Influence of Casimir-Lifshitz forces on actuation dynamics of MEMS

W. Broer, G. Palasantzas, J. Knoester
Zernike Institute for Advanced Materials, University of Groningen, the Netherlands

V. B. Svetovoy
MESA+ Institute for Nanotechnology, University of Twente, the Netherlands & Institute of Physics and Technology, Russian Academy of Sciences, Yaroslavl, Russia

Acknowledgments

We acknowledge useful discussions with H. W. Broer, I. Hoveijn, and A. Doelman. The authors benefited from exchange of ideas within the ESF network CASIMIR.

Conclusions

• Roughness brings saddle and center closer together
• Rough surface benefits more from high spring constant than a flat surface
• To be done: hydrodynamic force with roughness

References:


Motivation

Under what condition(s) can the switch move back up?

Casimir Force is always there

“Lawn and Trees model”

Statistical analysis of AFM data:

Peaks ~ where this graph starts to behave linearly

\[ P(z) = \text{probability} \quad h < z \]

\[ f(z) = dP/dz \]

\[ \phi(z) = -\ln[1 - P(z)] \]

Normal distribution for small \( |z| \), Gumbel distribution for large \( |z| \) [1]

Flat surfaces: Lifshitz formula [2] for Casimir for electrostatic force

Perturbative roughness correction [3,4] for asperities ~ r.m.s

Pairwise additive summation for peaks defined above

Peaks exist!

Low roughness, high Casimir force

Surface with roughness: high Casimir force

Hydrodynamic Friction?

Preliminary result: new order (hv).

Possible benefit of roughness: equilibrium points decrease with roughness

Bifurcation parameter for electrostatic force

\[ \frac{1 - \gamma}{d_0} \frac{F_{\text{elas}}(z)}{F_{\text{elec}}(z)} \]

\[ \frac{F_{\text{elas}}(z)}{F_{\text{elec}}(z)} = 0 \]

As before, but now distance between center and saddle-max value of bifurcation parameter decrease with \( V \)

Stable

Unstable

Casimir vs electrostatic forces

Model MEMS as harmonic oscillator:

\[ m z'' + k (z - z_0) - F(z) \]

where

\[ F(z) = F_{\text{cas}}(z) + F_{\text{elec}}(z) \]

Equivalent voltage: equate Casimir to electrostatic force and determine \( V \)

Bifurcation parameter for electrostatic force

Stationary points: total force = 0:

\[ \lambda_{\text{elas}} = \left(1 - \gamma \right) \frac{F_{\text{elas}}(z)}{F_{\text{elec}}(z)} \]

- Distance between stable centers and unstable saddles decreases with roughness
- Minimum value of spring constant to obtain stationary points decreases with roughness

Conclusions

We acknowledge useful discussions with H. W. Broer, I. Hoveijn, and A. Doelman. The authors benefited from exchange of ideas within the ESF network CASIMIR.

References: