NONLINEAR DYNAMIC MODELING OF MICROMACHINED MICROWAVE SWITCHES

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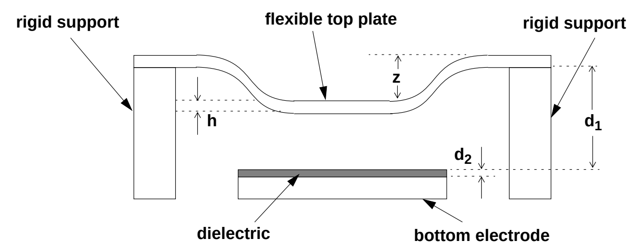
MICROMACHINED MICROWAVE SWITCH

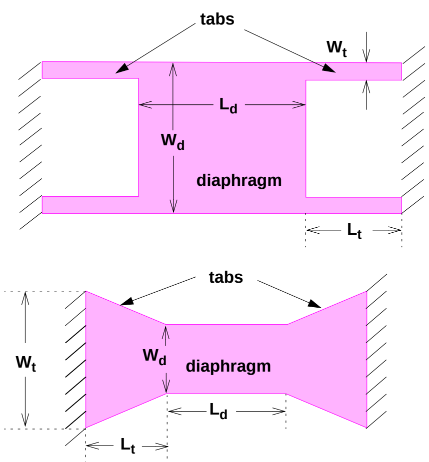


Cross-section

MICROMACHINED MICROWAVE SWITCH

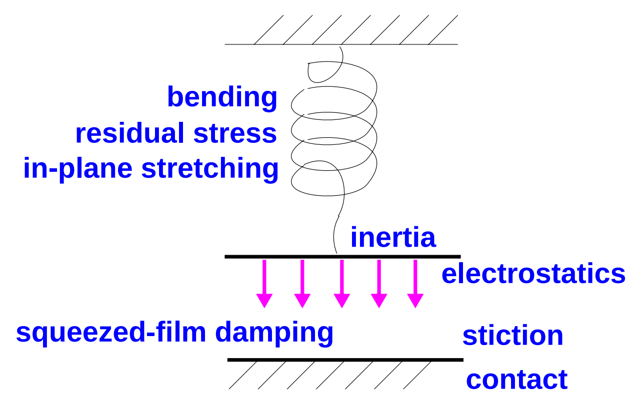
Type I

Type II

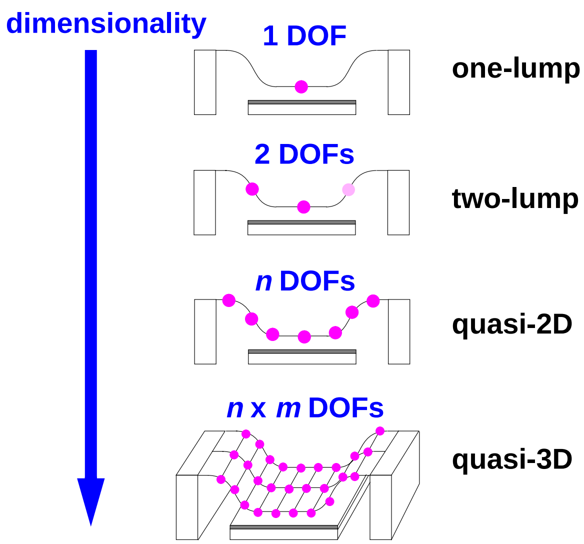


Plan view of different switch designs

PHYSICAL MODELS



Geometrical Hierarchy



Equation of Motion for One-Lump Model and Each Node of Quasi-2D Model

$$F_{bend} + F_{stretch} + F_{stress} + F_{electro}$$

$$+ F_{damp} + F_{VDW} + F_{contact} = m\frac{d^2 z}{dt^2}$$

Vertical Motion Only

Equations of Motion For Two-Lump Model

$$F^t_{bend} + F^t_{stretch} + F^t_{stress} + F^t_{electro}$$

$$+ F^t_{damp} + F^t_{VDW} + F^t_{contact}$$

$$- F^d_{bend} - F^d_{stretch} - F^d_{stress} = m_t\frac{d^2 z_t}{dt^2}$$

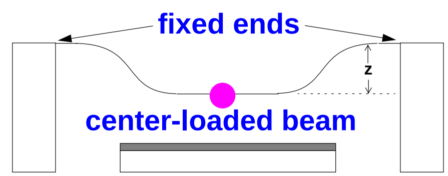
Motion of Inner Edge of Tab

$$F^d_{bend} + F^d_{stretch} + F^d_{stress} + F^d_{electro}$$

$$+ F^d_{damp} + F^d_{VDW} + F^d_{contact} = m_d\frac{d^2 z_d}{dt^2}$$

Motion of Center of Diaphragm

Solid Mechanics Model For One-Lump System



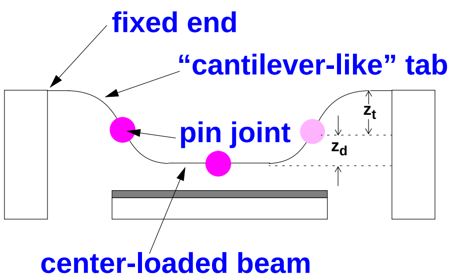
$$F_{bend} = -\frac{\pi^4 E h^3 W_t}{48 L_t^3} z$$

$$F_{stretch} = -\frac{h W_t \pi^4 E}{64 L_t^3} z^3$$

$$F_{stress} = -\frac{h W_t \pi^2 \sigma}{4 L_t} z$$

$E_{plate} = E_{beam}/(1-\upsilon^2)$ $\sigma_{plate} = \sigma_{beam}(1-\upsilon)$

Solid Mechanics Model For Two-Lump System



*tip of "cantilever-like" tab is constrained to move vertically only

Tab:

$$F_{bend} = -\frac{Eh^3W_t}{2L_t^3}z_t$$

$$F_{stretch} = -\frac{32hW_tE}{9L_t^3}z_t^3$$

$$F_{stress} = -\frac{8hW_t\sigma}{3L_t}z_t$$

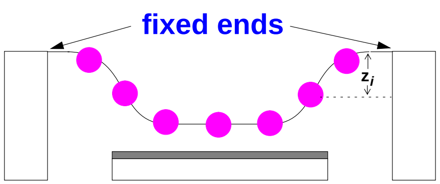
Diaphragm:

$$F_{bend} = -\frac{4Eh^3W_d}{L_d^3}z_d$$

$$F_{stretch} = -\frac{\pi^4hW_dE}{4L_d^3}z_d^3$$

$$F_{stress} = -\frac{\pi^2hW_d\sigma}{2L_d}z_d$$

Solid Mechanics Model For Quasi-2D Model

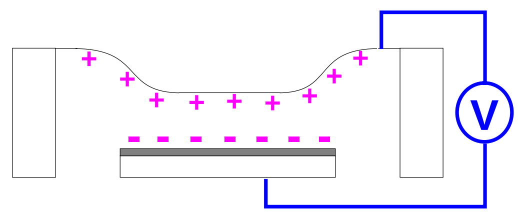


$$F_{bend} = -\frac{\partial^2}{\partial x^2}\left(\frac{Eh^3W}{12}\frac{\partial^2 z}{\partial x^2}\right)$$

$$F_{stress} = -hW\sigma\frac{\partial^2 z}{\partial x^2}$$

$$F_{stretch} = -hWE\left[\frac{1}{L_{tot}}\int_0^{L_{tot}}\frac{1}{2}\left(\frac{\partial z}{\partial x}\right)^2 dx\right]\frac{\partial^2 z}{\partial x^2}$$

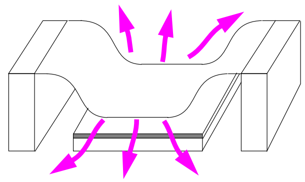
Electrostatics Model



fringe effect

$$F_{electro} = \frac{\varepsilon AV^2}{2\left(d_1 + \frac{d_2}{\kappa} - z\right)^2} \times \left(1 + 0.65\frac{d_1 + \frac{d_2}{\kappa} - z}{W}\right)$$

Squeezed-Film Damping Model

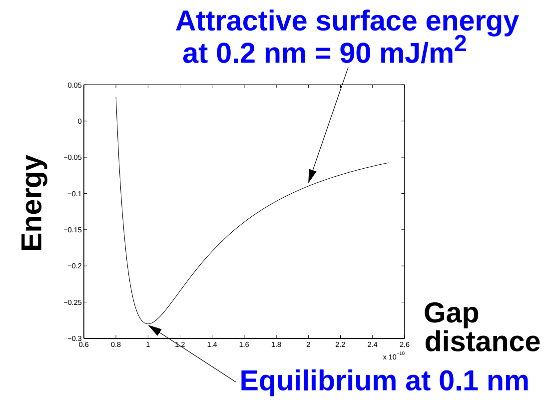


$$F_{damp} = -\frac{\mu L W^3}{d_1^3}\frac{dz}{dt}$$

Approximations:

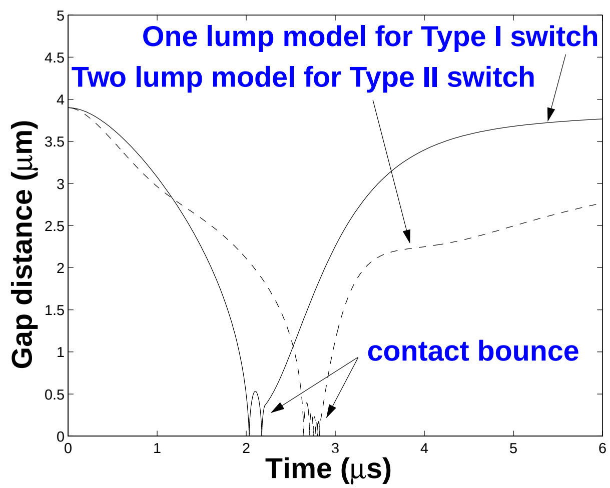
1. Small Reynolds number $\frac{\omega d_1^2 \rho}{\mu} \ll 1$
2. Continuum gas model
3. Form factor for different aspect ratios (W/L)
4. Small displacement for large fraction of T_{ON}

Stiction and Contact Model

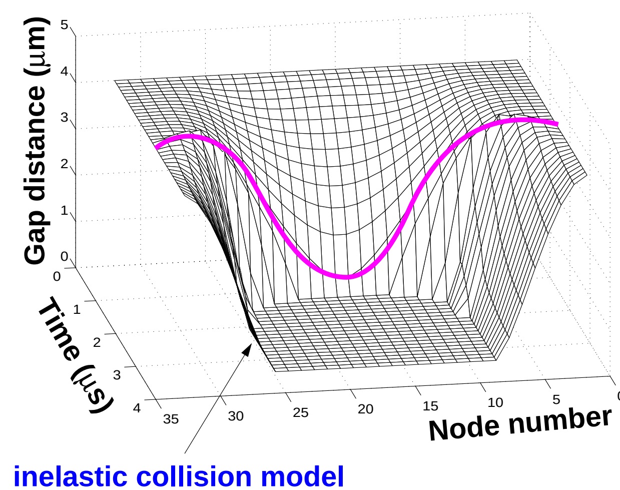


$$F_{VDW} + F_{contact} = \frac{K_1 A}{(d_1 - z)^3} - \frac{K_2 A}{(d_1 - z)^{10}}$$

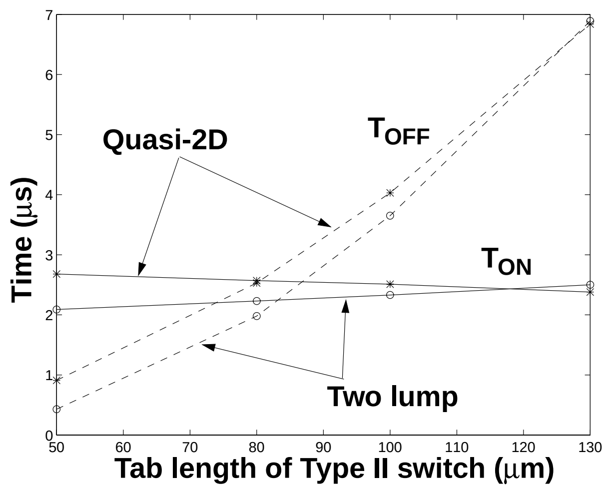
Simulation of Switching Transient



Quasi-2D Transient Simulation

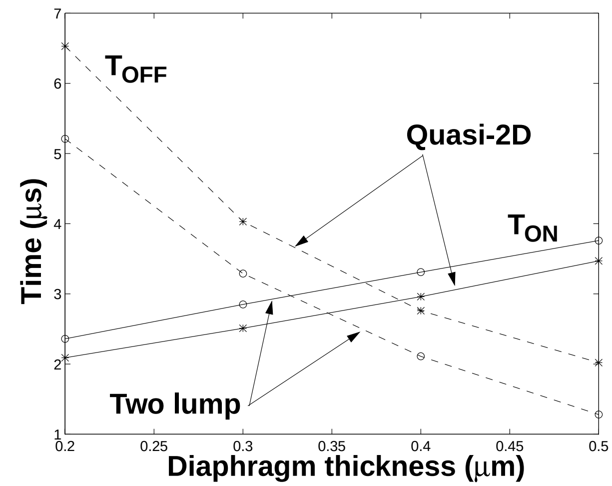


GEOMETRICAL SCALING



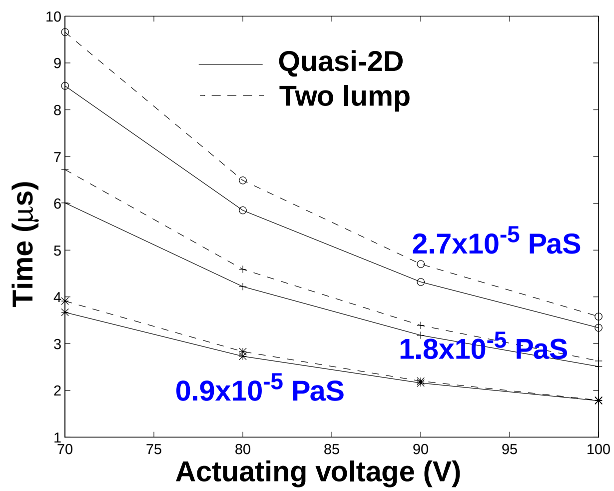
Variation of T_{ON} and T_{OFF} with tab length

GEOMETRICAL SCALING



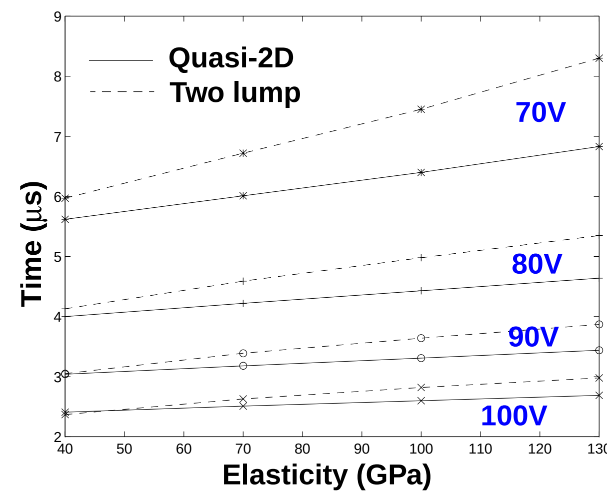
Variation of T_{ON} and T_{OFF} with thickness

SENSITIVITY TO PARAMETERS



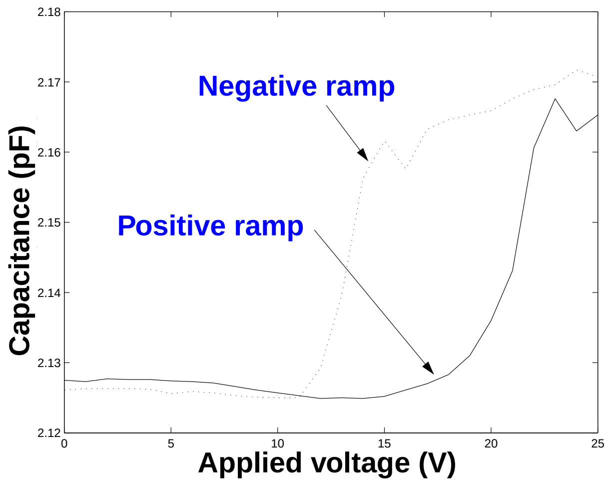
T_{ON} vs actuating voltage for various µ

SENSITIVITY TO PARAMETERS



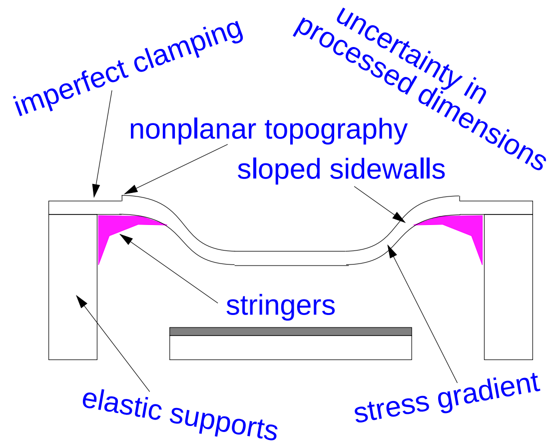
Variation of T_{ON} with E for various V

Preliminary Measurements



Measured devices are tunable VCSELs incorporating electrostatically-actuated MEMS Courtesy of F.Sugihwo

Processing Non-Idealities



Summary & Future Work

Summary:

Physical models
Geometrical hierarchy of models
Transient simulations
Geometrical scaling
Parameter sensitivity

Future work:

Validate by measurements
Fill in hierarchy with quasi-3D and full 3D
Improve contact and stiction simulation
Model process non-idealities
Quantify effects of dimensionality