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 pre-existing 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 QOs 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 dielectric field-dependent fringe field correction and a finite, asymmetric electrode
  - Fluid Damping – Compact model for squeeze-film damping
  - Soft Bounce – Distributed linear spring.

- New model capabilities
  - As a reduced-order model, each run is quick and efficient
  - Several effects, such as contact, use very simplified models
  - Greater accuracy requires significantly more computational time
  - A wide variety of parameters and their effects are included in the model
  - Deflection, Pull-in voltage as a function of time, and Pull-in times due to creep

Advantages

- Changes in pull-in voltages over time
- Creep with variable initial curvatures
- Distributed electrostatic loading causing creep
- Creep causes an undesirable increase in the deflection of the membrane, an increase 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 in which deformation occurs due to the movement of atoms and vacancies along grain boundaries.

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 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. Through significant, the effects of creep had previously been neglected in the development of a simplified model of the device.

Discussion

Results

- New model capabilities
  - Pull-in times due to creep for small loads
  - Changes in pull-in voltages over time
  - Permanent deflection shapes after loading ceases
- Modified GUI

Motivation

- Creep causes an undesirable increase in the deflection of the membrane, an increase of the device pull-in voltage, and eventually a possible collapse of the membrane.

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Creep Model

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.

Coble Creep in 3-D:

\[
\dot{\varepsilon}_c = A_c \left( \frac{\sigma}{\sigma_y} \right)^n \]

\[
\varepsilon_c^d + \varepsilon_c^p = \varepsilon_c^t
\]

\[
\varepsilon_c^t = \varepsilon_c^d + \varepsilon_c^p
\]

\[
\varepsilon_c^t = \frac{1}{\sigma_y} \left( \frac{\sigma}{\sigma_y} \right)^n
\]

\[
\varepsilon_c^d = \frac{1}{\sigma_y} \left( \frac{\sigma}{\sigma_y} \right)^n
\]

\[
\varepsilon_c^p = \frac{1}{\sigma_y} \left( \frac{\sigma}{\sigma_y} \right)^n
\]

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 \( A_c \), which includes creep coefficient, grain boundary diffusion coefficient, Burgers vector, grain size, temperature, Boltzmann Constant, and initial yield stress.

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

UQ

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.

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).