Simulation of MEMS for the Next Generation Space Telescope

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Presented by:

Brent Mott
Detector Systems Branch/Code 553
Goddard Space Flight Center
Greenbelt, Maryland 20771

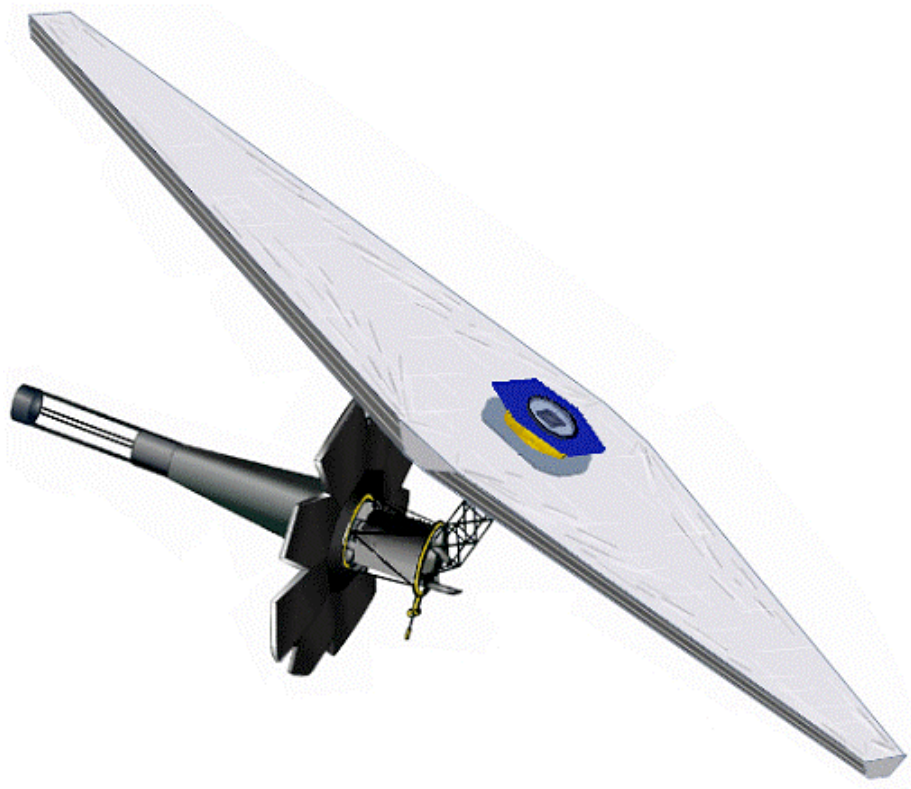
For:

Jonathan Kuhn
Sowilo Networks
Columbia, Maryland

James Loughlin
Mechanical Systems Analysis & Simulation Branch/Code 542
Goddard Space Flight Center
Greenbelt, Maryland

Next Generation Space Telescope (NGST)

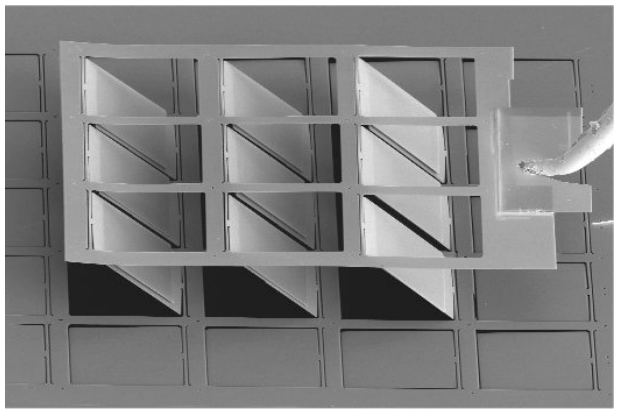
- 8 m primary mirror
- 0.6-27 µm wavelength range
- 2009 launch
- 5 year mission life (10 year goal)
- Passively cooled to <50K
- L2 orbit
- 3 core instruments:
  - 0.6-5 µm camera
  - 1-5 µm Multi-object Spectrometer (MOS)
  - 5-27 µm camera/spectrometer



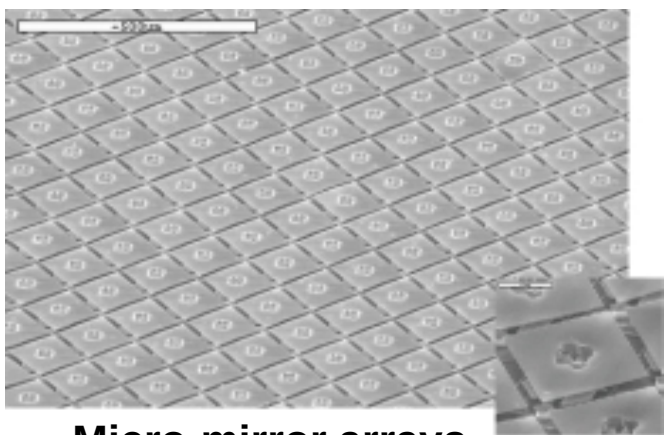
See: http://mems.gsfc.nasa.gov/workshop/presentations/matt_greenhouse.pdf

MEMS Aperture Masks

Application: Multi-object spectrometer



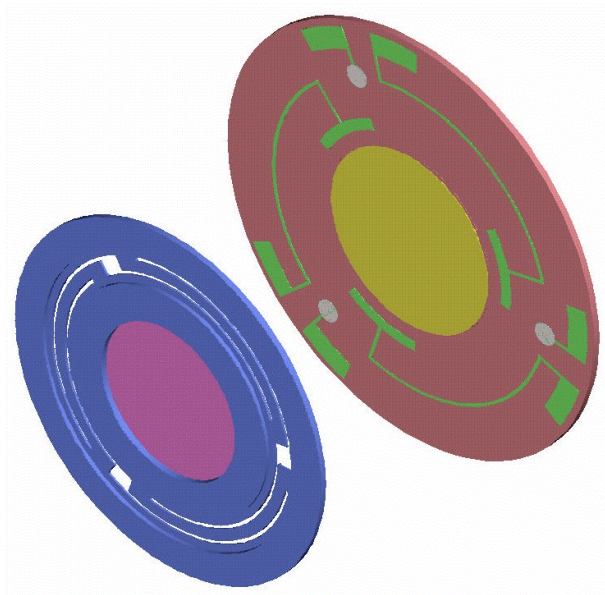
Micro-shutter arrays



Micro-mirror arrays

MEMS Tunable Filters

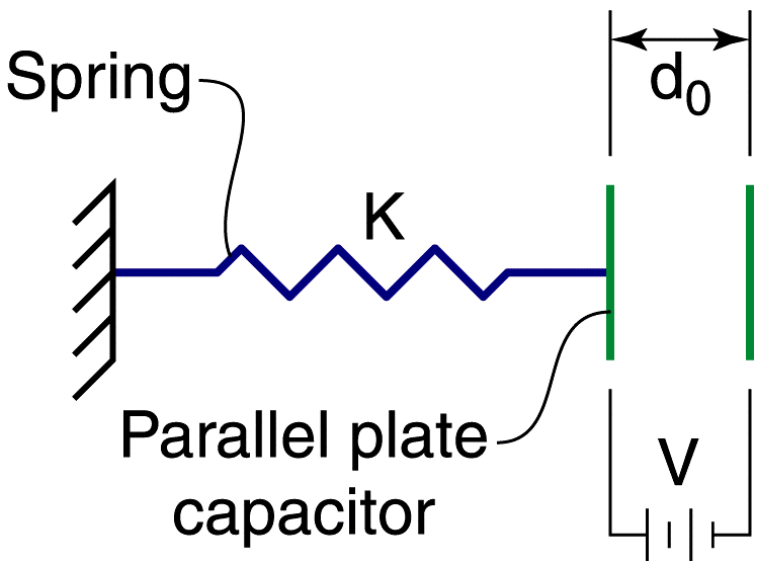
Application: Wide field camera

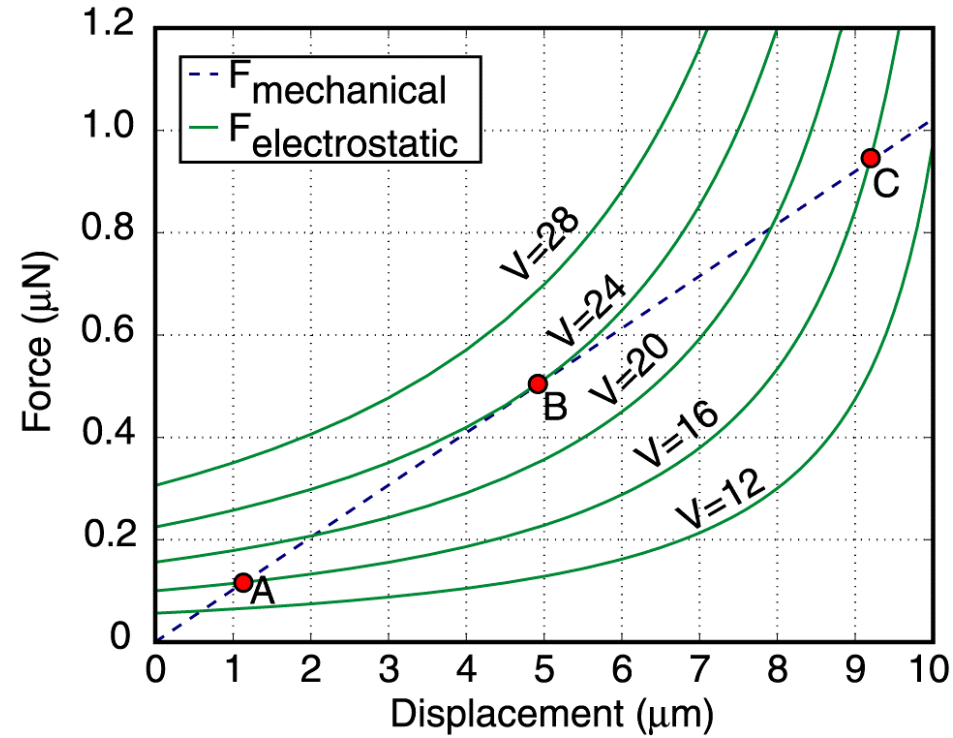


Fabry-Perot interferometer

Electrostatic actuation

Electrostatic Actuation





$$F_{\text{mechanical}} = K\delta$$

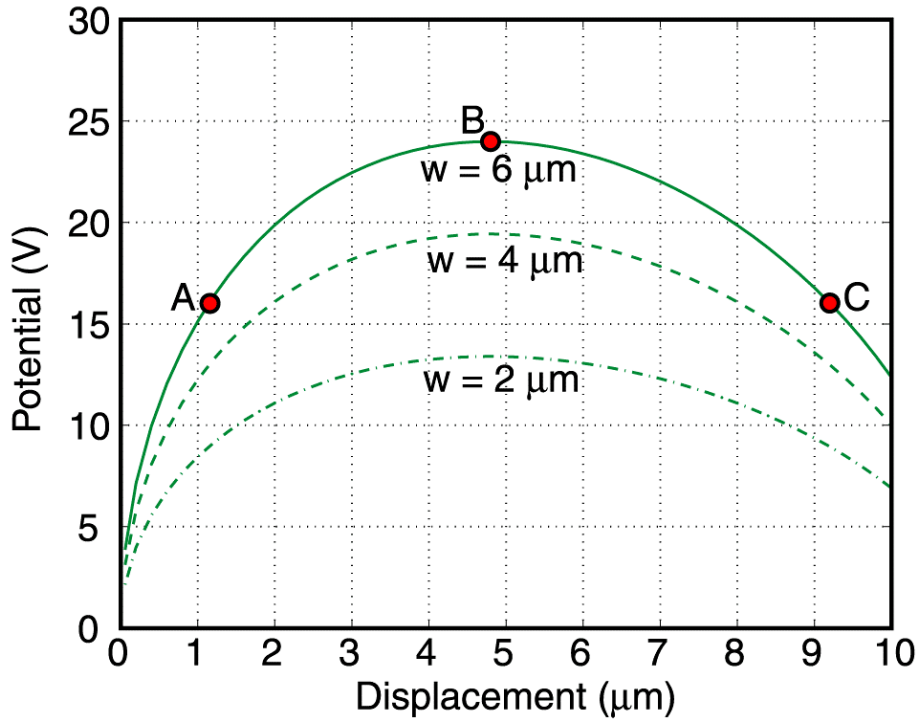
$$F_{\text{electrostatic}} = \frac{\varepsilon V^2 A}{2(d_0 - \delta)^2}$$

Coupled Electro-mechanical Response

Static equilibrium:

$$F_{\text{mechanical}} = F_{\text{electrostatic}}$$

$$V = \sqrt{\frac{2K\delta(d_0 - \delta)^2}{\varepsilon A}}$$



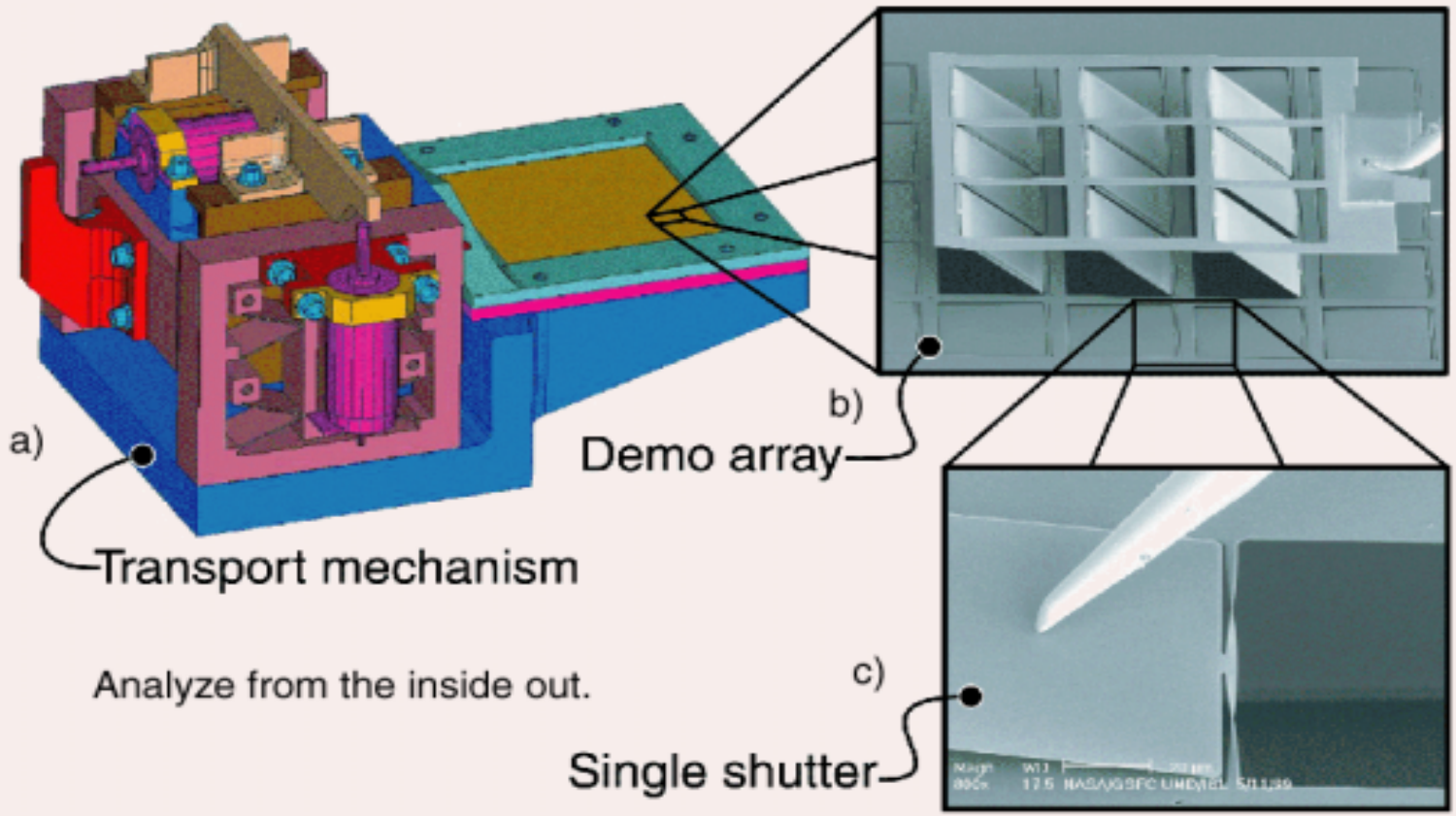
Unstable pull-in voltage:

$$\frac{dV}{d\delta} = 0$$

Dynamic response:

$$\frac{\varepsilon V(t)^2 A}{2(d_0 - \delta)^2} = m\ddot{\delta} + c\dot{\delta} + K\delta$$

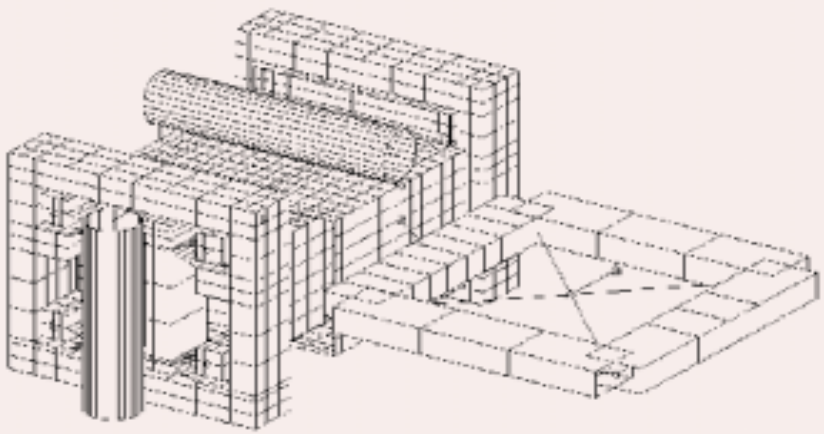
Micro-shutter Array Concept



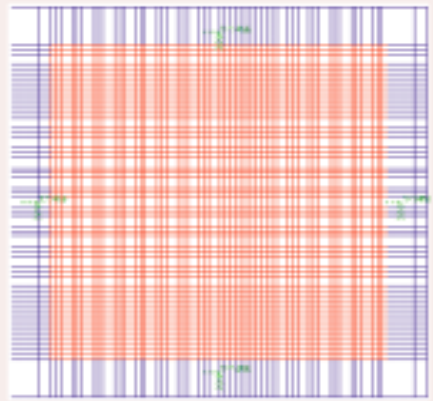
Analyze from the inside out.

The double-shutter concept is comprised of three distinct length scales of the a) macro-scopic transport mechanism, b) support grid, and c) micro-shutters.

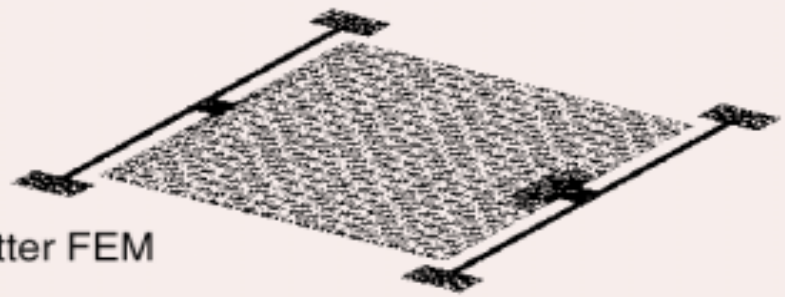
Micro-shutter Modeling



Transport mechanism FEM
(NASTRAN)



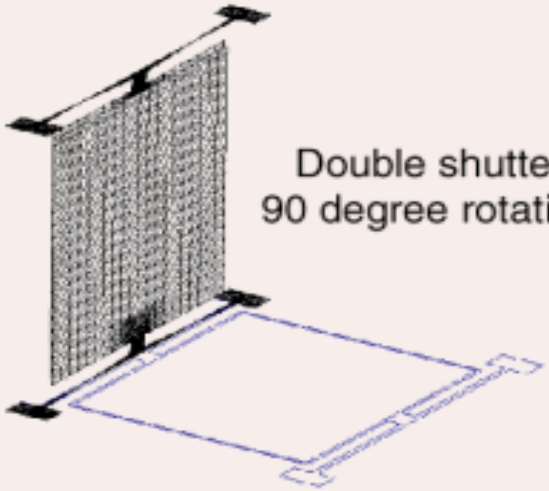
Homogenized support grid FEM
(NASTRAN)



Detailed double shutter FEM
(ANSYS)

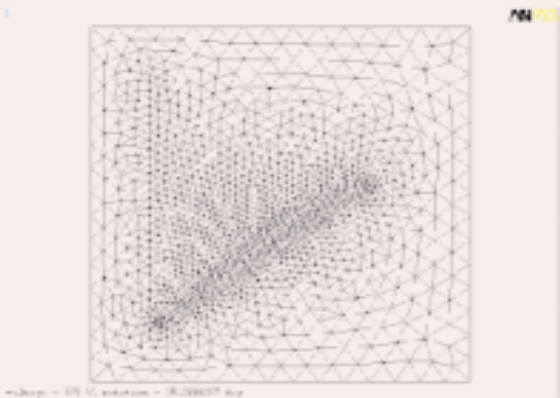
Multi-scale homogenization is used to simulate each length scale. Detailed analysis of the micro-shutters is used to determine loads propagated up-ward and visa-versa.

Micro-shutter Results

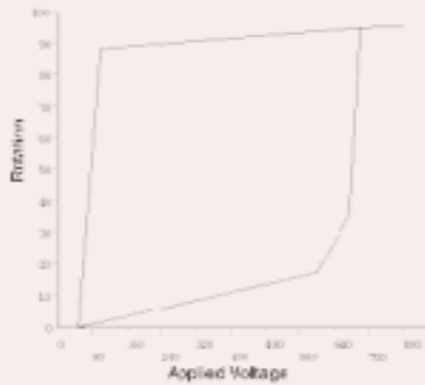


Double shutter
90 degree rotation

Detailed stress results
(~2 GPa max)



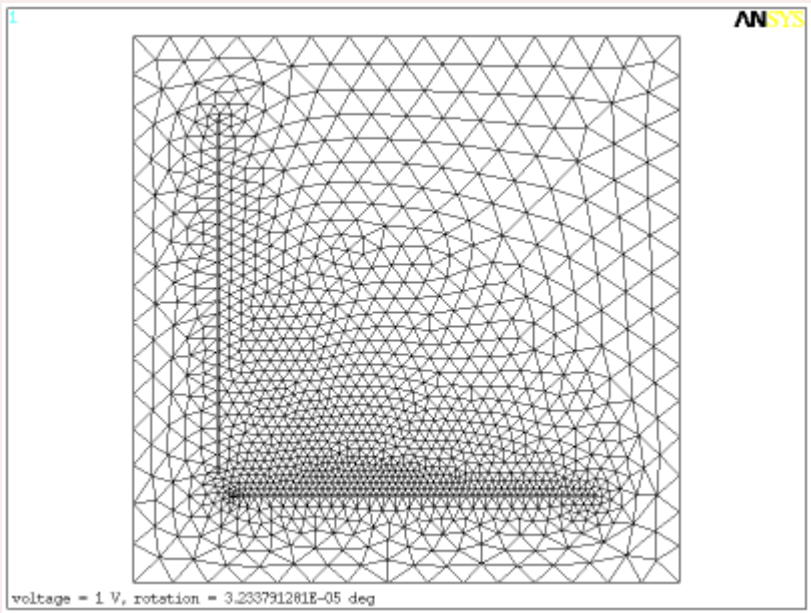
Alternative electrostatic
actuation concept



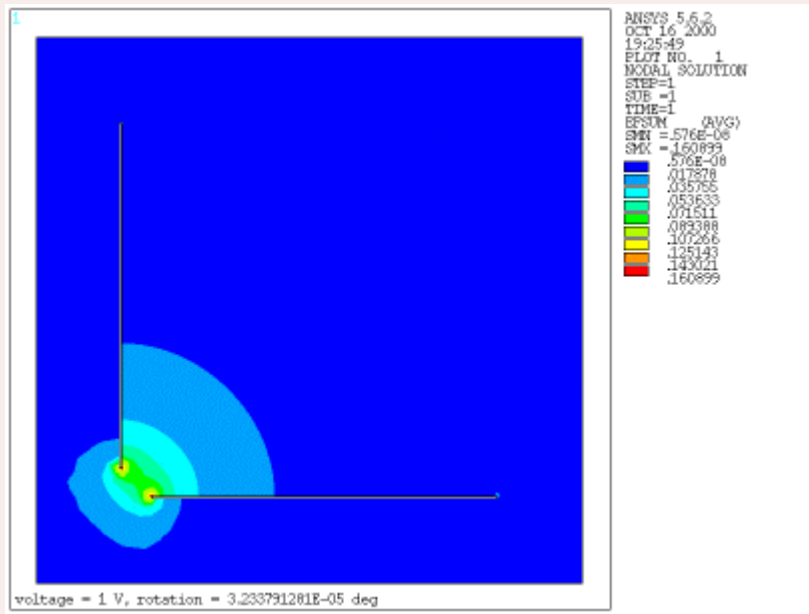
Electromechanical actuation
hysteresis curve

Electrostatic Actuation

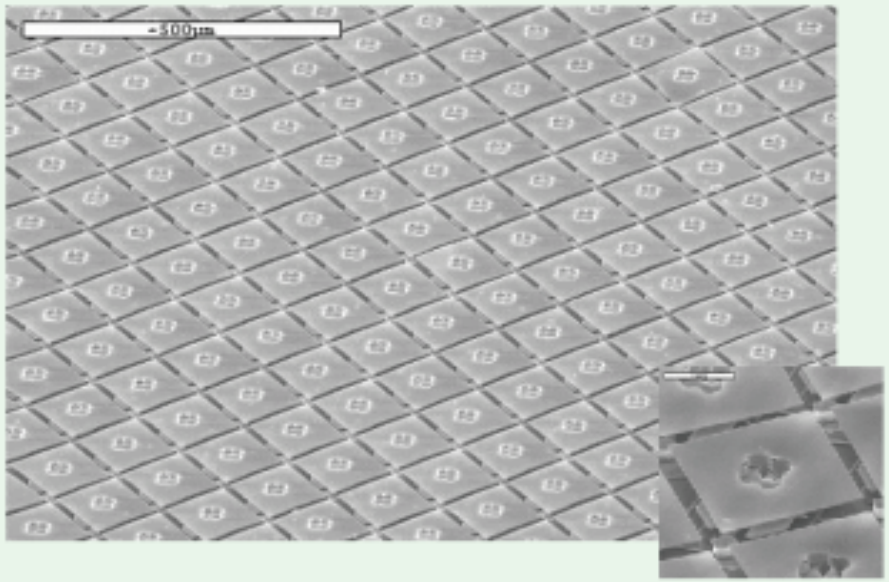
Micro-shutter motion



Electrostatic field intensity

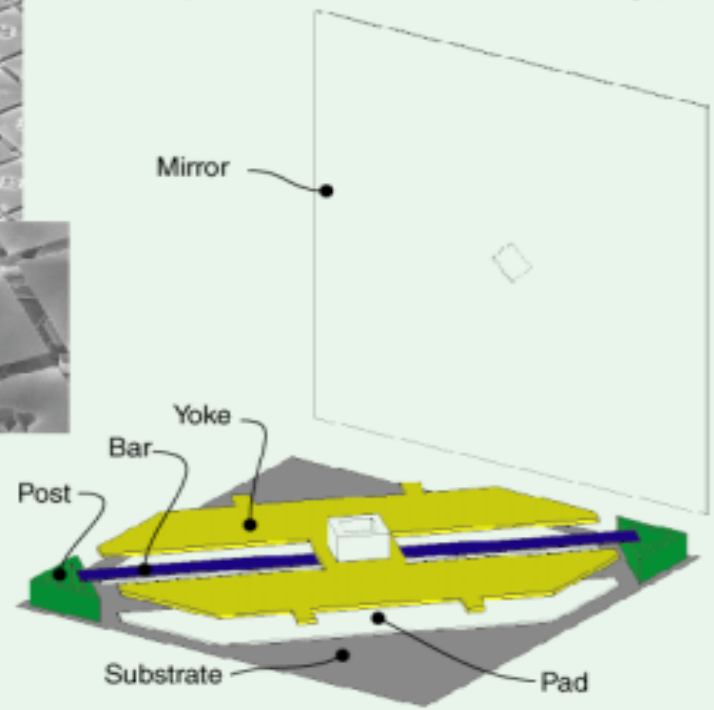


Micro-mirror Array Concept



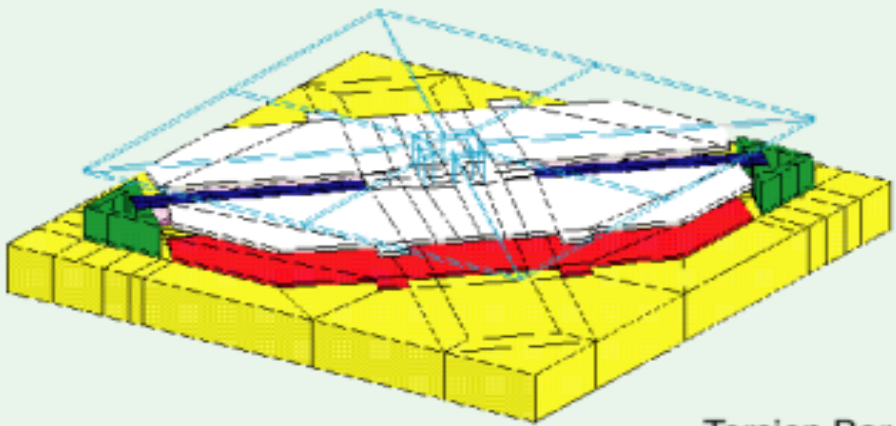
Fabricated Micro-Mirrors Array (MMA)

Single MMA unit-cell
(mirror removed for clarity)



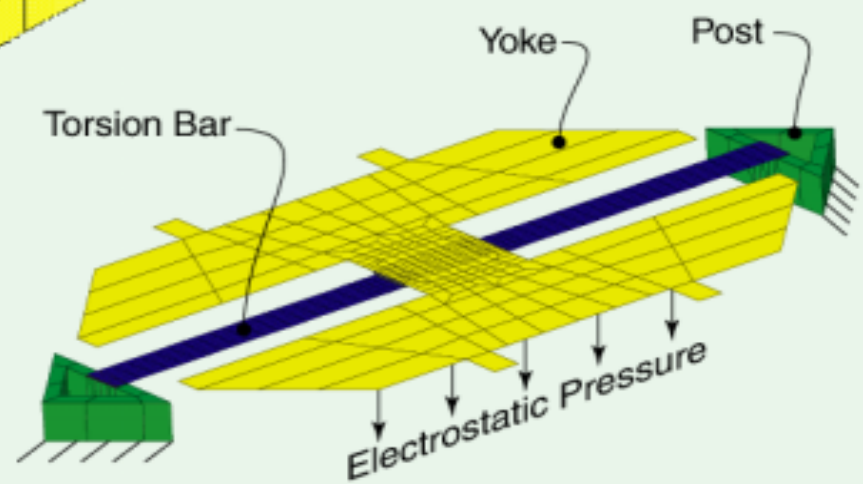
The tiltable aluminum micro-mirror design is comprised of a yoke suspended above two capacitance pads. An applied voltage induces bi-stable +/- 10 degree rotations.

Micro-mirror Modeling



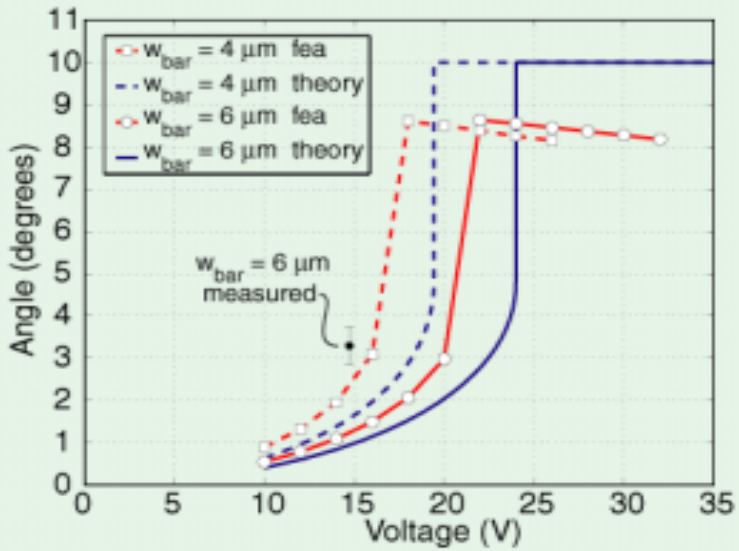
20-node brick FEM
(IntelliSuite)

4-node shell FEM
(NASTRAN)



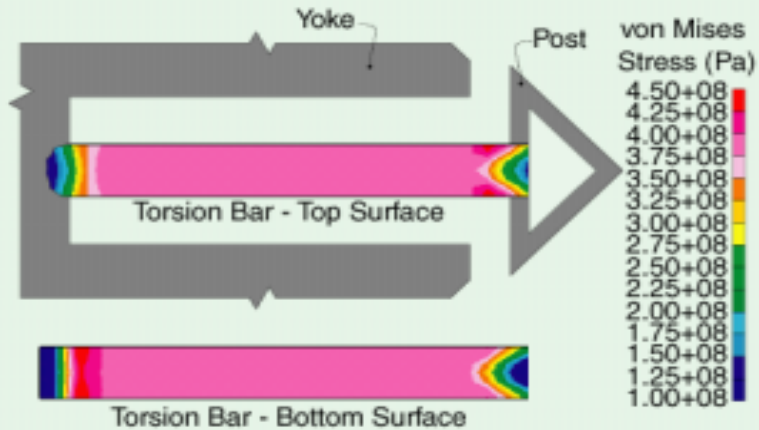
Both closed form and numerical techniques are used to predict the coupled electro-mechanical and thermal responses.

Micro-mirror Results



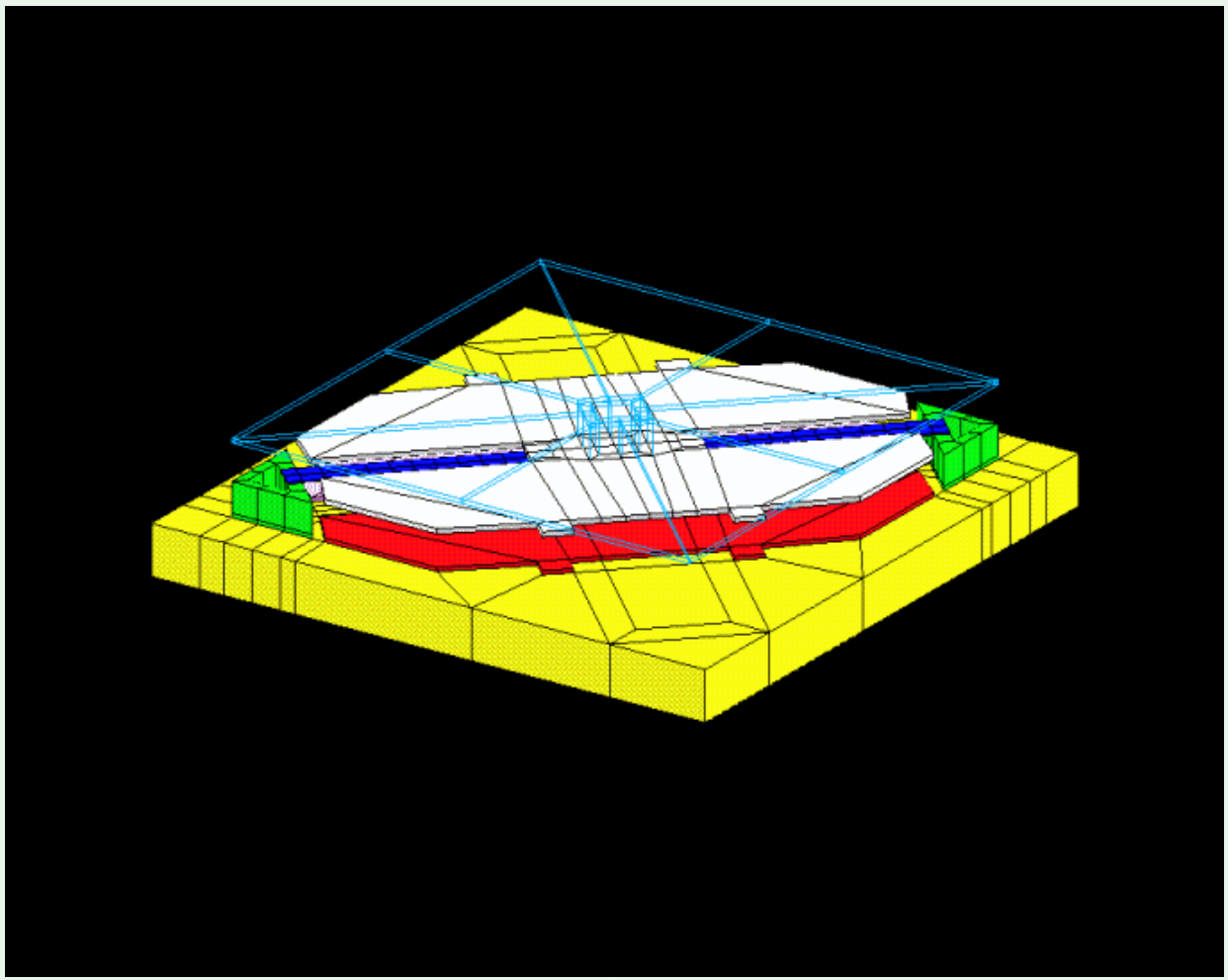
Coupled electro-mechanical response

Torsion bar thermally induced stresses

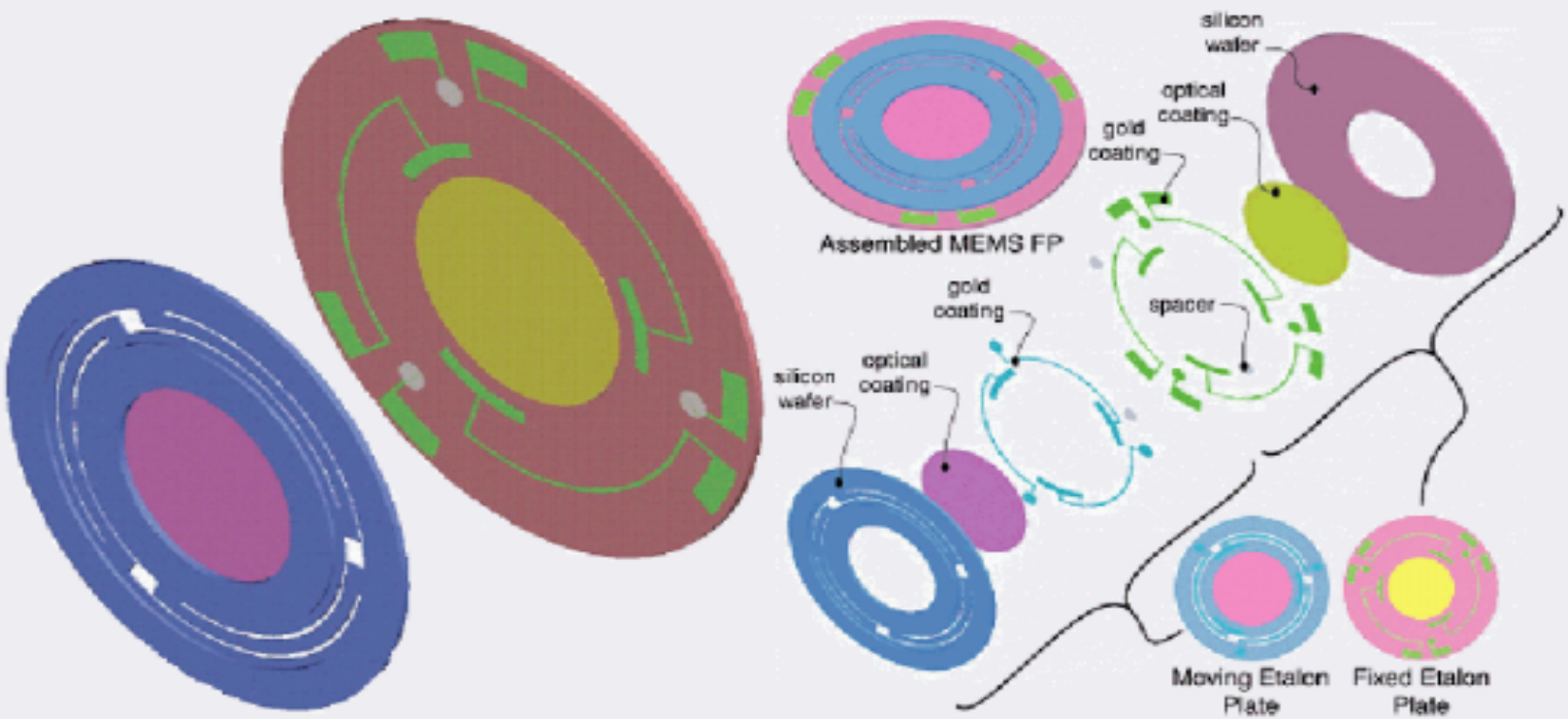


For this particular geometry the electro-mechanical response is strongly affected by vertical deflection of the torsion bars. The torsion bars may yield locally due to thermally induced loads.

Electrostatic Actuation

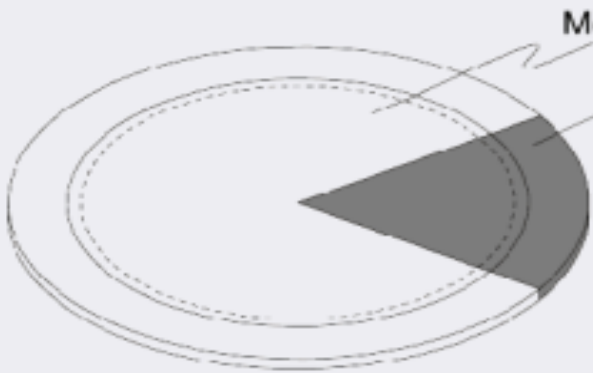


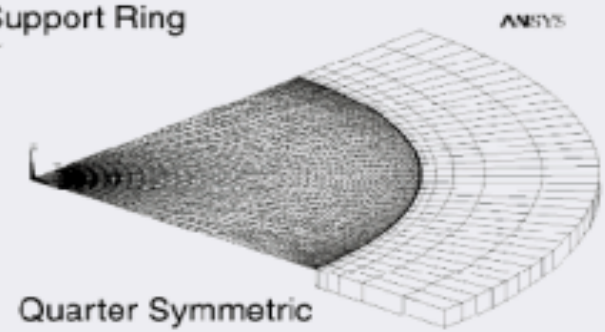
MEMS Fabry-Perot Concept



The electrostatically actuated MEMS Fabry-Perot tunable filter is comprised of two sub-assemblies fabricated from silicon wafers. The optical coatings are held in drumhead tension to meet stringent flatness requirements.

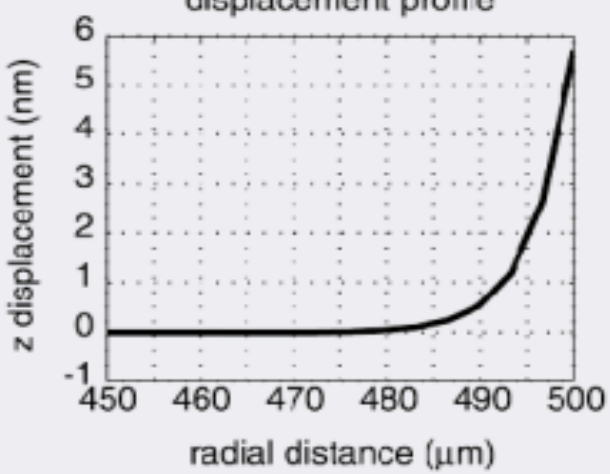
MEMS Fabry-Perot Membrane Modeling

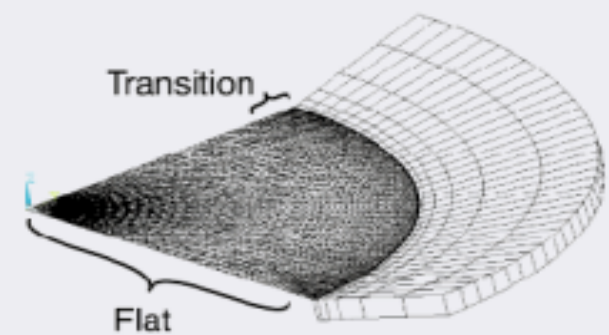




Quarter Symmetric
Finite Element Model

displacement profile

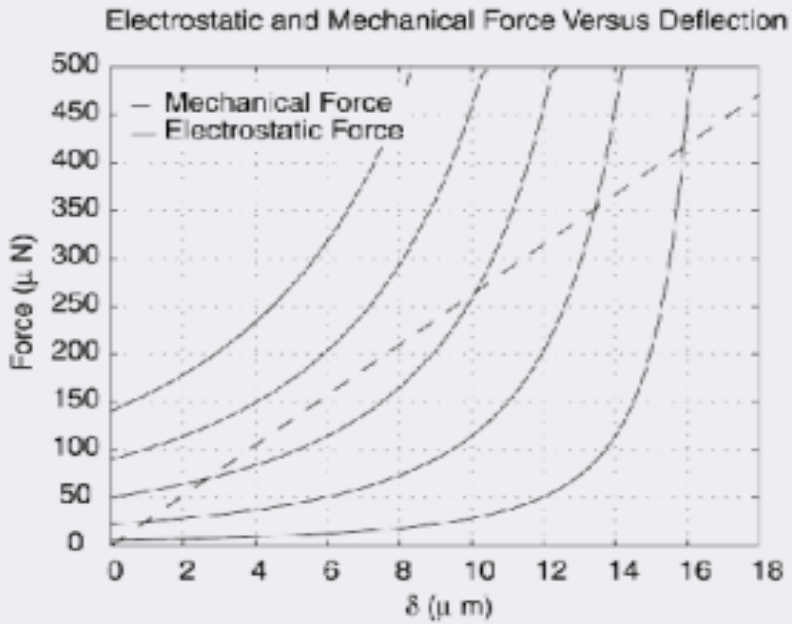


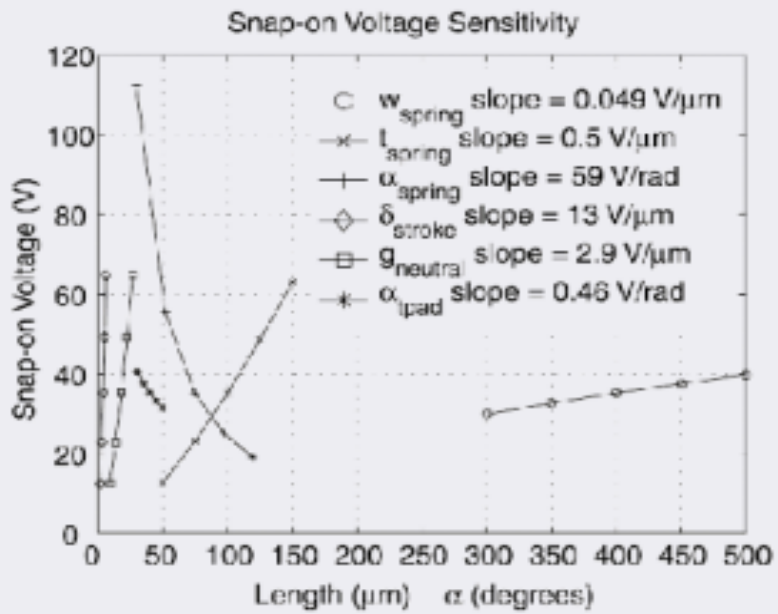


Deformed Mesh

Membrane model consisting of a pre-stressed membrane suspended from a silicon support ring.

MEMS Fabry-Perot Mechanism Modeling





Quasi-static mechanical response of the capacitor/spring actuation mechanism, and detailed parameter studies based on closed form solutions.

Electromechanical Simulation - Recap

Goals:

- Predict performance
- Predict reliability
- Optimize design
- Prevent failures

Environment:

- Ground handling
- Launch
- Space flight

Challenges:

- Large non-linear deformations
- Complex surface contact
- Coupled electromechanical interactions
- Severe thermal mismatch

Software Tools:

- MSC/NASTRAN
- IntelliSuite
- ANSYS/Multiphysics
- In-house code