## Modeling of PRISM Switch Including Creep

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### **Objectives:**

- To quantify the effects of a micro-scale-informed model of creep incorporated into a preexisting first-principles-based, reduced-order model of the nanocrystalline nickel membrane [1] in the PRISM RF-MEMS switch; To model the experimentally determined effects of creep on the device; To extrapolate those effects to untested regions;
- To quantify uncertainty, the sensitivity of QOIs to creep, & vice-versa;
- To verify and validate multiple scales of simulations of the device dynamics.

### Beam Geometry:



### Model Development:

**Euler-Bernoulli Beam accounting for:** 

- •Residual Stress Modeled with axial pre-stresses
- •In-Plane Stretching Additional axial stresses caused by stretching
- Electrostatic force Parallel plate model with displacement-dependent fringe field correction and a finite, asymmetric electrode
- •Fluid Damping Compact model for squeeze-film damping
- •Soft Bounce Distributed linear spring.
- •<u>Creep</u> Coble creep model

### Equation of Motion:



## Motivation

# Creep Model



Creep (permanent deformation resulting from sustained moderate levels of stress) is a significant failure mechanism of the PRISM RF-MEMS device [2]. Creep causes an undesirable increase in the deflection of the membrane, an increase of the device capacitance, a decrease of the device pull-in voltage, and eventually a possible collapse of the membrane.

Experiments performed by Hsu and Peroulis [3] have demonstrated the effect of creep on the nanocrystalline nickel RF-MEMS device. Though significant, the effects of creep had previously been neglected in the development of a simplified model of the device.

Coble creep has been shown to be the dominant creep mechanism in nanocrystalline nickel RF-MEMS devices [3]. Coble creep is a form of diffusion creep in which deformation occurs due to the movement of atoms and vacancies along grain boundaries.





 $\dot{\varepsilon}_{ij}^P$ **Plastic Strain Rate**  $\sigma_{ij}^a$ **Deviatoric Stress Material Parameter**  $\sigma_v$ Yield Stress

The equation above describes the plastic (permanent) strain rate of the membrane as a function of the stress in the membrane, the material's yield stress, and the collection of material parameters A<sub>c</sub>, which includes creep coefficient, grain boundary diffusion coefficient, Burgers vector, grain size, temperature, Boltzmann Constant, and initial yield stress.

Pull-In Voltage

time(n)

1000 <sup>~</sup> 2000

## Results

- New model capabilities
  - Pull-in times due to creep for small loads
  - Creep under variable boundary conditions
  - Distributed electrostatic loading causing creep
  - Creep with variable initial curvatures
  - Changes in pull-in voltages over time
  - Permanent deflection shapes after loading ceases
- Modified GUI



### Cantilever pull-in times for a range of initial curvatures



### Fixed-Fixed pull-in times for a range of initial curvatures





0.31

0.9e

7.5e-5

400e-6

4.6e-6

120e-6

3.6e-6

8.85e-12

240e-6

0-1.8e-6

0-1.8e-6

#### Quasistatic pull-in voltage as a function of time



#### Elastic and Plastic Deflection due to Creep as a Function of Time



## Discussion

### Results

- A model of Coble creep has been incorporated into a reduced-order beam model of the PRISM RF-MEMS device
- Deflection, Pull-in voltage as a function of time, and Pull-in times due to creep for various initial curvatures have been demonstrated.

#### Advantages

- A wide variety of parameters and their effects are included in the model
- As a reduced-order model, each run is quick and efficient
- Greater accuracy is possible with the use of more mode-shapes

### Disadvantages

- As a reduced-order model, the accuracy of the results is diminished
- Greater accuracy requires significantly more computational time Limitations
- Several effects, such as contact, use very simplified models

### Verification & Validation

- Verification against codes available on Memshub.org and against simple cases where analytical solutions exist
- Comparison to existing higher-order models will yield the range of values for which this simplified beam and creep model is acceptable.

### 30 Volts 100 Hours



### 30 Volts 500 Hours



#### UNIVERSITY



[1] Snow, Michael G. "Comprehensive Modeling of Electrostatically Actuated MEMS Beams Including Uncertainty Quantification." Thesis. Purdue University, 2010. [2] Hartzell, Allyson L., Silva Mark G. Da, and Herbert R. Shea. "Creep." MEMS Reliability. New York: Springer Science, 2011. 114-17. [3] Hsu, Hao-Han; Koslowski, Marisol; Dimitrios Peroulis. An experimental and theoretical investigation of creep in nanocrystalline Nickel in RF-MEMS devices, MTT, submitted, 2011.

### Sensitivity Analysis

- Built-in GUI uses Monte-Carlo sampling to produce response surfaces due to input pdfs. These response surfaces illustrate the global sensitivity of the quantities of interest to the input parameters.
- MEMSHUB PUQ tool allows the use of various UQ methods (see the graphs of Pull-In Time to the right).