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Dynamic Pull-In and Switching for Sub-Pull-In Voltage Electrostatic Actuation

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Overview

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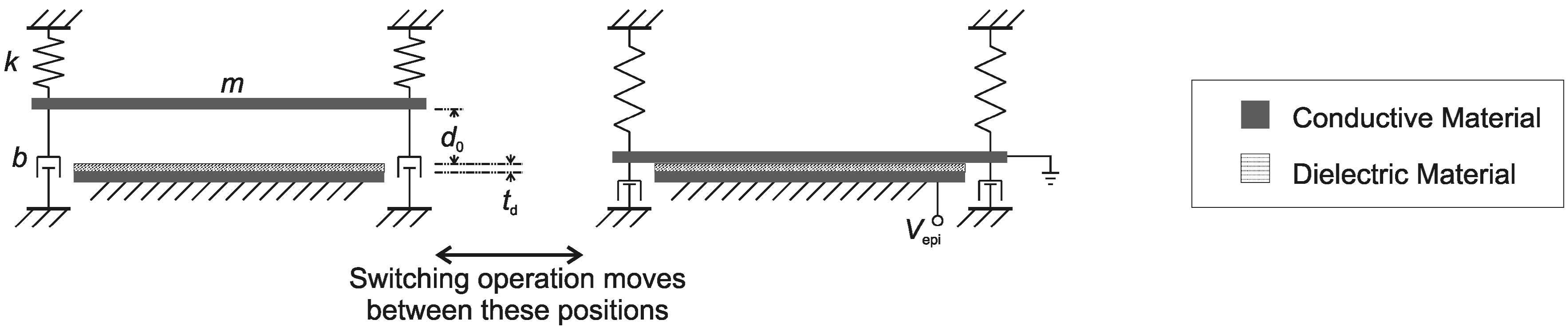
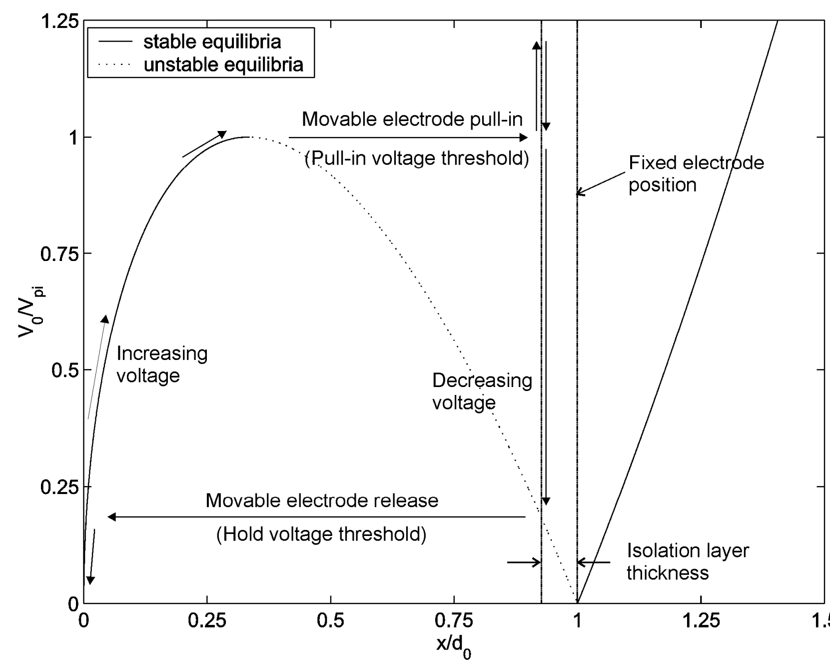
Motivation

- MEMS switching has demonstrated extraordinary performance (insertion loss, extinction, cross-talk, etc.) in RF MEMS and optical MEMS switching but…
- High voltage (electrostatic, piezoelectric) and/or high operating power (thermal, magnetic) along with slow switching speeds (all current methods) have limited the utility of MEMS switches.

Standard Electrostatic Actuation



Standard parallel plate electrostatic actuation operates due to opposite signed charges building up on adjacent plates and pulling them together. Due to nonlinear nature of the electrostatic effect, there is an equilibrium bifurcation that results in a “pull-in” effect that snaps the plates together. Release of the pulled-in plate is accomplished by reducing the applied voltage to below the “hold” voltage.



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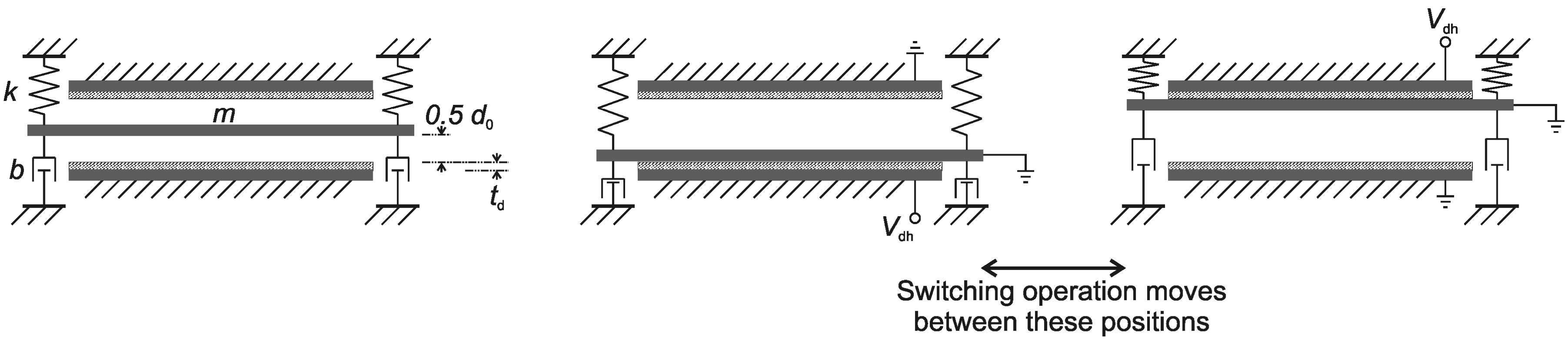
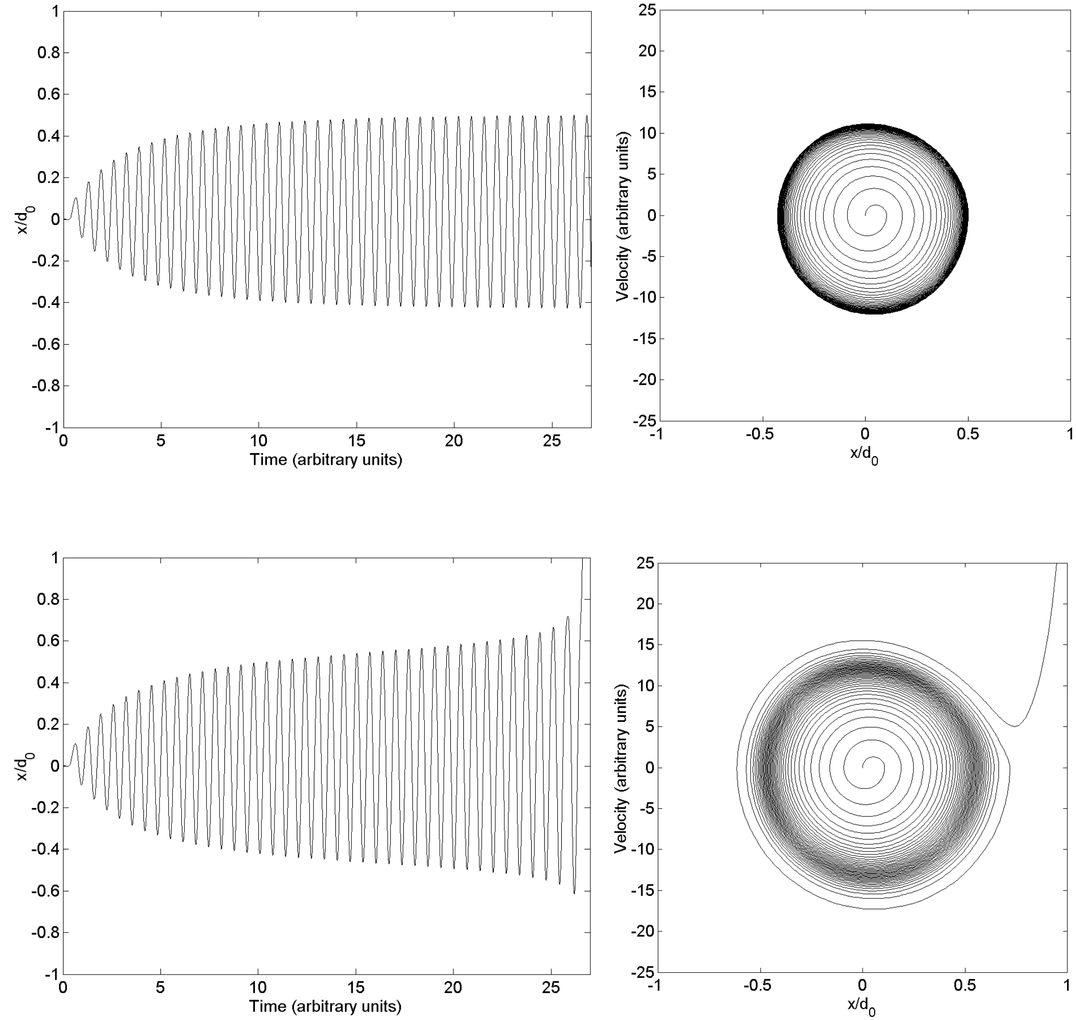
Dynamic Switching



Dynamic switching takes advantage of stored elastic potential energy to drive the mechanical structure from one pulled-in state to another pulled-in state. This is accomplished by underdamping the mechanical system such that the overshoot of drives the movable electrode near the opposing fixed electrode. In theory, the hold voltage is the limiting voltage of this switching approach.

Dynamic Pull-In

Dynamic pull-in can be used to initially pull the MEMS switch into a pulled-in state. Ideally this is also done at a voltage below the hold voltage. Here the MEMS structure is excited with a electronic signal that matches the resonance of the mechanical structure. Eventually enough energy is stored in the mechanical structure to achieve pull-in at a reduced voltage.



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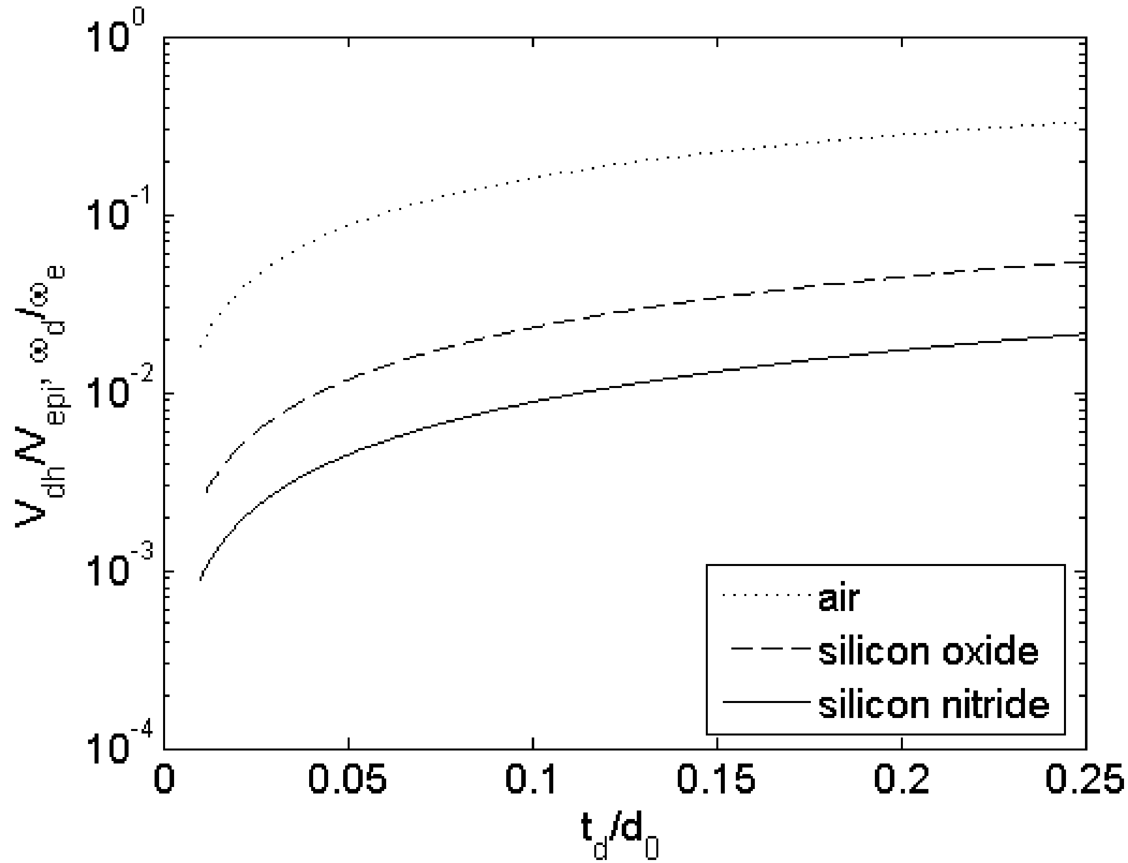
Performance vs. Traditional Switching

Dynamic switching provides switching at lower voltages and/or faster speeds. It also provides for a slower impact velocity potentially leading to less material damage with contact.



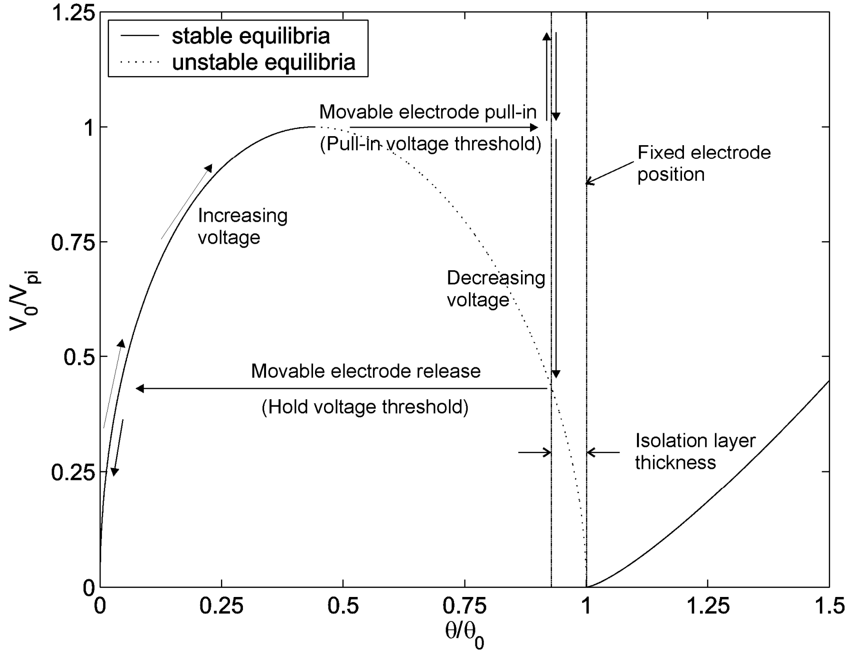
Source of Performance Improvements

- Total displacement is the same while effective electrostatic gap is half as large.†
- Operates at hold voltage instead of pull-in voltage.
- Energy required reduced by decrease in operating voltage.
- Energy recycled through potential-kinetic-potential energy conversion

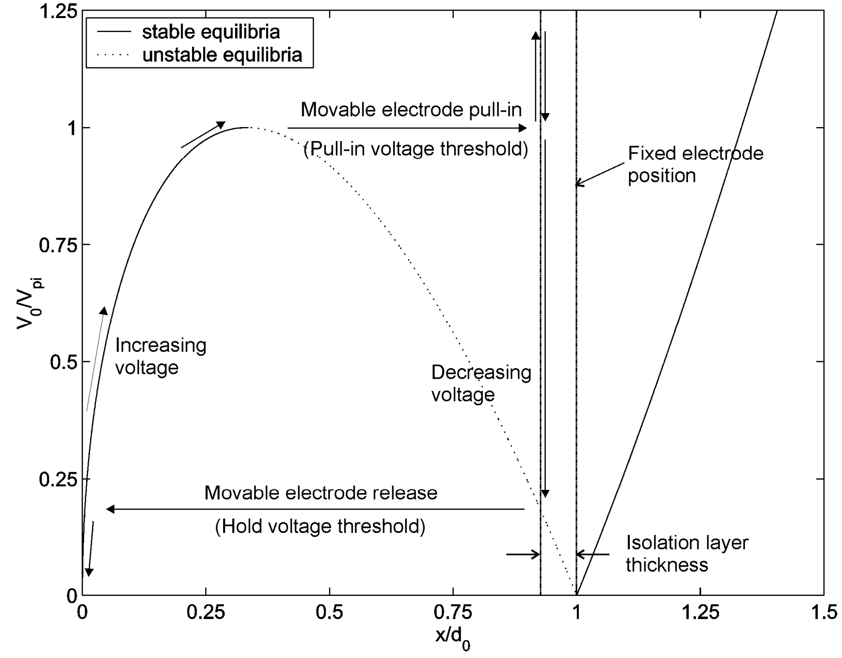
† D. Peroulis, S. P. Pacheco, L. P. B. Katehi, *IEEE Trans. On Microwave Theory Tech*., vol. 52, pp. 59-68, 2004.

Torsional Dynamic Switching

- Torsional actuators can also benefit from dynamic switching and pull-in, however, the ultimate benefit is stronger is parallel plate actuators due to the ability of the electrodes to come into more intimate contact.



Torsional Actuator

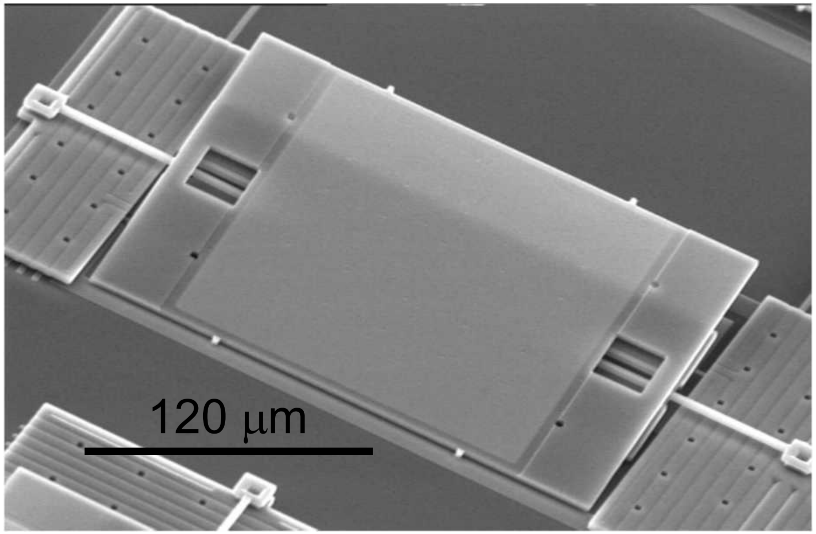


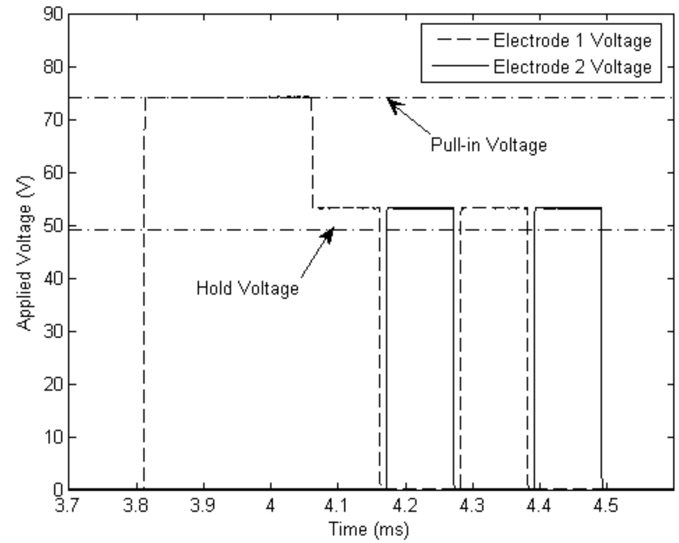
Parallel Plate Actuator

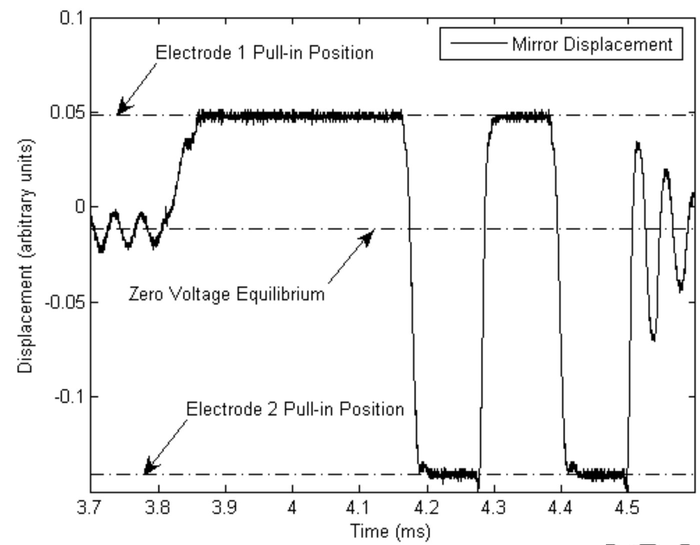
Practical Considerations

- Control timing is critical for both dynamic pull-in and switching
- Properties of dielectric separating plates defines ultimate performance.
- Best performance requires operation in reduced pressures

Large MEMS Micromirror

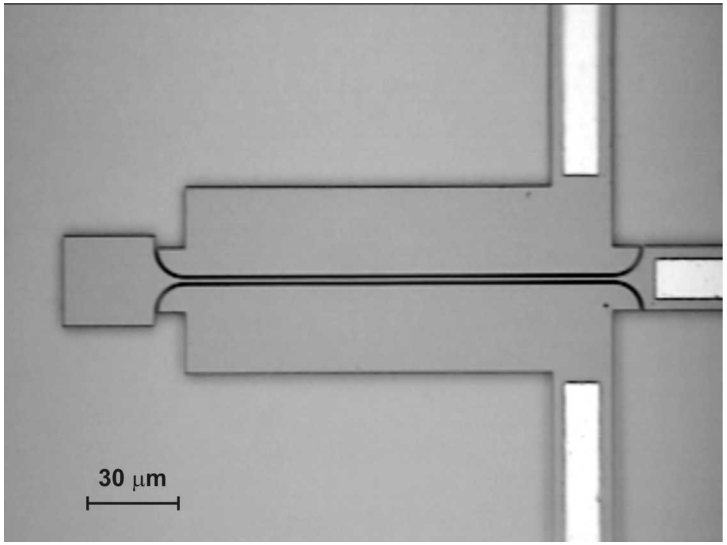


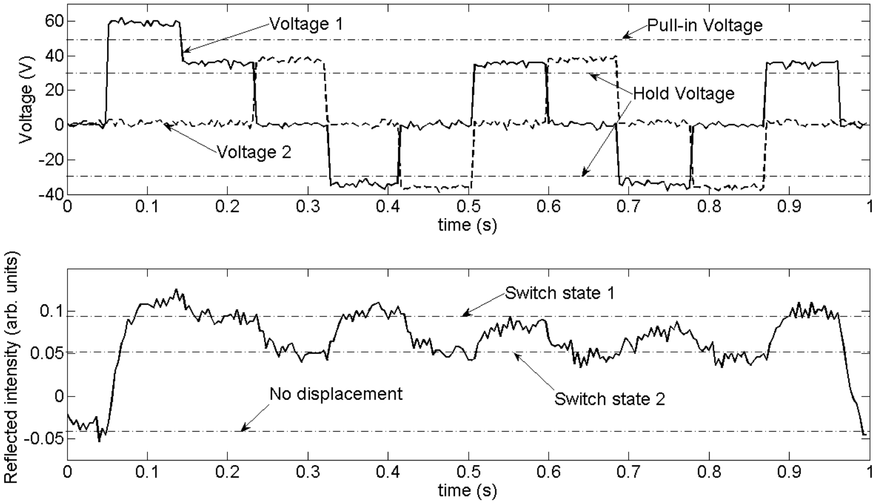




- Pull-in voltage 74 V
- Hold voltage 49 V
- Switched at 53 V
- Also demonstrated achieving pulled-in position from equilibrium position at below the pull-in voltage. (Utilized an open-loop control algorithm.)

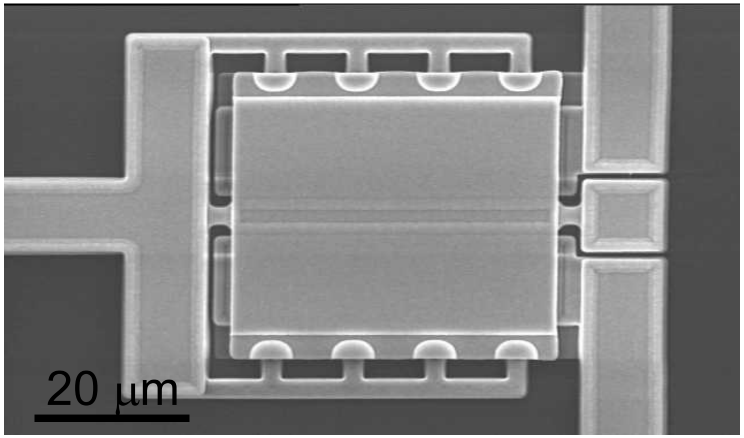
Horizontal MEMS Switch

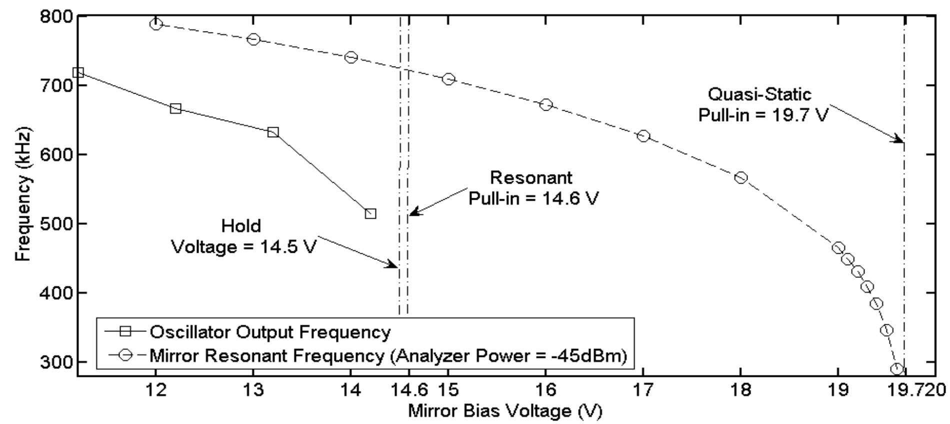




- Switched between pulled in states with a voltage that was 25% less than the pull-in voltage.
- Switching speed was under 500 ns.

Fast MEMS Micromirror





- Demonstrated dynamic pull-in at 100 mV over the hold voltage.
- Utilized an oscillator circuit (closed loop control).
- Mirror switched in 225 ns.

Conclusions

- Utilizing dynamic switching concepts can provide for reduce operating voltage and/or higher speed switching than can be achieved with traditional MEMS switching techniques.
- Demonstrated dynamic switching between pulled in states at voltages significantly less than the pull-in voltage.
- Demonstrated dynamic pull-in using both open and closed loop control mechanisms.

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