ENGINEERED EDGE EFFECT STRESS REDISTRIBUTION IN SUSPENDED THIN FILM STACKS FOR FLATNESS CONTROL

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Novelty / Progress Claim(s)

This paper presents a systematic study of edge effect stresses and interaction between thin film stacks to achieve flat suspended thin film structures. Finite element modeling (FEM) was used for rapid analysis of support structures on microshutter array (MSA) shutter blades. The design aims to flatten the blades to provide ultra-high contrast to optical instruments using MSAs as field masks. This is the first comprehensive study of microscopic surface feature edge effects and film-to-film stress interaction in micro electromechanical systems (MEMS). This study demonstrates flattening of thin film stacks by stress redistribution through induced shear forces at the edge of strategically designed reinforcement structures.

Background / State of the Art

The microshutter array (MSA) is a programmable field mask (Fig. 1) that enables large-format multi-object spectroscopy at extremely high contrast ratios of over 10^5 [1]. Assessment of the first generation MSAs used on the James Webb Space Telescope (JWST) revealed light leakage and stuck shutters likely due to warping in the blades (Fig. 2) [2]. Such leakage can be partially reduced with larger light shields but at the sacrifice of fill area. To advance the MSA technology towards better optical performance for future missions such as the Habitable Worlds Observatory Flagship [3], it would be advantageous to increase contrast through less drastic design changes.

Common methods in morphology control in MEMS fabrication include overall stress reduction in layers through thermal treatment [4,5] modification to fabrication parameters [6], or structural strengthening [7,8]. Stress reduction on the layer material level for the MSA is not a viable option due to constraints induced by other parts of the device that are necessary to prevent distortion and maintain device functionality. Therefore, maintaining the same layer stress with localized stress diversion is desirable to achieve flatness of blades.

Description of the New Method or System

The Next-Generation MSA (NGMSA) [9] blade is a multilayer thin film structure (Fig. 3). Tensile stress exists within the membrane. The MoN support structures are designed with compressive stress to balance the stress in the membrane. They define the direction of blade deformation from disordered warping to consistent bow shapes. However, the maximum bow height in the blade can still be more than 10 µm.

Finite element simulations of the blades with unoptimized MoN strip design were used to calibrate the model parameters to observed NGMSA blade deformation. Numerous design variations were then generated. We were able to inspect the resulting stress redistribution from these designs and the effectiveness in bowing reduction. Eighteen designs were selected for fabrication to verify the simulation results and test their practical performance in relation to the rest of the device (Fig. 4).

Experimental Results

Our simulations show that the contour of the deposited MoN plays a significant role in the redistribution of stress to the blade surface. Stress tends to concentrate at curved edges (Fig. 5(b)), creating a sheer force between the support structure and membrane. The original JWST design, shown in Fig. 5(c) and (d), with sharp corners, does not redistribute film stresses.

In contrast, when the rounded corners are implemented (Fig. 5(e)-(g)), the stresses appear to be "guided" to form "invisible reinforcement beams" in the blade that offsets bowing.

To understand the physics behind stress distribution at the layer edges, we selected eighteen designs to demonstrate the difference in stress mitigation effects. Designs with arrays of MoN dots, as shown in Fig. 5(h), are found to drastically reduce blade deformation to submicron levels.

Arrays with the test designs are being fabricated and detailed findings will be reported in the full paper.

Word count: 574

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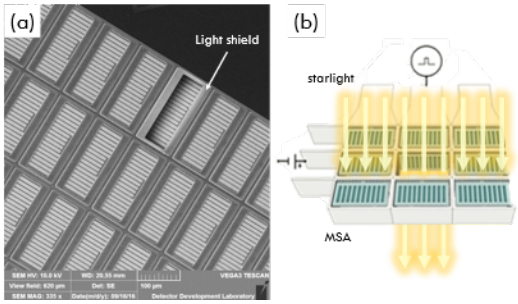

Figure 1: Operating principle of a microshutter array. (a) Scanning electron microscopy of a microshutter array demonstrating one partially opened shutter. (b) Electric 2D-addressing selectively opens individual shutters to allow light to pass through.

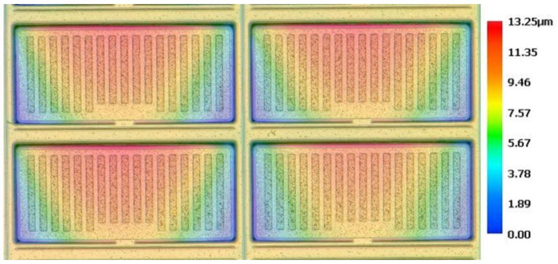

Figure 2: Optical measurement of microshutter blades shows more than 7 µm dip near the torsion bar corners and near 6 µm protrusion at the far edge of the blade.

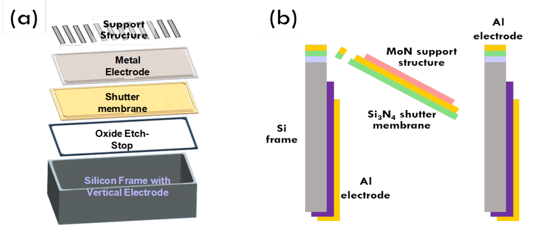

Figure 3: Schematic of a microshutter cell construction. (a) Exploded view of material layers in a microshutter cell. (b) Side view of a partially opened microshutter in a cell element.

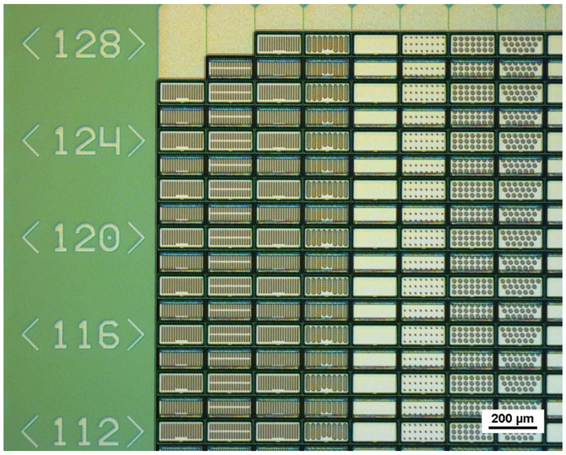

Figure 4: Selected MoN designs are being fabricated onto NGMSA devices for performance testing.

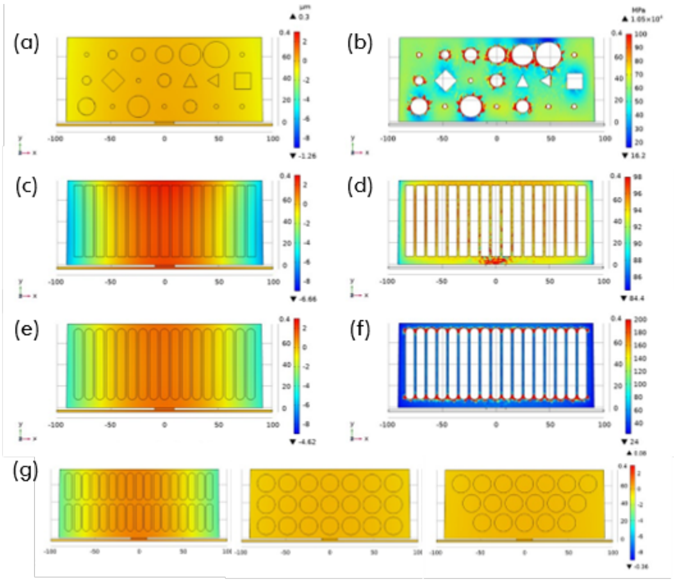

Figure 5: Selected MoN support structure redesigns illustrating their effects on stress distribution and shutter blade flatness. (a)(b) "Sprinkled" shapes. (c)(d) Original strip design. (e)(f) Modified strip design with rounded corners. (g)-(i) Example of redesigns to be tested with blade flatness improvement to sub-micron levels.