PERMANENT ATTACHMENT OF SILICON STRUCTURES VIA JOULE HEAT INDUCED WELDING

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This paper introduces a new method for the sub-micron adjustment of micromachined gaps and the attachment of assembled structures using a precision welding technique enabling permanent, post-release capacitive improvements. The proposed mechanism was incorporated into the sense mode of a silicon-on-insulator (SOI) symmetrically decoupled tuning fork gyroscope, Figure 1, to demonstrate its potential for high performance inertial sensors.

Electrostatic actuation and capacitive detection are commonplace for silicon MEMS due to the ability to easily fabricate parallel plate electrode structures. The nominal capacitance is strongly dependent on the separation of the plates, where smaller gaps are generally desired due to the increased forcing/sensing capacity. While sub-micron gaps have been achieved through fabrication process optimization [1], the depth of these trenches is usually limited to only a few microns; attempting to achieve these high aspect ratio gaps for thicker structural layers requires significantly increased processing time leading to potential aspect ratio dependent etching problems. This work deviates from the typical fabrication approach to achieve smaller capacitive gaps through a mechanical assembly technique independent of structural thickness. Previously, two methods for the post-release adjustment of capacitive gaps were proposed in [2-3]. Both concepts utilize the separate fabrication of mobile electrode structures with the minimum gaps allowed by the process; upon release, the pairs are assembled together thereby forming capacitors with significantly reduced plate separation. The downside of previous approaches, however, is the difficulty in achieving small, repeatable gaps using large motions and non-ideal microfabrication techniques with poor relative tolerances.

The presented concept expands upon the mechanical assembly techniques presented in [2-3] by enabling the fine position control of released electrode structures. SEM images of the mechanism are presented in Figure 2 which takes advantage of the motion reduction experienced by individual beams of a folded suspension. As the input shuttle is moved, the displacement is reduced proportionally to the number of folds in the reduction suspension (N); ultimately, this results in an 1/N reduction in the displacement enabling the fine positioning of the mobile anchor structure. This is demonstrated by the superimposed pictures in Figure 3 before and after assembly revealing that an input shuttle displacement (left) of 75.7 μm results in a parallel plate motion (right) of 5.83 μm reducing the gap from 7.5 to 1.67 μm. As shown, a ratcheting mechanism is employed to latch the shuttle at discrete positions while allowing increasingly smaller gaps. Two different 10-fold suspension reduction mechanisms were implemented with one of the designs having an additional spring to minimize torsional motion of the mobile anchor, Figure 2. Both mechanisms were assembled and calibrated optical microscope pictures were used to extract the displacement data presented in Figure 4. While both deviated from the intended 10% reduction in shuttle motion, the results validate the mechanical assembly and ratcheting approach employed in this work to achieve adjustments of capacitive gaps. Experimental rate responses are presented in Figure 5 for two different assembled gaps at atmospheric pressure revealing 1.7 times increase of scale factor demonstrating the functionality and advantages of increased capacitance. Finally, a precision welding technique is employed to permanently attach the mobile anchor as shown by the SEM image in Figure 6. The weld is achieved by applying 15 V with a current limit of 3 mA across the latching mechanism resulting in the permanent attachment of the two structures. Thus, when the desired gap is achieved, the previously released anchor can be fixed to eliminate any spurious motion of the electrodes. While these results demonstrate the feasibility of the approach on planar structures, it can be extended to enable the permanent, rigid attachment of out-of-plane and die-level 3-D assembled silicon structures that typically rely on epoxy bonding or solder assembly to maintain their shape.

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[2] G. K. Fedder, “Simulation of microelectromechanical systems,” Ph.D. dissertation, UC Berkeley, 1994.
[3] C. Acar and A. M. Shkel, “Structurally decoupled micromachined gyroscopes with post-release capacitance enhancement,” J. Micromech. Microeng., Vol. 15, pp. 1092-1101, 2005.

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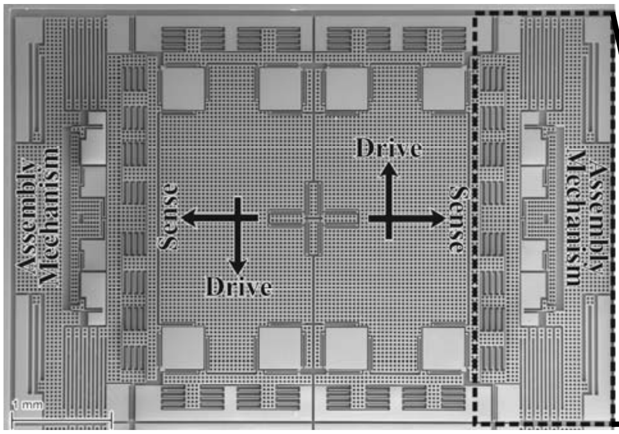

Figure 1: SEM of tuning fork gyroscope with assembly mechanism for increased capacitance in the sense mode.

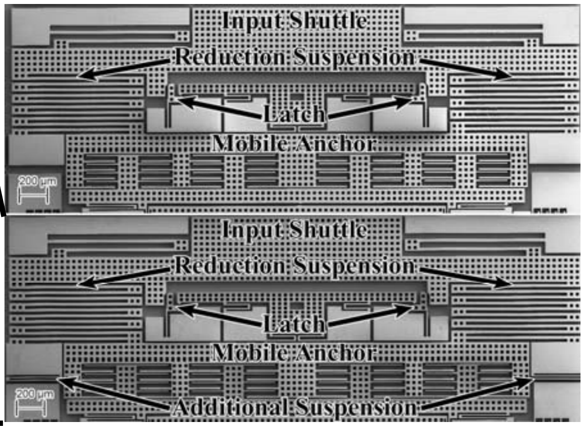

Figure 2: SEM images of assembly mechanisms with (bottom) and without (top) additional spring intended to reduce torsional anchor motion.

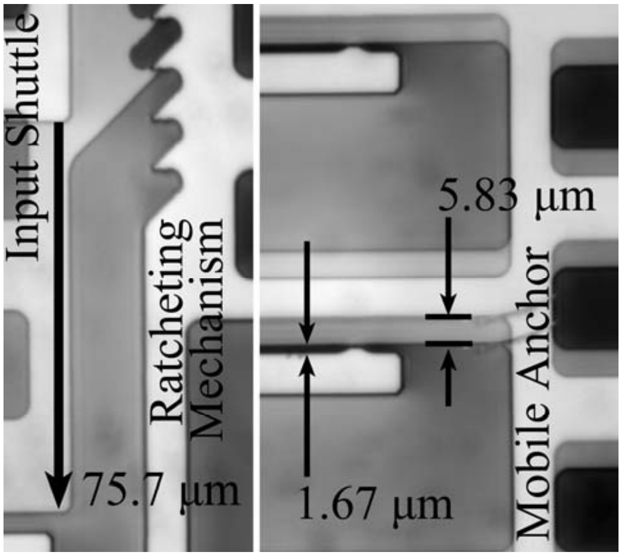

Figure 3: Pictures of input shuttle displacement (left) resulting in the plate displacement (right) and a reduced capacitive gap of 1.67 microns.

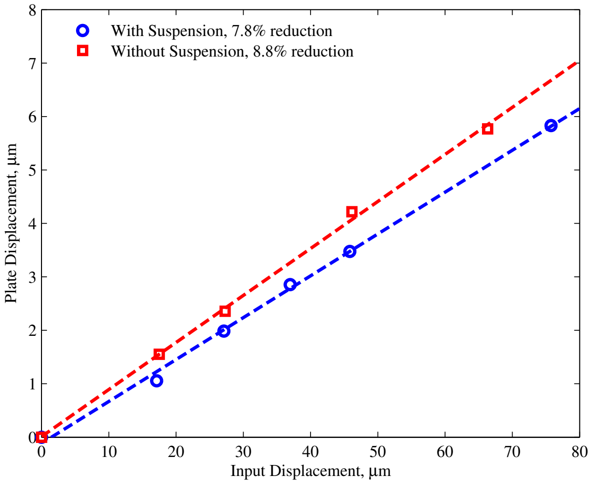

Figure 4: Measured plate displacement versus input shuttle motion revealing the amount of reduction for both types of mechanisms.

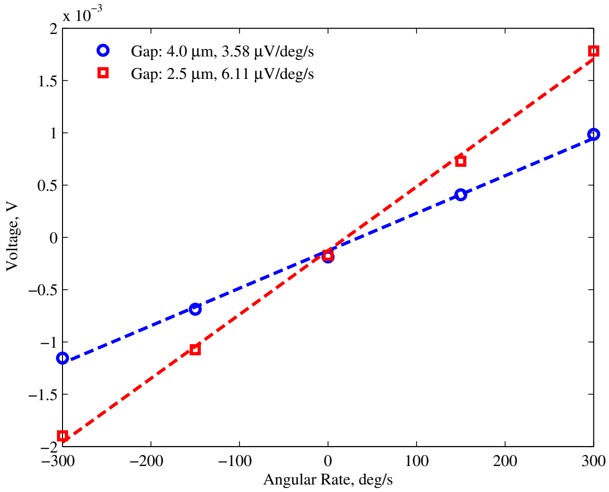

Figure 5: Angular rate response at different assembled gaps in air demonstrating scale factor improvement.

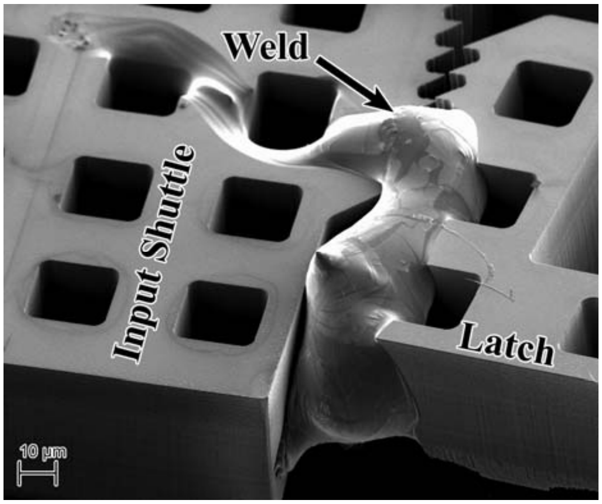

Figure 6: SEM image of the permanent attachment achieved via localized precision welding of assembly mechanism by applying 3 mA of current.