A Comparison of Mass Reduction Methods for Silicon-on-Oxide (SOI)-based Micromirrors

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Abstract

The use of SOI wafers in the design of micromirror systems has become popular the last 15+ years due to the simplicity and uniformity in fabrication offered in comparison to micromirrors fabricated using surface micromachining methods with thin films. These systems typically leverage the optically flat (radius of curvature > 0.5 m) surfaces available in the SOI device layer to fabricate the mirrors. However, when reflective coatings (usually metallic Au or Al) are applied to these surfaces in order to meet optical reflectivity requirements the resulting film stress (usually tensile) can be substantial. To compensate for the additional stress induced curvature the thickness of the mirror is usually increased substantially (often 50 µm or more) in order to maintain near optical flatness. The resulting mass of these mirrors can be a limiting factor in the dynamic performance of the devices for particularly demanding applications such as beam steering and adaptive optics. In order to address this issue, various approaches to mass reduction of micromirrors by backside etching have been offered in the literature [1-3]. While the trade between curvature and mass, or moment of inertia for tip/tilt systems, is often mentioned in the literature, a comprehensive quantitative comparison of the different approaches has been absent. This work provides such a comparison across three different approaches (hemispherical, square, and triangular) using a 1.1mm square plate tip/tilt/piston micromirror element as the representative example (Figure 1).

COMSOL Multiphysics® simulation software was used to parameterize the baseline element design, and designs with each of the three different mass reduction approaches. The Solid Mechanics module was then used to apply experimentally measured stress values and representative boundary conditions to the example design and generate 3D steady state deflection profiles of the mirror surface (ex. Figure 2). The selected geometric conditions pursued in the study did not span the entire design space but instead focused on establishing trends in parameters and capturing the tradespace boundaries imposed by realistic limitations in fabrication resolution. Deflection data was exported to MS Excel for postprocessing (least squares fitting) of curvature profiles and verification of analytical mass estimates.

Trends in radius of curvature and mass in individual geometric parameters were successfully identified (Figure 3) for different mass reduction approaches. A graphical depiction of the design trade between curvature and mass was successfully generated for the selected geometry conditions to show direct comparison of each approach (Figure 4).

The mass reduction approaches examined each offer access to reduced mass and curvature values not attainable by micromirror plate thinning alone. The isotropic (hemispherical) etch pattern is likely the simplest to fabricate and offers some improved design space. The square etch pattern offers the most potential benefit in mass reduction of the three, as it most efficiently uses the area. The triangular pattern may be appropriate for particularly curvature sensitive applications.

Reference

[1] Su G-D, et.al."Surface-micromachined 2D optical scanners with optically flat single-crystalline silicon micromirrors", Silicon-based and Hybrid Optoelectronics III Proceedings of SPIE, Vol. 4293 (2001)

[2] Milanovic V., et. al. "Gimbal-Less Monolithic Silicon Actuators for Tip-Tilt-Piston Micromirror Applications" IEEE Journal of Selected Topics in Quantum Electronics, Vol 10, No. 3, pp. 462-471 (2004)

[3] Chui B.W., et. al. "Simplified Monolithic Process for Fabricating Low-Cost, High Frequency, High Flatness Scanning Micromirrors", Solid-State Sensors, Actuators, and Microsystems (TRANSDUCERS 2013), pp. 1036-1039 (2013)

Figures used in the abstract

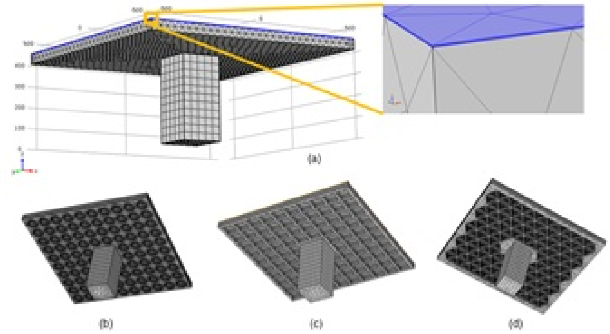
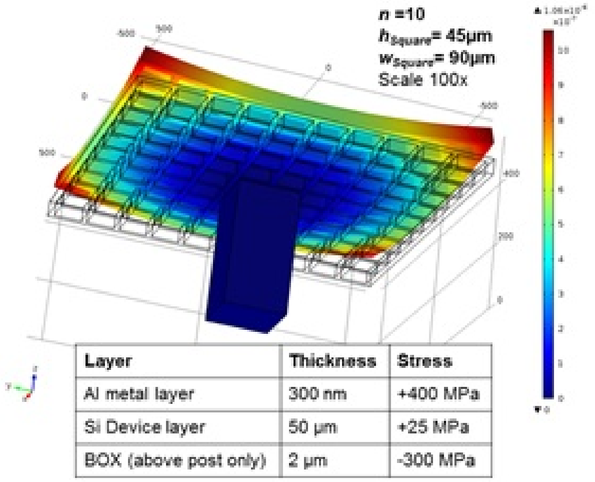


Figure 1: (a) Solid model of square solid plate micromirror with center post, inset shows metal layer (b-d) show different example backside etch profiles



Layer	Thickness	Stress
Al metal layer	300 nm	+400 MPa
Si Device layer	50 μm	+25 MPa
BOX (above post only)	2 μm	-300 MPa

Figure 2: Representative steady-state deflection profile for Al coated SOI based micromirror with square mass reduction backside etch pattern

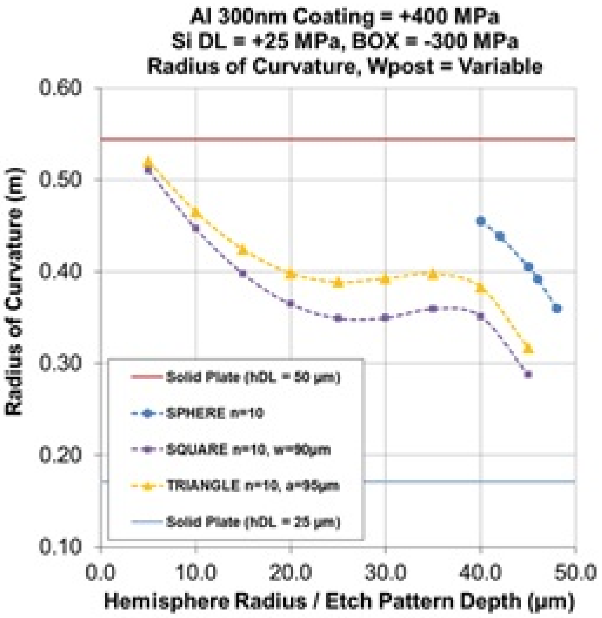


Figure 3: Effect of etch depth/etch radius on radius of curvature for different mass reduction patterns

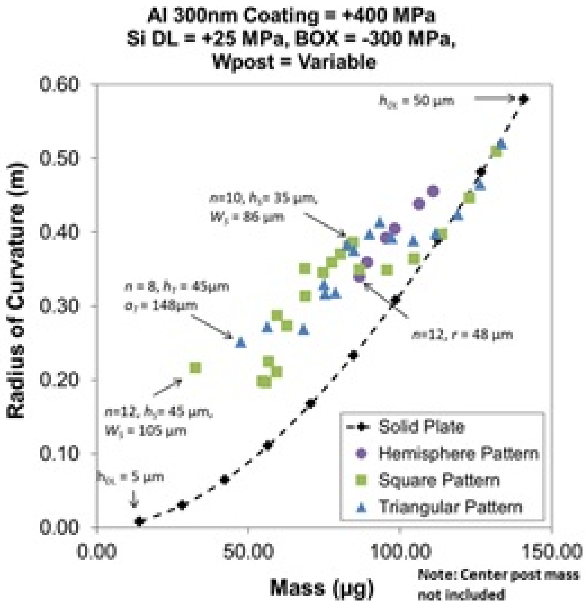


Figure 4: Depiction of trade space between curvature and plate mass for the different designs simulated