Characterizing non-linear viscoelasticity in metal microbeams

Materials innovation institute

Section Mechanics of Materials

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Introduction

MEMS consisting of Al-(1wt%)Cu thin films are affected by time-dependent elastic deformation. Device modeling and understanding of intrinsic material behavior can ameliorate this.

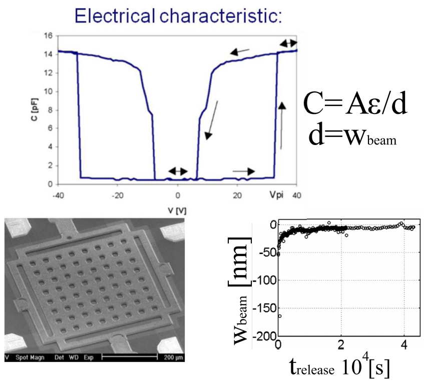

Figure 1: The capacitance (t) of an RF-MEMS parallel plate capacitor (bl) depends on the gap which is negatively influenced by mechanical time-dependent deflection w of the beam-shaped hinges (br).

Goal: investigate a suitable, simple model describing time-dependent elastic deformation in metallic microbeams.

Method

- A nm-precise microbeam bending experiment[1] gives $\varepsilon(t)$.
- Multimode viscoelasticity forms a simple yet sufficiently representative model:
  - moduli E_i: energy storage through back-stresses from dislocations.
  - viscosities η_i: dissipation from diffusion limited dislocation motion.
- Reformulate the model in terms of model parameters and $\varepsilon(t)$, because $\sigma(t)$ is not measured.

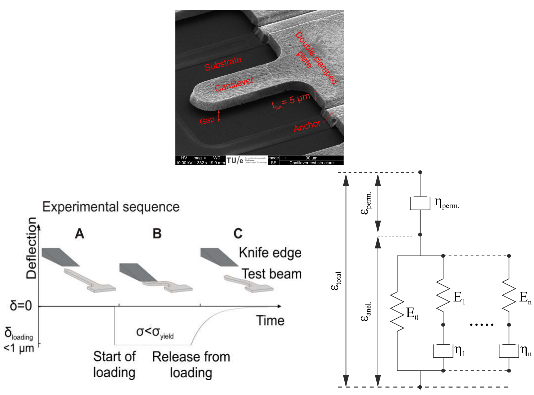

Figure 2: Al-(1wt%)Cu microbeam (top) deflected for several hours (left) to study viscoelastic material behavior that is modeled with a multi-mode standard linear viscoelastic material model (right).

Results

The deflection recovery is described by a 5-mode viscoelastic model for experiments in the elastic regime:

$$\varepsilon_{\text{anel.}}(t) = \sum_{i=1}^{n} \frac{\mathsf{E}_i}{\mathsf{E}} \left(\sum_{j=1}^{n} \mathsf{b}_i p_j(i) \mathsf{e}^{\lambda_j t}\right) \quad (1)$$

- Accurate calibration and prediction for other loads.
- Adequate for *system*, i.e. geometry+material, modeling.

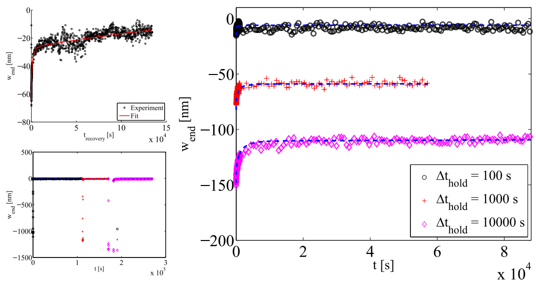

Figure 3: (tl) Model calibration after $t_{hold} = 24$ h. (bl) Sequence of various load durations on calibrated beam (r) Prediction of sequence by calibrated model.

Effect of nonlinear kinematics and material behavior is lumped into *system* parameters:

- Unsuitable for *material* characterization.
- So employ FEM and nonlinear material modeling to account for inhomogeneous deformation and nonlinear material behavior.

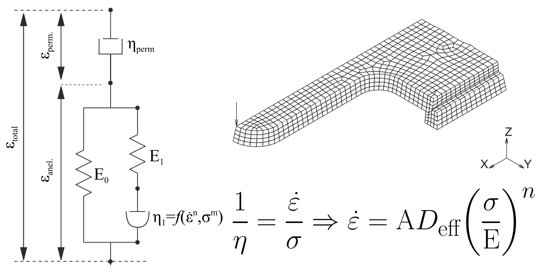

Figure 4: Improved characterization approach.

Conclusion and Outlook

- 5-mode standard solid viscoelastic model good for system modeling and design.
- Material characterization requires nonlinear finite element modeling.
- Combining nonlinear FEM, experiments and microstructural observations on varied alloy microstructures will reveal physical micromechanisms.

References:

[1] BERGERS, L. I. J. C., ET AL., MICROELECTRON. RELIAB., 2011;