Experiments for Quantifying Actuation/Release Voltages, Creep, and Uncertainty

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Annual Review
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Experiments and Devices Overview

- Actuation and release voltage vs. cycles
- Charging for sustained contact (Prof. Alam)
- Dynamic beam response (Prof. Raman)
- Displacement vs. voltage for property extraction
- Geometry characterization

Same fabrication process followed for all devices
Common Fabrication Process

1. Ti/Au Contacts
2. Silicon Oxide
3. Silicon Nitride Dielectric
4. PECVD Nitride Deposition
5. Contact Deposition
6. Patterned Nitride Etch
7. Seed Layer Deposition
8. Plating Mold
9. Electroplating
10. Release
11. CAD Drawing
12. SEM Image
Actuation and Release Voltages
• Beam tip deflection dependent on length due to gradient stress
• 250 µm beam has tip deflection of ~13 µm.

Measured beam profile from cofocal microscope
Cantilever Beam Variations

- Beam lengths of 100 µm, 150 µm, 200 µm, 250 µm.
- Dielectric thickness of ~550 nm
- Quantified uncertainty for beam thickness, beam gap/displacement
Cantilever Beam Geometry

Histogram of Beam Thickness

Histogram of Gap Near Anchor Point

Histogram of Gap at Tip for 200μm

Histogram of Gap at Tip for 250μm
Experimental Setup

Laser Doppler Vibrometer (LDV)

Viewing window
Variable Pressure Chamber

LDV Measurement Point
Cantilever beam
High voltage
Ground
Triangle Waveform bias applied to the beam. The resulting velocity vs. time is measured, bias travels through positive and negative voltage to mitigate dielectric charging.

Velocity spikes indicate pull-in/release behavior

Waveform sweeps from -120V to 120V

Pull-in

Release

Normalized Voltage

Normalized Velocity

Time [ms]
Examples of Experimental Results

Pos. Pull-in/Release Voltages vs. Cycles

Neg. Pull-in/Release Voltage vs. Cycles

Die 9, Device E3

70 µm long actuation contact
200 µm long beam
Examples of Experimental Results

Pos. Pull-in/Release Voltages vs. Cycles

Negative Voltage (V)

# of Cycles

Pull-in

Release

Neg. Pull-in/Release Voltage vs. Cycles

Voltage (V)

# of Cycles

Pull-in

Release

Die 10, Device A5

200 μm long actuation contact

250 μm long beam
Creep Experiments
Creep Experiments

- 2-µm electroplated Ni
- Bi-state bias condition
- Deflection extracted using direct optical measurements
- Results are very similar to the results shown in Oct. 2010 for fixed-fixed beams

Multiple scan positions to study entire beam behavior

Direct optical measurements using Olympus LEXT Confocal Microscope
Creep Experiments

- Bi-state biasing to reduce effects of charging
Examples of Experimental Results

- Decreasing gap seen over time
- Biased (ON state) and unbiased (OFF state) curves presented
- Varying behavior seen at tip vs. anchor (similar to fixed-fixed beam)
Updated Timeline
Timeline of Future Measurements

- Actuation and release voltage vs. cycles
  Measure ~10 devices up to 1,000 cycles
  Complete by April 2012

- Charging for sustained contact (Prof. Alam)
  Measure ~10 devices up to several hours
  Complete by April 2012

- Dynamic beam response (Prof. Raman)
  Measure ~10 devices
  Complete by April 2012

- Displacement vs. voltage for property extraction
  Complete model and data by January 2012
Related Research: Cycling Behavior of DC-Contact RF MEMS Switches
DC-Contact RF MEMS Switches

Electronic monitoring of packaged switches
- Identify failure modes in-situ (e.g. adhesion force changes)
- Does not interfere with RF MEMS switch performance
- Diagnostics and prognostics of RF MEMS

Accomplishments
- First contact bouncing behavior
- 60 – 100 µw power consumption
- Real-time (1 MHz) movement monitoring

Projects/Recognition
- DARPA S&T Fundamentals Center
- NASA SBIR

Holy Grail = Predict Remaining Lifetime
DC-Contact RF MEMS Switches

Omron RF MEMS Switch

First Reported Consistent Change of Bouncing Pattern vs. Number of Cycles
DC-Contact RF MEMS Switches

![Graph showing normalized bounce magnitude vs. millions of cycles](image)

- Dev 1: 1st Bounce
- Dev 2: 2nd Bounce
- 3rd Bounce
- 4th Bounce

Normalized Bounce

Magnitude

Millions of Cycles
Thank you!