of 3 µSLM pixels showing double cantilever electrostatic actuators with a post and mirror

bandwidth (> 60 kHz) and λ/2 deflection (λ=1.55 microns) [1]. The results and processes described in this paper will show the scalability of this design and challenges to maintain these characteristics for a large scale µSLM (array of 1024 elements). The integration effort of the devices is being led by Lawrence Livermore National Laboratories. Testing and characterization of the µSLMs will determine the electromechanical and optical properties, reliability of the device and processes, and will determine the method of metallizing to provide high reflectivity and packaging of the µSLM.

ELECTROMECHANICAL AND OPTICAL PROPERTIES

Electromechanical and optical characterization is necessary to determine an optical packaging environment for the device, which is severely air-damped at atmospheric pressures and is underdamped in vacuum. Efforts are underway to package the device at pressures that permit near-critically damped performance.

Phase Modulation

Deflection versus voltage was examined with a Wyko interferometer of both 1024 pixel µSLM and 144 pixels µSLM. Figure 3 shows a single actuator deflected on a 144 pixel µSLM device with the same structural design and from the same fabrication run as the
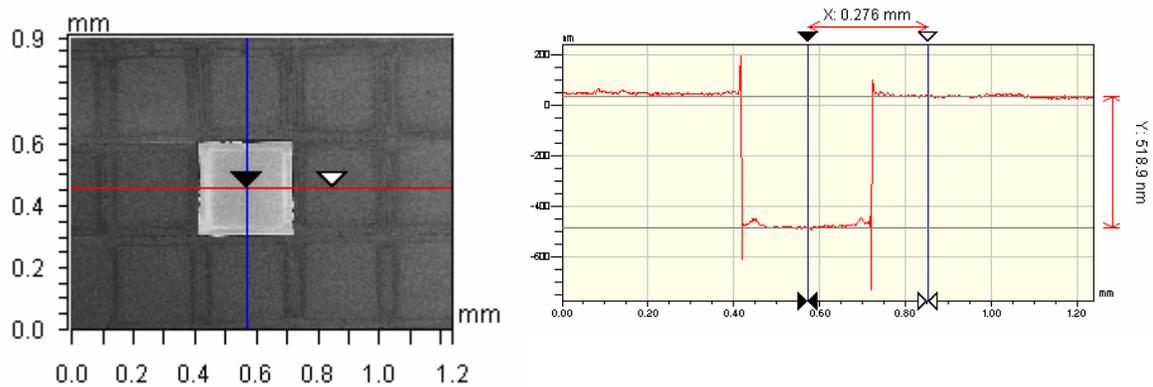
Figure 3. Wyko interferometric surface measurement and 2D plot of one pixel of a 1024 element μSLM deflecting 520 microns at 50 V.

1024 element μSLMs. Using a wyko interferometer, it is evident that the mirror is very flat (radius of curvature of 500 mm) and has a low roughness ($< \lambda/50$, $l = 1.55$ μm). Figure 4 demonstrates close deflection versus voltage curves of a 144 and 1024 element μSLM.
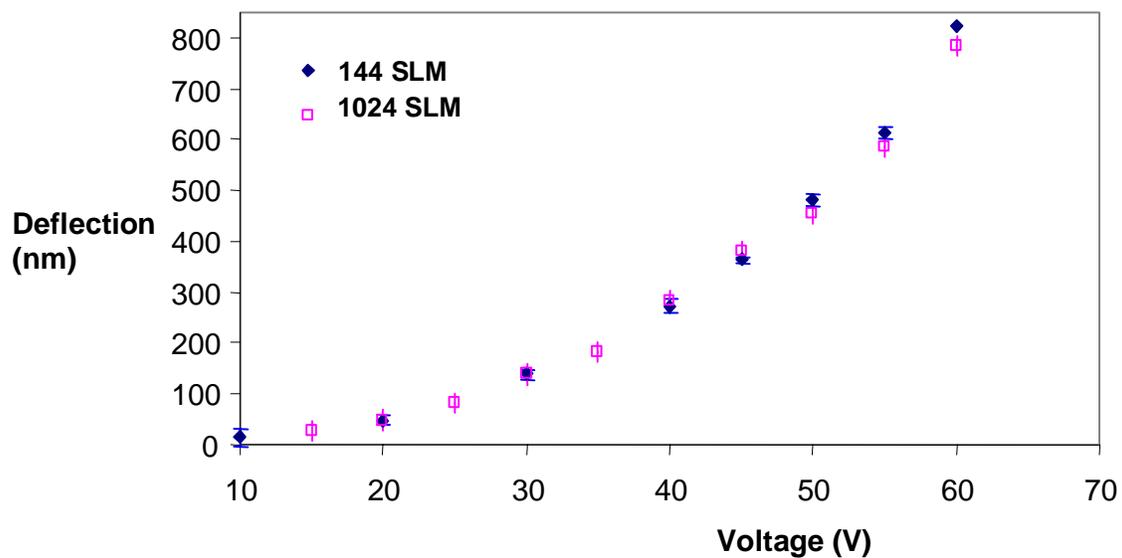

Figure 4. Voltage versus deflection curves for a 144 pixel μSLM and 1024 pixel μSLM from the same wafer differ within measurement error.

Frequency Response

Frequency response modeling of a single pixel was done using a commercial finite element software package, Abaqus©. The modeling showed a first order out of plane mode at 82 kHz. To validate the model, frequency response was measured using an interferometer. A custom vacuum chamber was designed and built to control ambient pressure surrounding the μSLM. A detailed description of this apparatus (developed at Boston University) and its use in frequency testing of μSLMs at various pressures is to be presented elsewhere. Preliminary results from this experiment are shown in Figure 5. In atmosphere, the μSLM pixel was shown to be overdamped. At 6 Torr, the pixel is underdamped, with a resonant frequency of ~80kHz. In previous devices [2] with twice the actuator gap (stroke), the pressure at which the devices were critically damped was twice that of the current device. This can be due to the effect of squeeze film damping which affects a device more as the gap decreases.
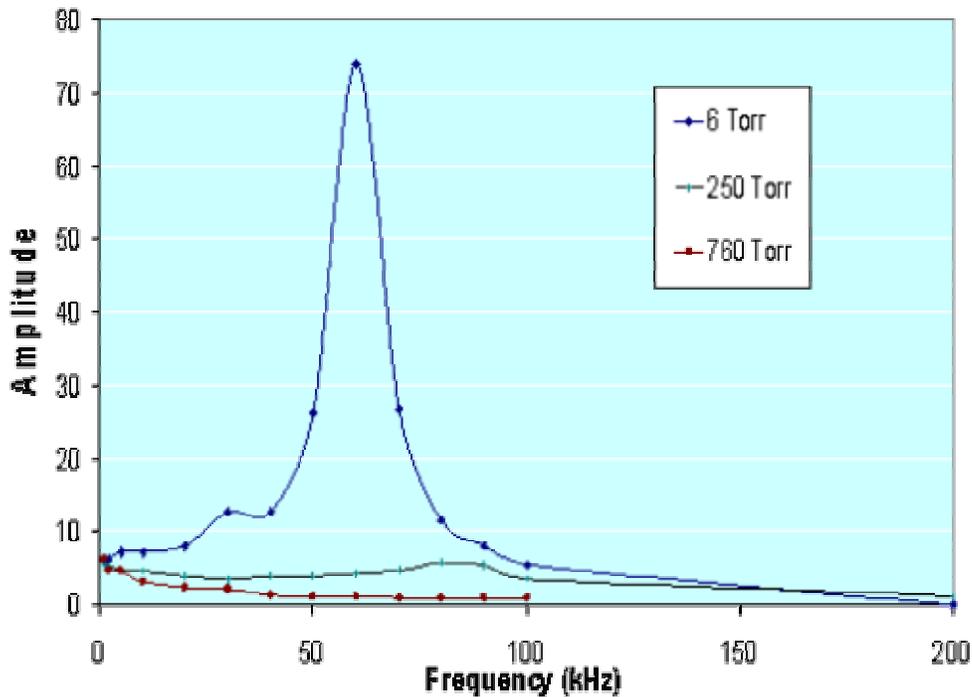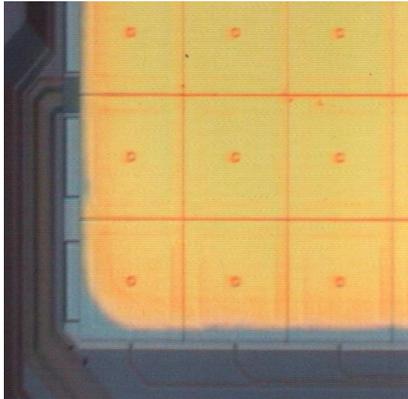

Figure 5. Intensity versus frequency at various pressures pixel from a 144 pixel μSLM.

Metallization

Deposition of a reflective film on the μSLM surface is required due to the low reflectivity of bare silicon at the wavelengths used. Post-release low-stress metal deposition has been used. This coating is performed using e-beam evaporation,

due to the optically smooth and directional coating it provides, and a shadow mask. Figure 6 depicts a corner of a metallized 1024 µSLM. Deposition rates and temperatures are used to control the stress in the film. A deposition of ~80nm occurs at 80 degrees C in less than 40 minutes. There is no measurable difference in roughness after metallization As seen in Figure 6, the roughness of a pixel after metallization is 30 nm RMS which is within specifications of the project for which this was developed. Using a high precision custom x, y, z, θ translation stage (Figure 8), shadow mask mis-alignment has been reduced to a small fraction of the clear aperture of the µSLM (~0.2%).
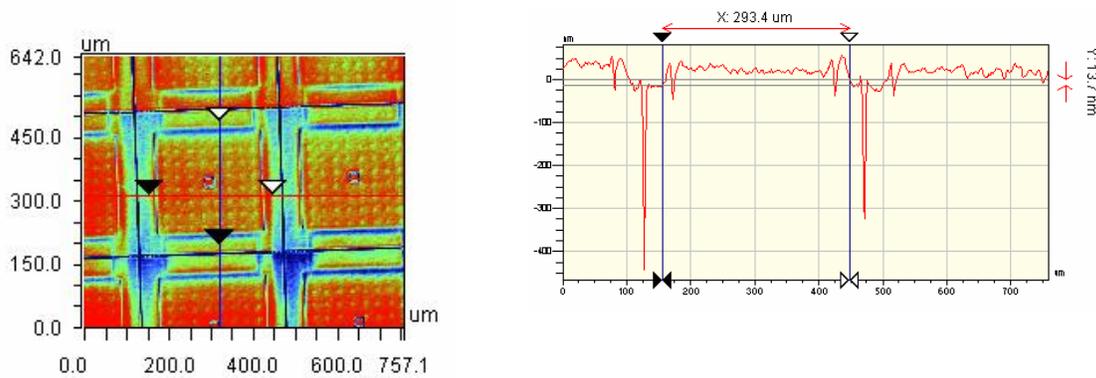
Figure 6. AU metalized 1024 element µSLM

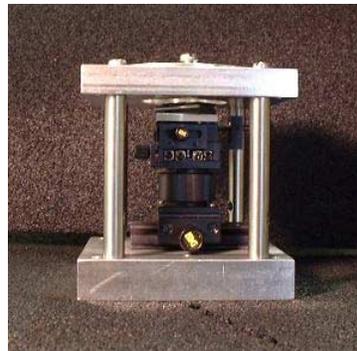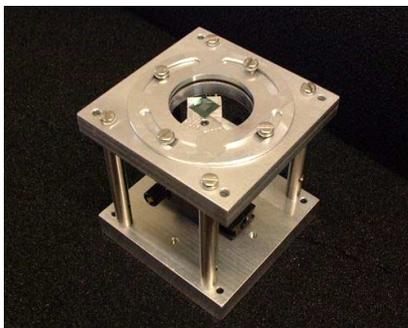Figure 7. Wyko interferometer surface and 2D measurement of a gold coated 1024 pixel µSLM.

Figure 8. Custom Alignment and die holder apparatus with x,y,z, and θ adjustment.

Pixel Electromechanical Performance

Pixel performance testing addresses the electromechanical lifetime and functional yield of the µSLM. The robustness and repeatability of the device can be tested with continuous high speed cycle testing.

Electromechanical performance of a number of measured pixels was measured on a 144 element µSLM. Repeatability in pixel performance and between adjacent actuators was examined using 144 pixel µSLMs. Using an interferometer, 100 measurements were averaged for each data point depicted in Figure 9. The average deviation between all measurements made on these five actuators was 4nm.
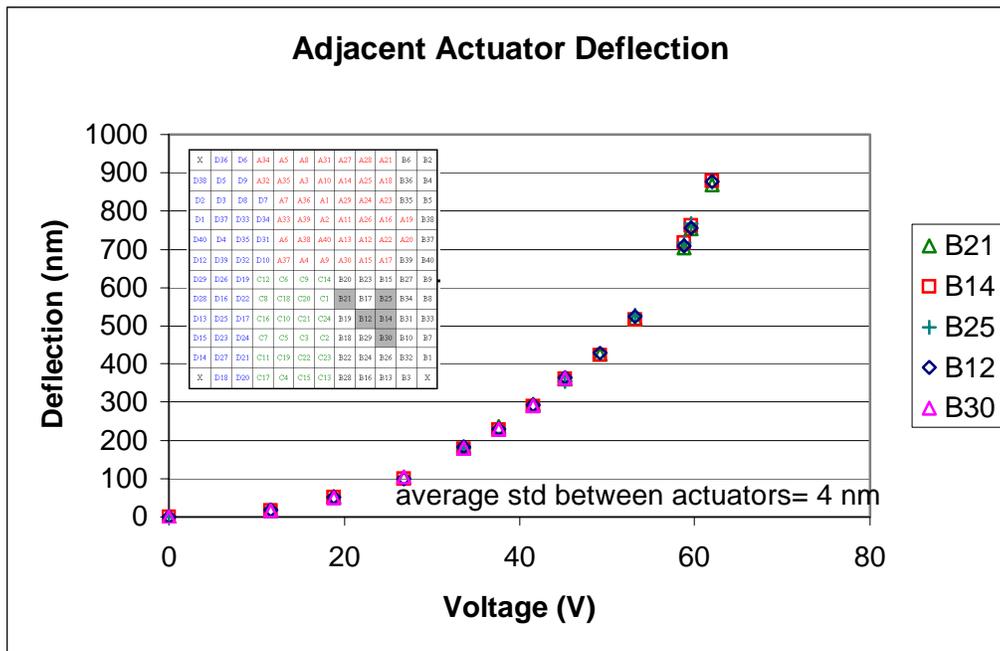

Figure 9. Deflection between adjacent actuators
(marked in gray) in a 144 pixel SLM had an average deviation of 4 nm.

A 2 kHz input HV sine wave with an amplitude resulting in half the maximum stroke was applied to an actuator to test robustness and repeatability. After 200 million cycles, there was no measurable difference in deflection for a given voltage (Figure 10).

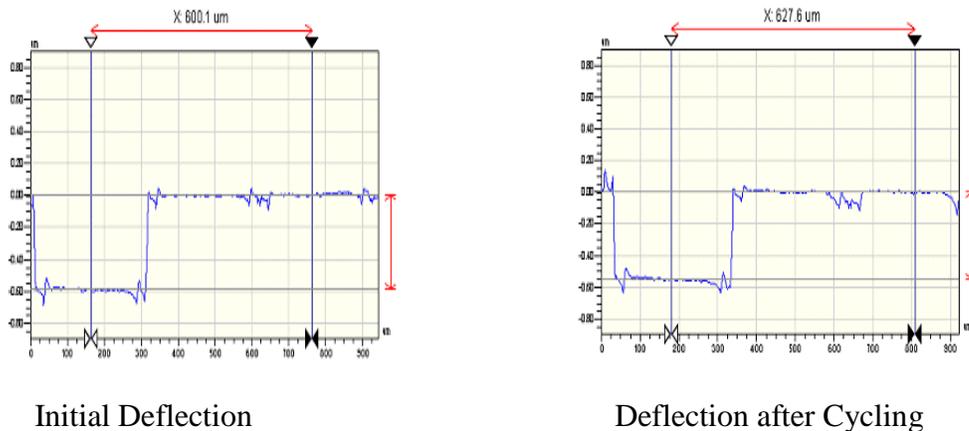| Initial Deflection | Deflection after Cycling |

Figure 10. Cross section measurements prior to and following 200 M cycles of deflection. Difference in deflection was within measurement error.

Functional Yield

Preliminary tests on the 1024 element μSLM show a functional yield to be above 99%. The most (above 99%) 144 pixel μSLMs which were not damaged during fabrication, metallization and packaging, had a 100% yield. Tests conducted at Lawrence Livermore National Laboratories on a metalized 1024 pixel μSLM, demonstrated a 99.6% yield of working actuators.

CONCLUSION

In summation, the above electromechanical and optical characterization the μSLM will be used to optimize the packaging, environment and functionality. Based on data taken thus far, the design specifications of good optical quality, reliable and consistent mechanical responses, and high yield have been met.

REFERENCES

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2. Dimas, C., Bifano, T., Bierden, P., Perreault, J., Krulevitch, P., Roehnelt, R., Cornelissen, S., "Polysilicon Surface Micromachines Spatial Light Modulator with Novel Electronic Integration" Design, Test, Integration, & Packaging Conference, 2002