Total Dose Degradation of Optical MEMS Mirrors†
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Abstract
We present the first radiation test results of optical MEMS devices. Tests were performed on two very different deformable MEMS micromirror arrays. Test results are discussed with respect to the different device constructions.

I. INTRODUCTION
There are many possible implementations of microelectromechanical (MEMS) devices, including cantilevers, diaphragm assemblies, mirrors, springs, and even motors. Many of these are of interest for space applications. To date, however, Radiation studies have been done on only a limited number of MEMS structures [1-5]. The results of this work have shown that charge trapping in insulators within various MEMS devices can cause a shift in the voltage required to activate mechanical motion. Most MEMS devices are significantly degraded at total dose levels between 30 and 100 krad, unless they are fabricated without dielectric materials between the two regions that are mechanically actuated [5].

This paper reports the results of total dose degradation on deformable optical mirror arrays that can be deflected by applying an external voltage. Devices of this type are proposed for use in ultra-large lightweight space telescopes [6]. The purpose of the present study is to determine how mirror arrays of this type fabricated in different processes are affected by space radiation, as well as on more general insight into the susceptibility of optical MEMS devices to radiation.

II. DEVICE DESCRIPTION
The devices studied in this work are MEMS deformable mirror arrays manufactured by Boston Micromachines Corporation (BMC). These devices are fabricated using silicon micromachining techniques with structural silicon and sacrificial oxides. As shown in Fig. 1, they consist of two polysilicon membranes, separated from each other by a thin airgap. The top membrane provides the mirror surface. The lower membrane is fixed at the edges to the substrate. The two membranes are attached at the center with a silicon-dioxide spacer, 5 μm thick. The lower membrane can be deflected by the electrostatic attraction that results from applying a voltage to the lower electrode, which induces an image charge in the membrane. Electrodes at the bottom layer, formed on a silicon wafer isolated with a one-micron layer of nitride, are individually addressable. Voltage is applied to the individual lower electrodes to achieve the desired mirror contour. The upper membranes are both grounded.

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The deflection of the mirror varies with distance from the edge, where the “anchor” membrane is attached to the substrate. The mirrors were designed for a typical center deflection of approximately 1.5 micron at a deflection voltage of 140 V. The maximum voltage that can be applied is 250 V. The peak deflection at the center of the mirror is a key parameter for mirror applications. The deflection is nonlinear with voltage, as shown in Fig. 2. The typical deflection contour for a mirror segment is shown in Fig. 3.

Rather than being electrostatically driven, mirror segments in this device are controlled by a piezoelectric actuator. Further the JPL device is fabricated using a wafer bonding silicon membrane transfer technique. The resulting cross sectional structure, shown in Fig. 4, consists of a silicon mirror membrane, connected by an indium post to the controlling piezoelectric membrane. This membrane is lead zirconium titanate (PZT) on silicon nitride. The moving structure is supported on silicon posts.

This device is controlled by applying a voltage across the piezoelectric membrane. Flexure of this membrane moves the mirror surface. One advantage of this structure is that the resulting device has a much larger stroke than the typical micromachined device.

III. EXPERIMENTAL PROCEDURE

Measurements of the peak deformation depth of the BMC micromirrors were made using a Wyko model RST Plus Optical Profiler. This device scans the surface of the device measuring the deflection by counting interference fringes. The maximum deflection occurs at the center of the mirror. This deflection was measured at a specific drive voltage by performing difference scans between the 0V and 140V applied condition. Control voltage was applied using a mirror drive system provided by BMC. This is a time-consuming process, requiring careful attention to alignment of the mirror assembly with the laser measurement apparatus. The maximum voltage that can be applied to the device is 250 V. A voltage of 140 V, which produces a deflection of approximately 1.5 μm, is typical of many applications, and measurements at that voltage were used to determine how the mirror actuation was affected by radiation.

Testing was done using cobalt-60 gamma rays at the JPL high dose rate (HDR) facility. Testing was performed on two groups with five mirror segments each, all located on a single device. One group of segments was irradiated without bias (electrodes at ground), while the other was irradiated with a deflection voltage of 140 volts. The device was removed after each exposure run temporarily removing bias from the segments that were biased, and measured with the optical profiler. This required about one hour between successive irradiations.

IV. EXPERIMENTAL RESULTS

Total dose testing of the biased and unbiased mirror segments was done in several steps to a maximum of 3 Mrad. Deflection data for both of the test groups indicated no significant effects due to
radiation. Data for the biased devices, with measurement error bars is shown in Fig. 5. Similar results were obtained for the unbiased segments. Although there is a slight change at lower total dose levels, the change is within the measurement accuracy (2%).

A similar approach will be used for the PZT actuated micromirrors which will be measured using the same optical profiling system.

The completed paper shall include gamma total dose tests of the JPL/Penn State device. If significant changes occur then proton testing shall be performed as well because it has shown that proton irradiation may produce different effects in MEMS structures [4].

III. DISCUSSION

It has been previously shown for other electrostatically actuated devices, that the presence of charge trapping dielectric materials could result in significant radiation effects. Ideally, there is no dielectric between the lower and upper electrodes of the BMC mirror actuator. However, during fabrication the entire region between the electrodes is filled with silicon dioxide. This material is removed by chemical etching through a manifold of very small holes in the anchor membrane. If some of this material remains, it could trap charge between the electrodes during irradiation. The null result obtained for several different mirror segments suggests that this did not occur. The electric field required to operate these devices is 3 MV/cm. To generate this field strength would require the presence of a substantial dielectric layer.

In contrast to the BMC device, the JPL/Penn State device has a silicon nitride structural layer on the lower membrane. Thus it is more likely to be affected by ionizing radiation.

The complete paper shall include discussion of the additional proton tests and tests of the piezoelectric structure. Discussion shall expand on the effects of dielectric charging and the resultant electric fields. Due to the very small distances involved with the MEMS devices the large electric fields produced by dielectric charging can result in significant mechanical forces.

IV. CONCLUSIONS

This paper has shown the first results for optical MEMS devices. Although the first type of micromirror was not affected by radiation, the PZT device, which has a much longer stroke, contains dielectric material in a region where charging of the dielectric can potentially affect device operation.

Micromirror are an important new class of devices that are of interest for space applications. Thorough radiation characterization studies are required to determine the possible radiation effects. The tests reported herein are part of a continuing effort to evaluate these effects.

REFERENCES