Off-Chip Angular Position Control of MEMs Mirrors

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Abstract:

Polysilicon hinged plates have found numerous applications in beam steering [1] and cross connect switches for optical communication [2]. We report on the actuation of hinged and compliant microstructures by using sequential and/or simultaneous application of ultrasonic and electrostatic actuation to achieve semi-permanent theta positioning of hinged plates. At Transducers-07, ultrasound-enhanced electrostatic batch assembly was used for assembly of hinged mirror arrays with high yields, but only close to 90° from the die surface [3]. Here, we show that by novel lock-in structures and pulsed actuation, the mirrors can be trapped and freed from different rotation angles, such that zero static power is needed to maintain an angular position.

Figure 1: Schematic of the experimental setup. Microstructures are actuated off-chip by electrostatic forces due to DC potential, and ultrasonic forces due to AC excited piezoelectric ceramic (PZT).

Summary of Research:

In ultrasound-enhanced electrostatic batch assembly (Figure 1) [3], DC-voltage between the chuck holding the die and the global top electrode works to pull the microstructures away from the surface of the die. In addition, AC-voltage across the piezoelectric ceramic (PZT) underneath the die, generate stress waves that reach the hinges of the rotatable plate. The stress waves modulate the tribological gap between surfaces in contact. This modulation acts as a lubricant so that external forces such as the electrostatic force can rotate the plate [4]. Once the hinged or compliant structures are assembled using conventional permanent lock-in configurations [3], it is difficult to de-assemble them controllably using the same methods used for assembly. Our method to enable reversible actuation employs a temporary lock-in mechanism, the tail-beam (Figure 2), to convert the circular motion of the rotating plate/mirror into linear motion. Sample

Figure 2: Drawing of the cross section of the mirror at an actuated state. $L_0 = 914 \, \mu m$, $L_1 = 937 \, \mu m$, $L_2 = 423 \, \mu m$, $L_3 = 503 \, \mu m$. 
devices, fabricated by SANDIA-SwIFT™ process and released in the critical point dryer at CNF, have a mirror region that can rotate around a torsional rod anchored at two ends. While one end of the tail-beam is connected to the mirror by the moving-hinge, the other end is constrained to move under the slider-rail (Figure 3). The slider-rail is populated with a periodic array of bumps at 6 micrometer pitch. These bumps act as mechanical stoppers/friction-enhancers as the tail-beam slides along the slider-rail, and they provide temporary lock-in/latching.

Rotation angle during the RESET operation [5] reveals that the mirror can be made to hold positions at seven different angles between 72° and 45°. The duration of motion during steps is roughly equal to the period of the frequency sweep of the ultrasound. Therefore angle control at higher precision can, in principle, be achieved by tailoring the ultrasonic drive parameters like sweep time and drive amplitude.

The presented structure and method can be useful for modular, large-area, beam-steering applications, where the actuation speed requirements are relaxed, while fill-factor and cost per unit area are extremely important. Additionally, semi-permanent latching ensures zero-idle power, eliminating not only the leakage across dielectrics or air-gaps, but also power consumption due to high-voltage drive electronics.

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References:

In actuation, PZT is AC driven with a swept frequency and samples are heated to drive-off humidity on the structures. When DC-bias is applied between the global top electrode and the chuck in the presence of ultrasound, tail-beam moves over the bumps along the slider-rail allowing the rotation of the mirror. If ultrasound is turned off at this point, the mirror keeps its position as static friction forces keep it in place, even in the absence of DC field. This sequence of controlling can be called a SET operation. The mirror can then be moved in the reverse direction by a RESET operation, which occurs when ultrasound is turned-on in the absence of DC-bias such that torsional restoring force and gravity pulls the plate down. The mirror can be switched between rotated and relaxed positions by successive SET and RESET operations as quantified by the optical measurements of mirror rotation angle (Figure 4).

![Figure 3: SEM view of one of the assembled dies. Tested die has two identical mirrors with geometrical parameters summarized in Figure 2. The mirrors are labeled as ‘LEFT’ and ‘RIGHT’, and they have different rotations due to position dependence of average ultrasonic actuation.](image)

![Figure 4: Optically measured rotation angle of the mirrors as a function of time during a series of SET and RESET operations. First SET and RESET operations are indicated in the data set. Stepped operation can be observed by zooming in the region highlighted, and is explained in [5].](image)