SAND2011-3506P

Dynamics of Micro-Electro-Mechanical Systems

(*Dinámica de MEMS*)

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(*Laboratório Nacional Sandía*)
Albuquerque, New Mexico, USA

Meeting with University of Guadalajara and CINVESTAV
19 May 2011

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NNSA National Nuclear Security Administration

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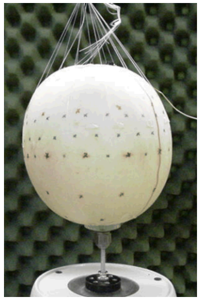
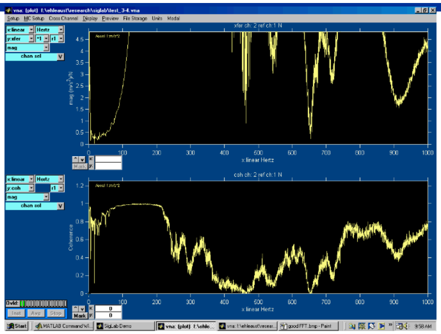
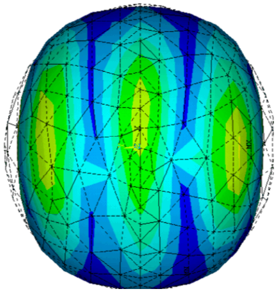
Porque se llama “Laboratório Sandía”

No por la fruta,





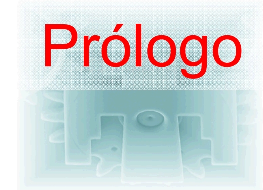


sino por la montaña de Sandía.

Así se llama.

http://www.paulkeysar.com/images/
080407_Watermelon_Slice_TN.jpg

Dynamics and Vibration are important in MEMS

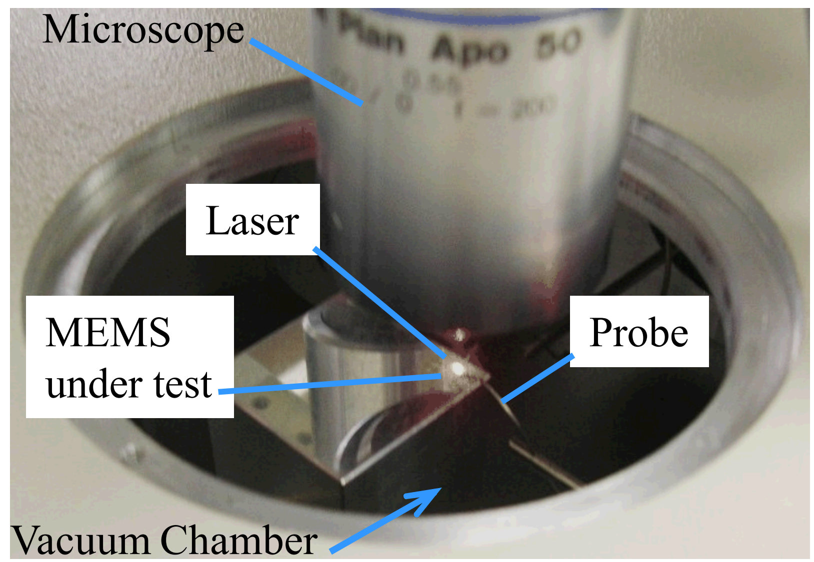


- This presentation will illustrate vibration and dynamic testing and modeling.

- Functional testing
  - Electrical
  - Mechanical
    - Static
      - Stress
      - Deflections
      - Fracture
      - Etc.
    - Dynamic
      - Tribology
      - Dynamics
      - Vibration
      - Shock
      - ...
  - Optical
  - Etc

Mechanical Dynamic Measurements

- A laser Doppler vibrometer (LDV) in the optical train of a microscope measures the motions of MEMS.
- Laser spot has ~1 μm diameter .
- A vacuum chamber enables testing at various pressures.



Sensor Testing Examples

APPLIED PHYSICS LETTERS **92**, 114102 (2008)

Highly sensitive mass detection and identification using vibration localization in coupled microcantilever arrays

Matthew Spletzer,[1] Arvind Raman,[1,a)] Hartono Sumali,[2] and John P. Sullivan[3]

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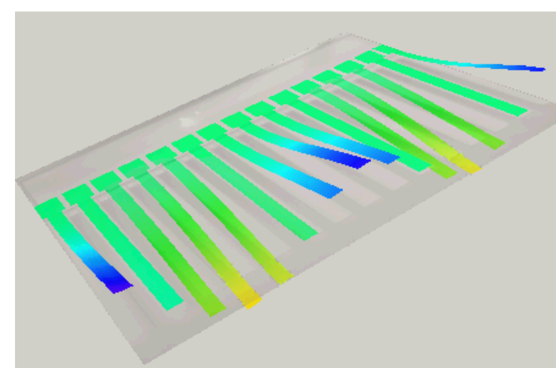
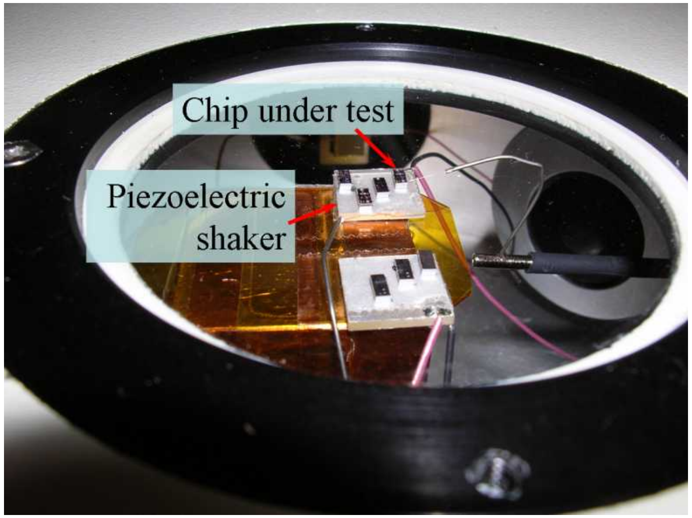
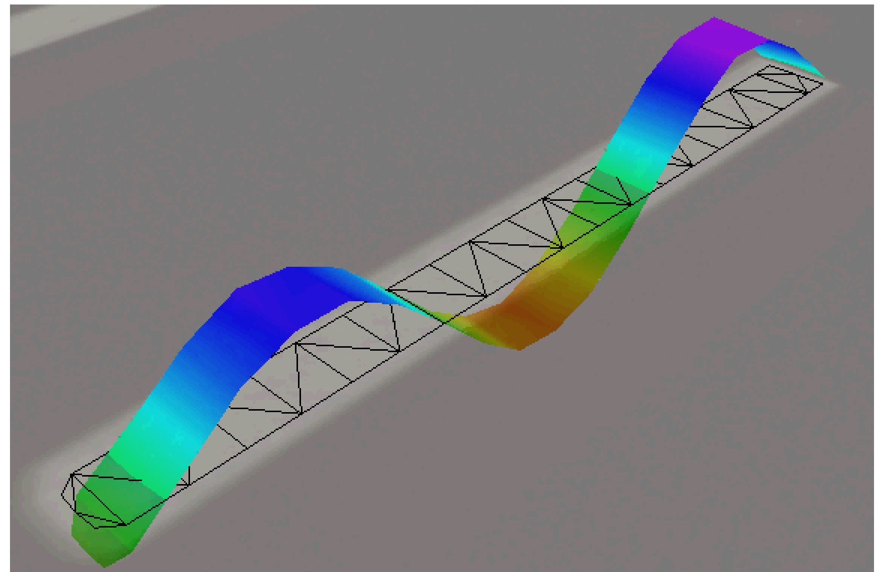


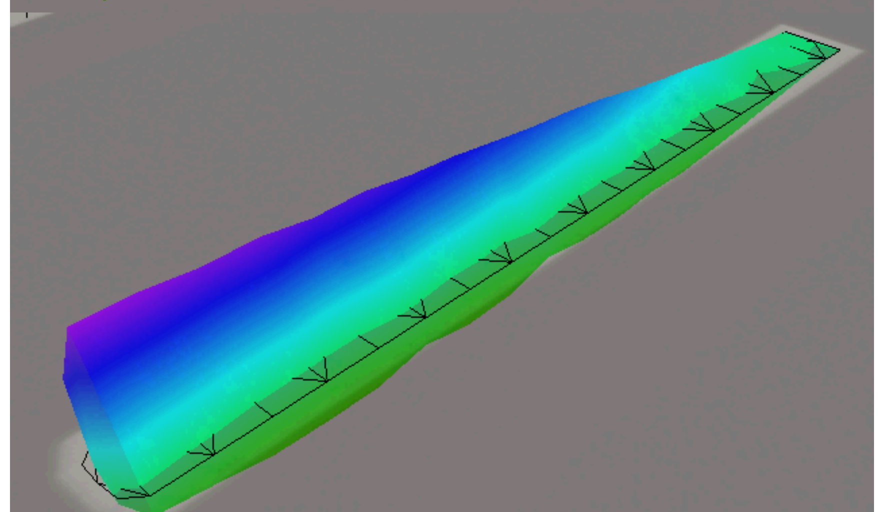
Laser Doppler Vibrometer measures the vibrations of an AFM cantilever probe



Measured with laser Doppler vibrometry, in a vacuum chamber.



A bending mode,440kHz

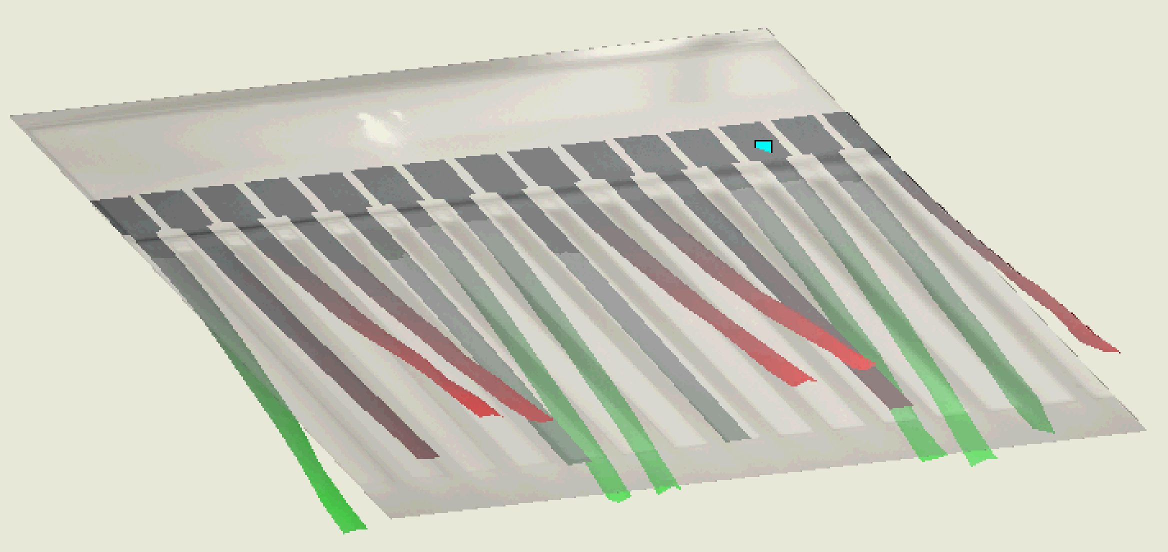


Torsion mode,190kHz

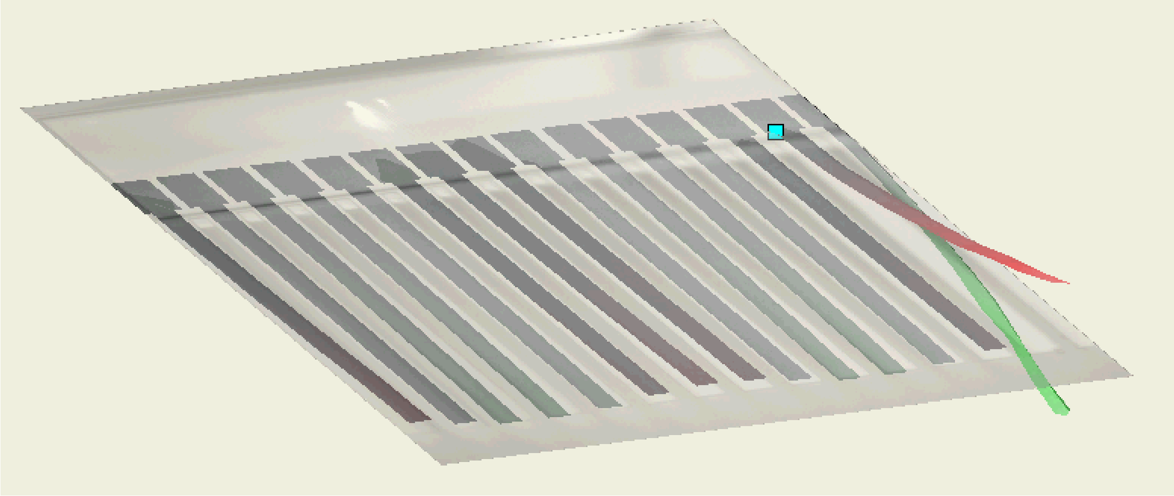
An array of micro cantilevers is capable of measuring 10 picogram of mass.

Detección de 10^{-14} kg

Vibration mode shape of array without mass.



Vibration mode shape of array with 10 picogram (10^{-14} kg) mass attached.



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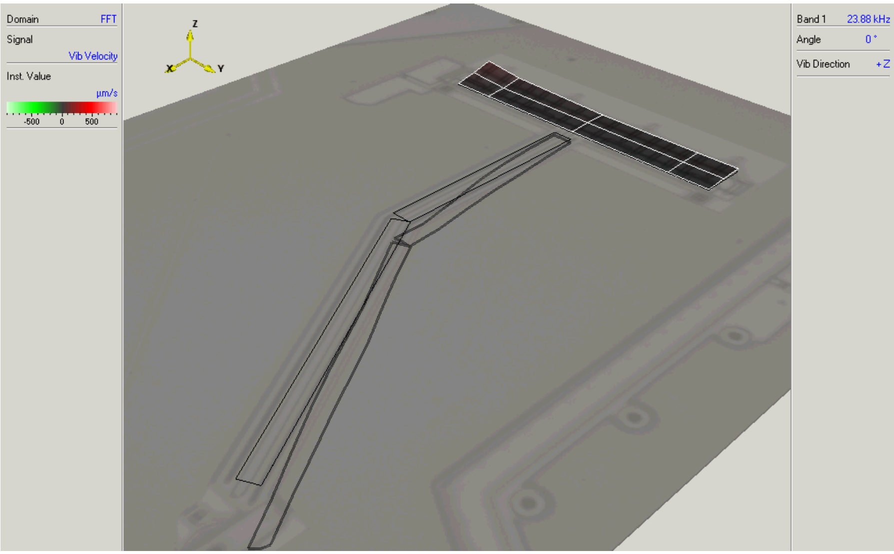
Dynamics of a MEMS Mirror

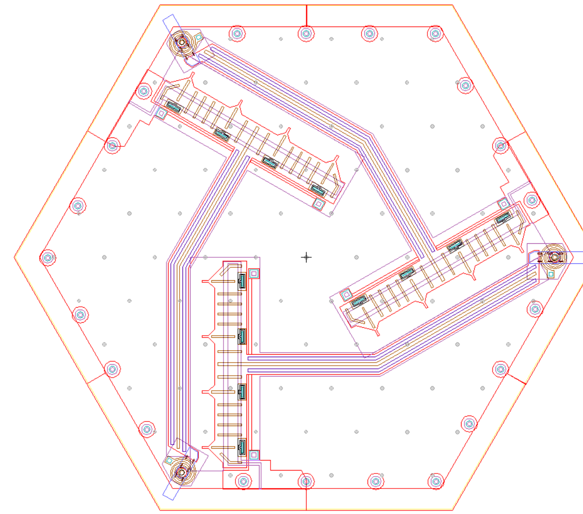
Hexagonal mirror is actuated by three actuators.

- Electrostatic actuation, measured.

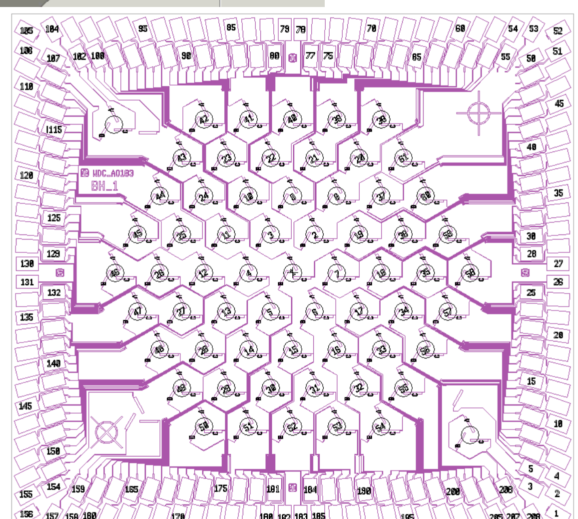


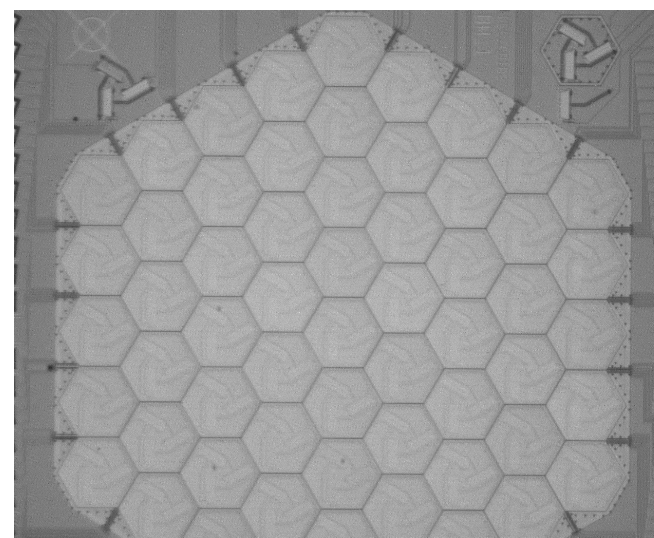
Three actuators enable three degrees of freedom:

- Vertical
- Tilt about x
- Tilt about y



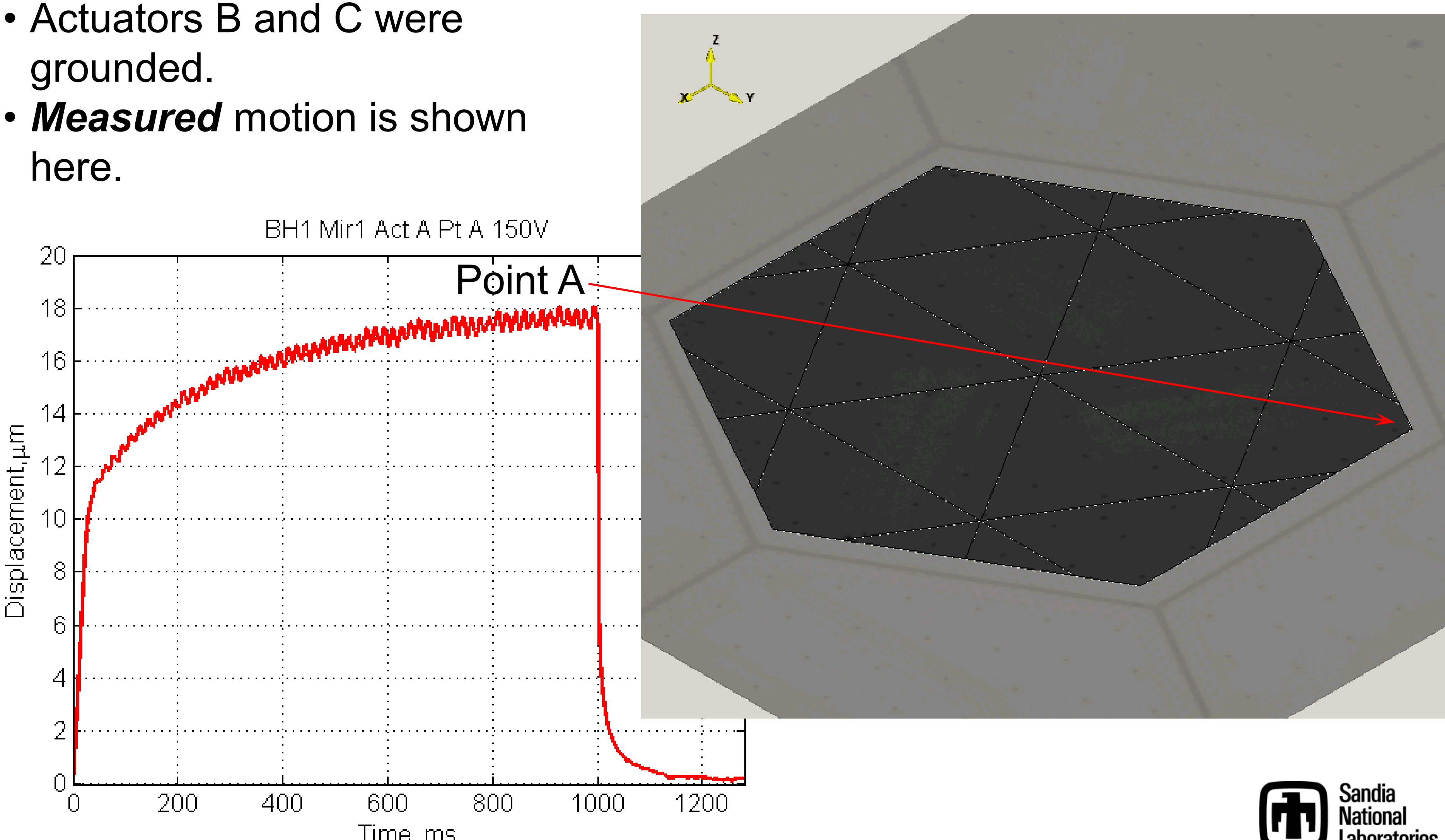
- Mirror array enables many types of optical processing.





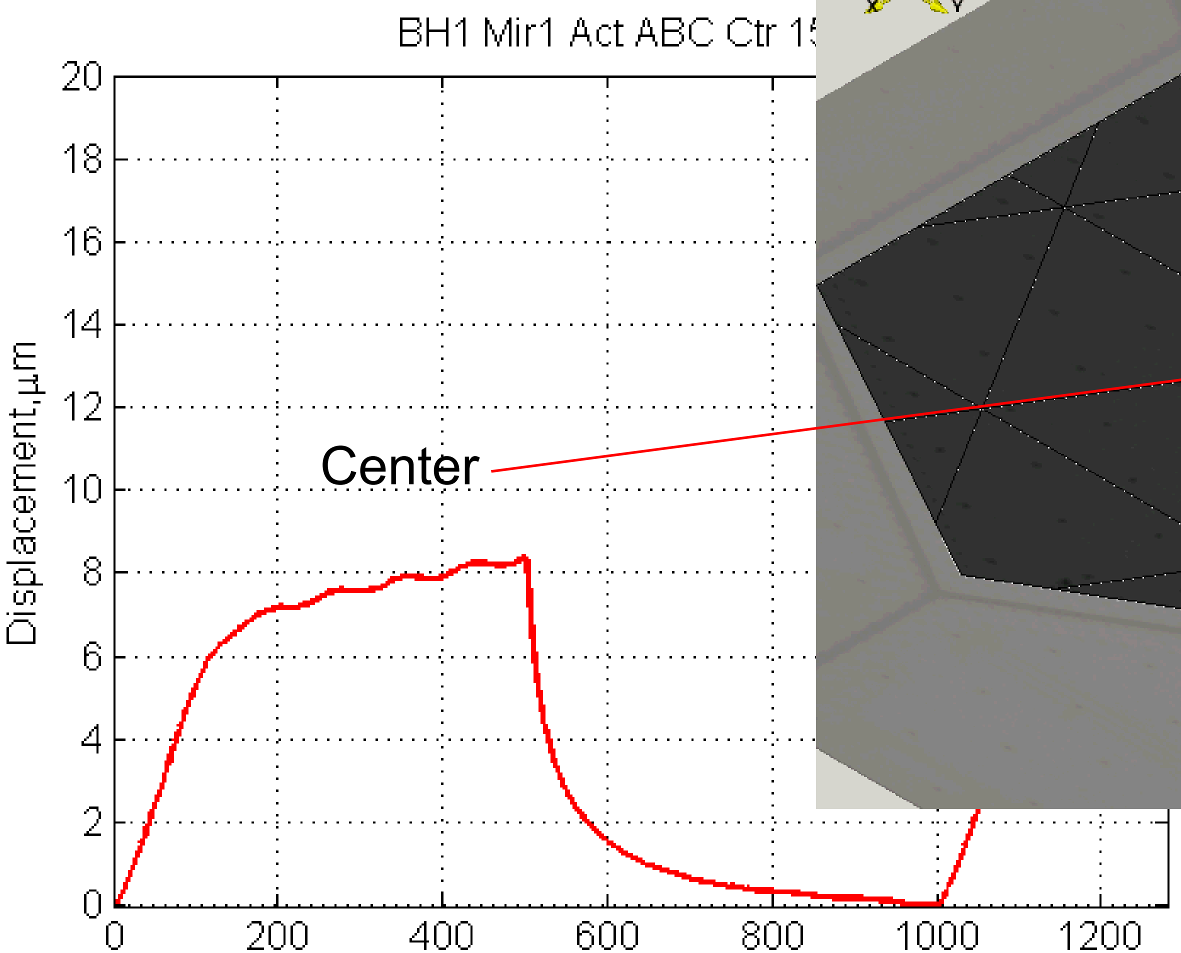
Step voltage to one actuator causes tilting.

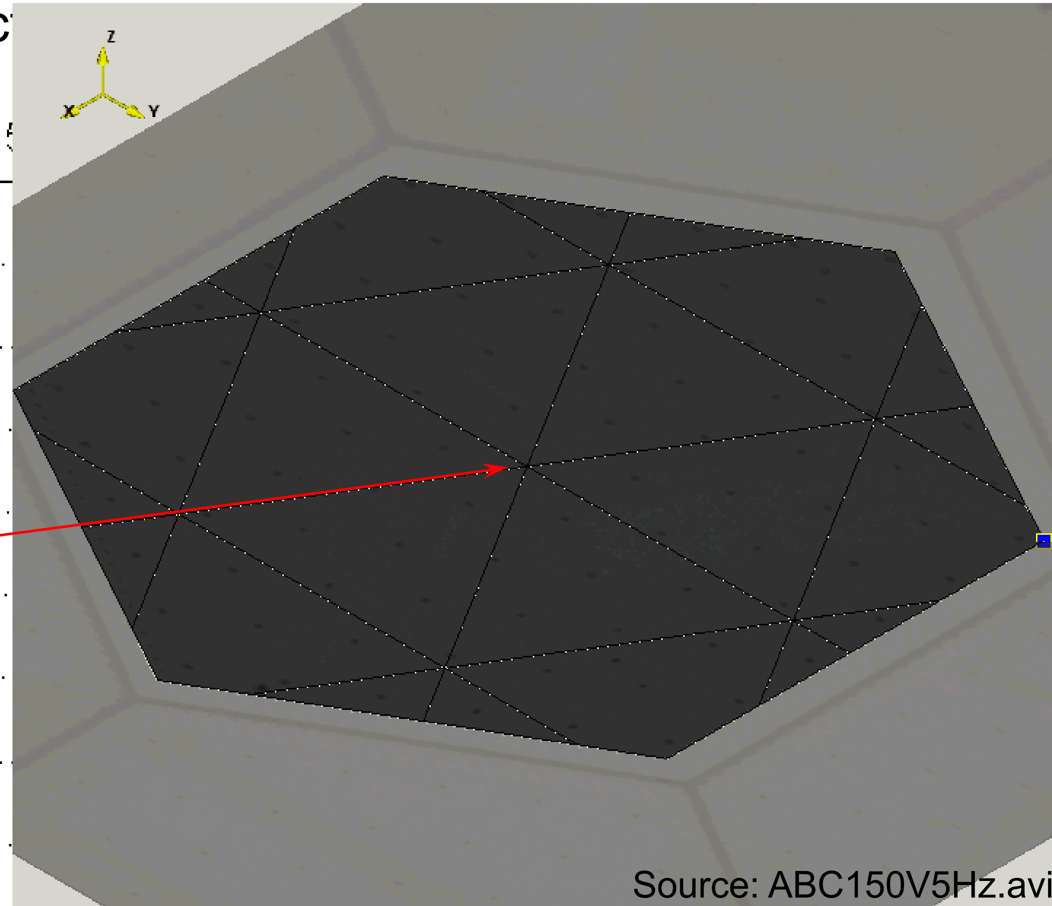
- Only Actuator A was connected.
- Actuators B and C were grounded.
- ***Measured*** motion is shown here.



Step voltage to three actuators causes vertical lifting.

Stepped from 0V to 149V to 0V.
Actuators A, B and C were connec

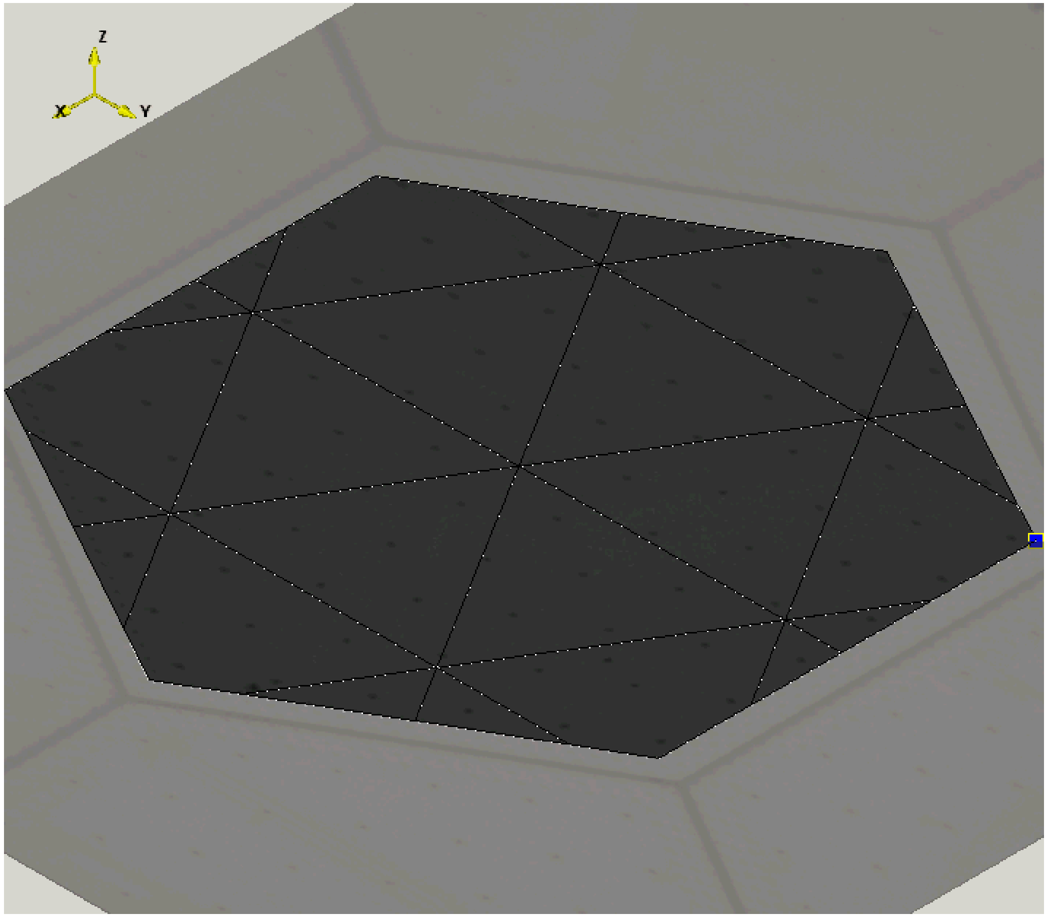




Source: ABC150V.png

Return motion is slowed down by gas damping.

Amortiguación de moción por gas



- Squeeze-film damping slows down the motion significantly.
  - especially when the mirror is close to the substrate.
- Squeeze-film damping needs to be studied and understood in design.

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Squeeze-Film Damping in MEMS

IOP Publishing — Journal of Micromechanics and Microengineering
J. Micromech. Microeng. 17 (2007) 2231–2240 — doi:10.1088/0960-1317/17/11/009

Squeeze-film damping in the free molecular regime: model validation and measurement on a MEMS

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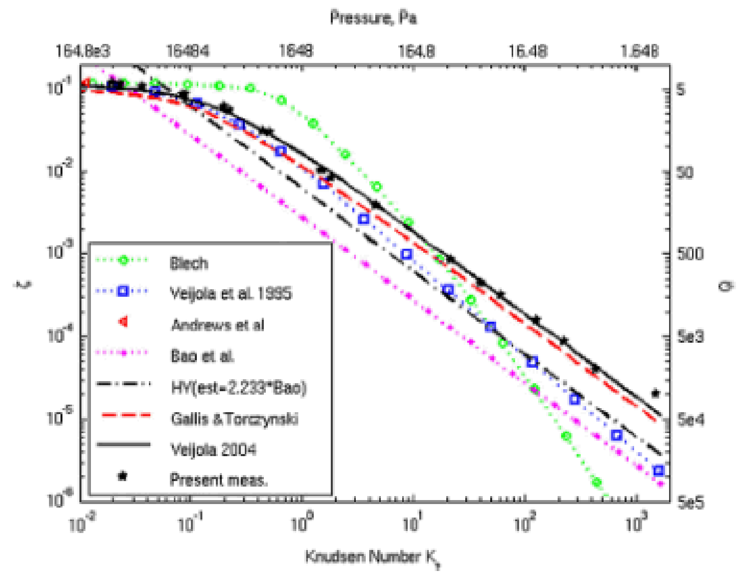


Gas damping is important in MEMS.

Motivation:

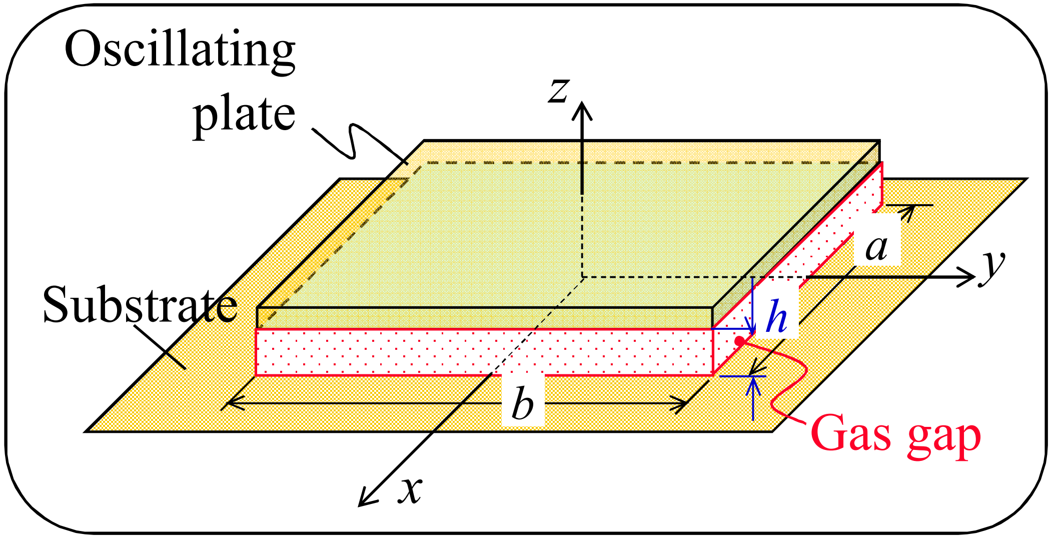
- Many micro/nano devices need high Q factor. Examples abound in
  - MEMS switches need high speed (high Q).
  - Resonant cantilever sensors need high responses.
  - MEMS gyroscopes.
  - MEMS accelerometers need controlled damping.
- Damping can reduce Q from several hundred thousands to below ten.
- Squeeze-film damping determines the dynamics of plates moving a few microns above the substrate.
- Continuum models are not known to be valid in rarefied (free molecule) regime.
- Molecular-dynamics-based models for predicting squeezed-film damping give different results.
  - So which model should one use?
  - Need experimental validation!
- Published experimental data were obtained for squeeze-film damping on *flexible* structures. Have been used to validate theory derived for *rigid* structures.

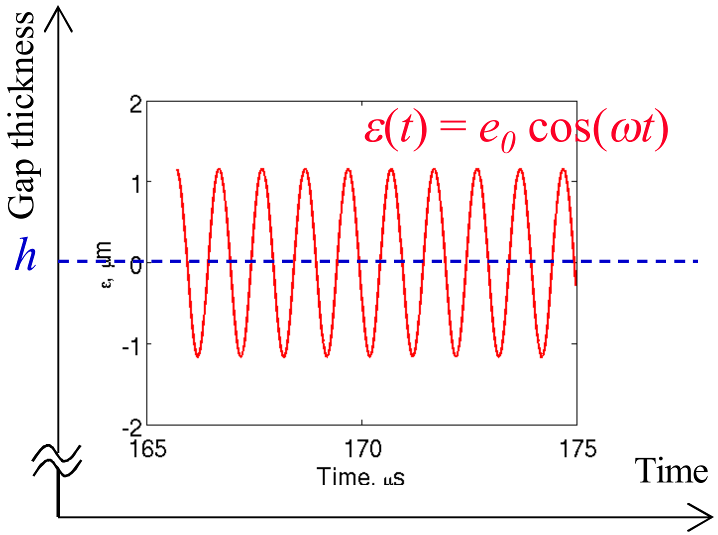
Objective:

- Provide experimental validation to squeezed-film damping models for rigid plates.

Squeezed fluid damps oscillation.

Plate oscillates at fequency ω.





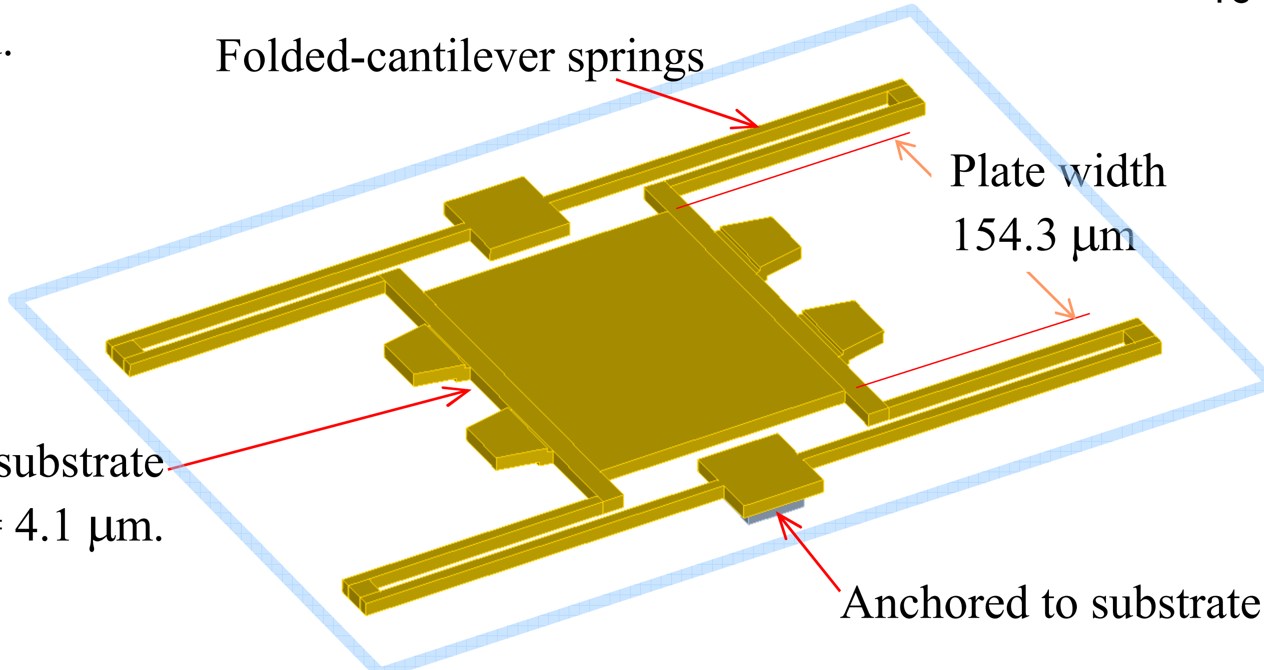
The squeezed fluid between the plate and the substrate creates damping forces on the plate.

Present measurement was done on an oscillating plate.

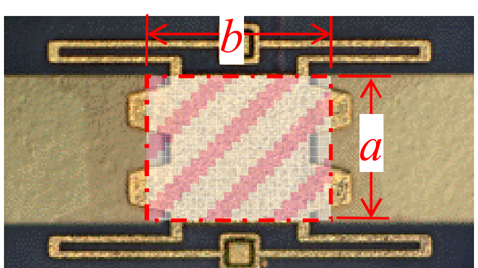
- Structure is electro-plated Au.
- Thickness around 5.7 µm.
- Substrate is alumina.

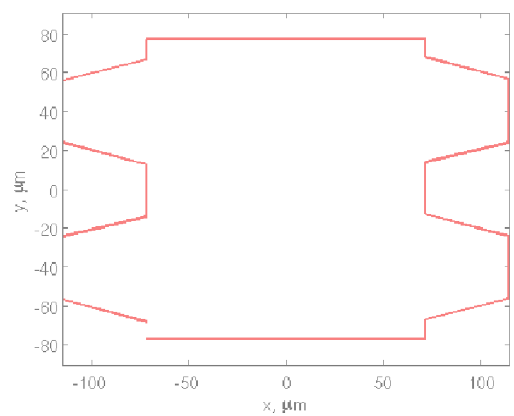
$A = 29717 (\mu m)^2$

$a = 154.3\ \mu m$

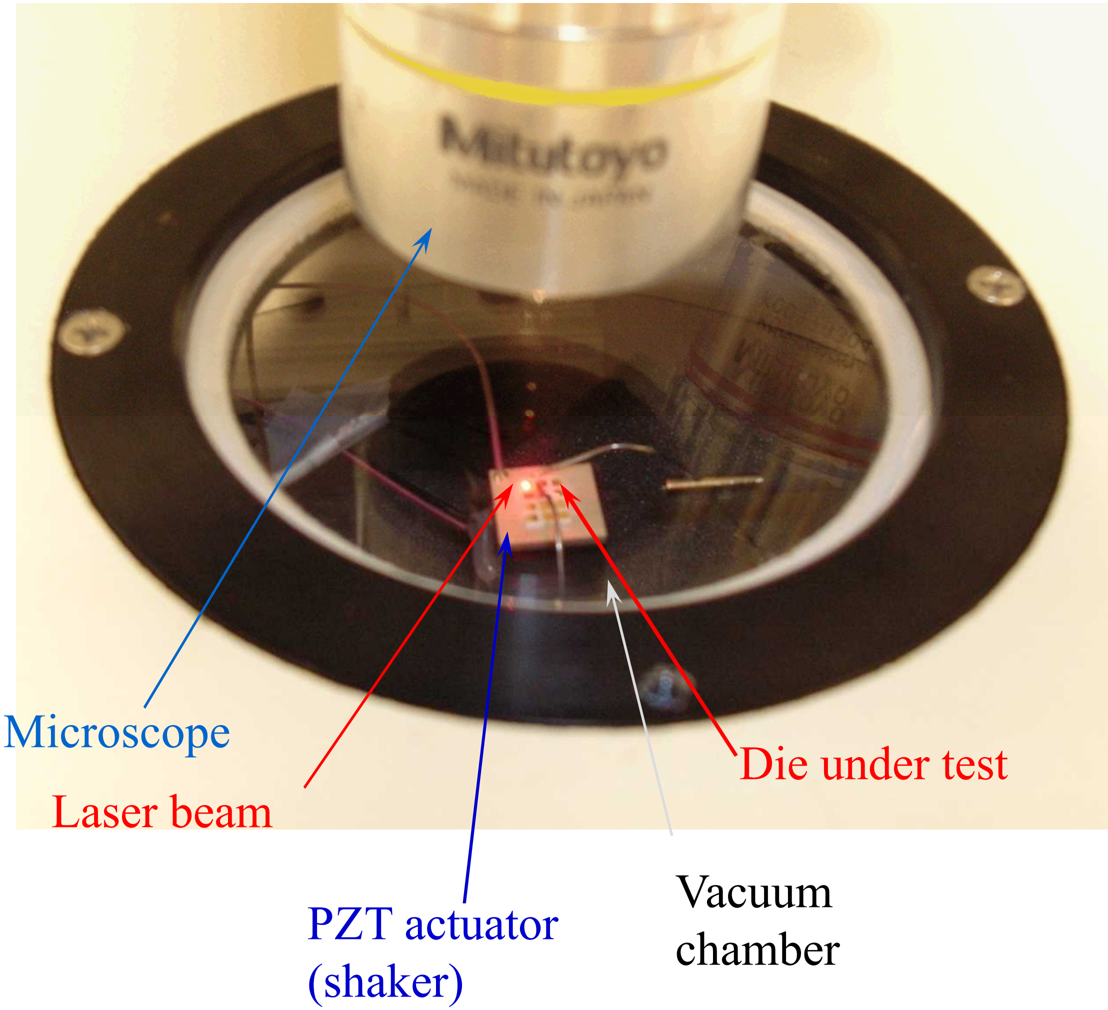


- Assumed width *a* and length *b*, where *ab* = true plate area.





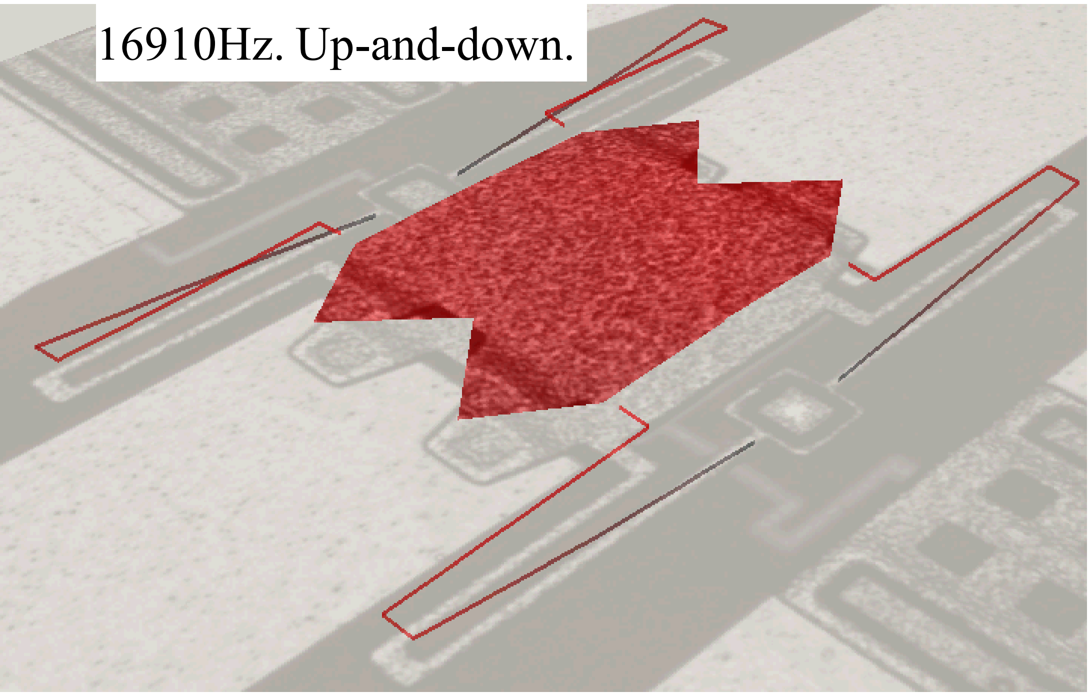
Measurement uses LDV and vacuum chamber.



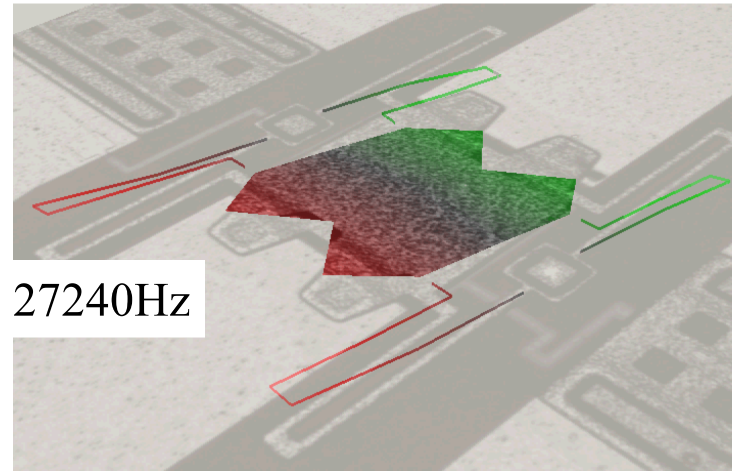
- Substrate (base) was shaken with piezoelectric actuator.
- Scanning Laser Doppler Vibrometer (LDV) measures velocities at base and at several points on MEMS under test.

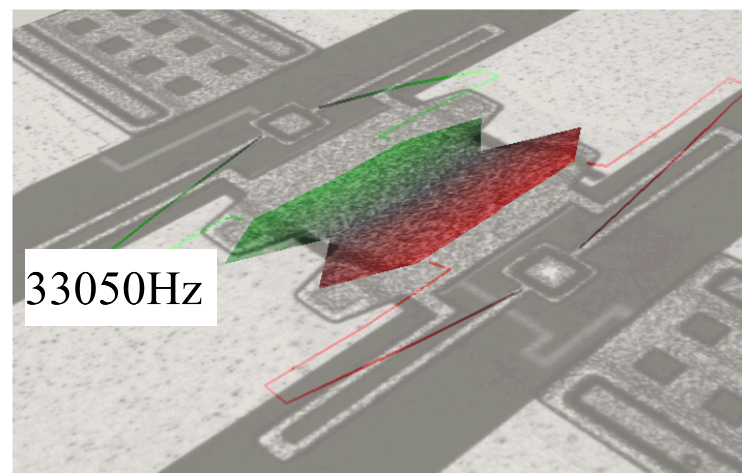
Experimental modal analysis gives natural frequency, damping and mode shapes.

Measured deflection shape, first mode.



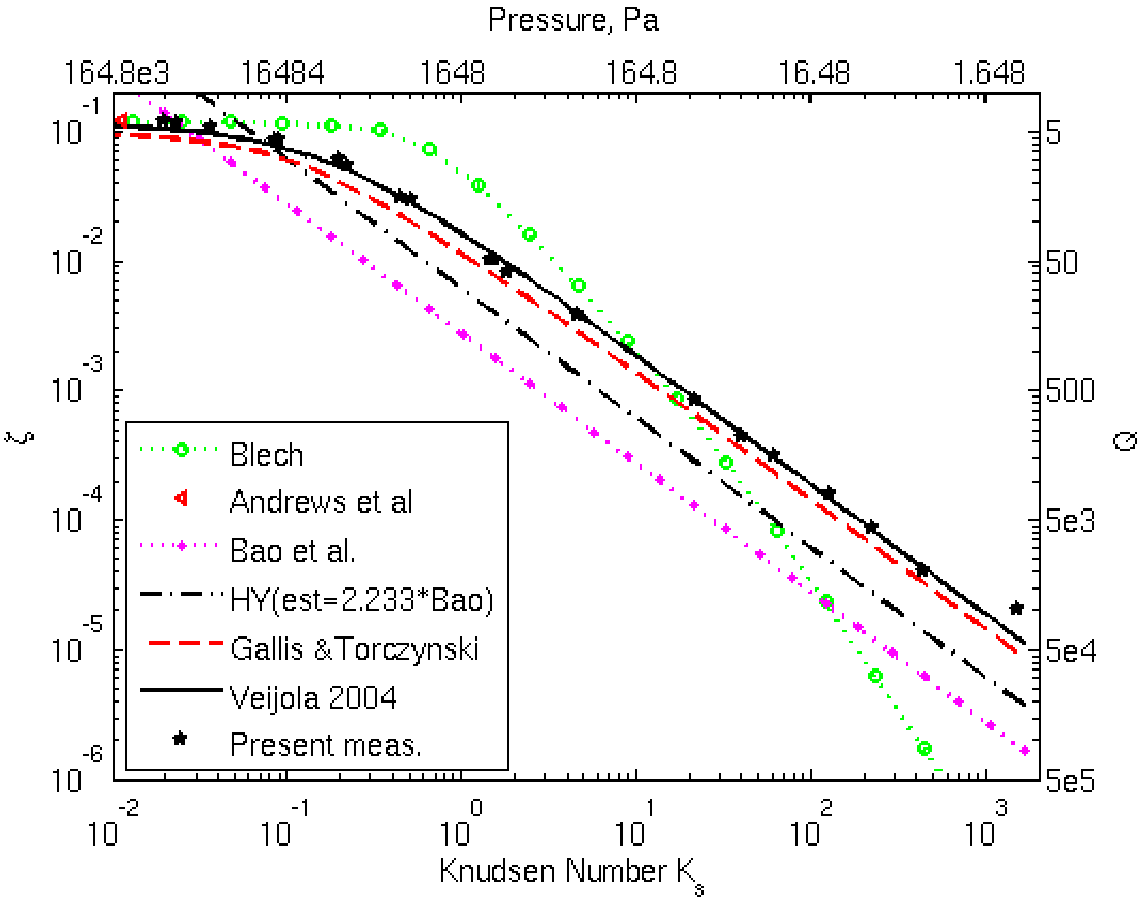
Higher modes are not considered.





- Tests were repeated at different air pressures from atmospheric (640 Torr) to near-vacuum (<1 milliTorr).

Test data were compared with several theories.

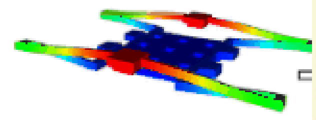


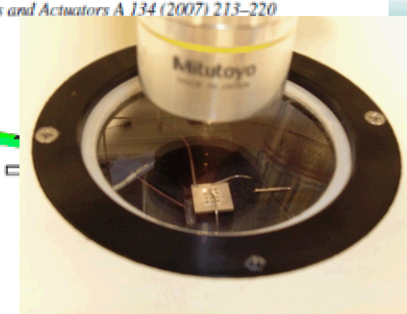
- Blech model is valid only for low Knudsen numbers.
- Andrews et al's limit is accurate at low K_s.
- Literature[1] showed Bao et al's model to be more accurate after modification.
- Gallis-Torczynski model agrees well with test data.
- Veijola's model agrees very well with test data.

[1]Minikes A, Bucher I and Avivi G Damping of a micro-resonator torsion mirror in rarefied gas ambient *Journal of Micromechanics and Microengineering* 15 1762-9

Conclusions

H. Sumali et al. / Sensors and Actuators A 134 (2007) 213–220





3-D FE Model

Fig. 5. Equivalence between 3-D FEM and 1-D model.

- Dynamics is important in MEMS.
- Laser Doppler vibrometry enables high-resolution measurement of MEMS motion.
- We have seen the measurement of the vibration modes of an AFM probe cantilever, and a cantilever array capable of detecting ten picograms of mass.
- We have studied the dynamics of a hexagonal mirror with three actuators.
- Squeeze-film damping slows down the motion.
- Experimental study of squeeze-film damping validate two theories and invalidate most of other theories.

- Sandia National Laboratories conduct extensive research on MEMS, and collaborates with many universities and private companies.

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Acknowledgment

Many people from Sandia National Laboratories in Albuquerque, New Mexico, USA contribute to this presentation.

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Questions? (¿Preguntas ?)

Thank you! (¡Gracias!

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