COMSOL Multiphysics Modeling of Rotational Resonant MEMS Sensors with Electrothermal Drive

Stephen Nelson*, Mustafa G. Guvench
University of Southern Maine
*Corresponding author: 123 John Mitchell Center, Gorham, ME 04038,
stevenelson.me@gmail.com

Introduction

COMSOL Multiphysics is employed to model, simulate and predict the performance of a high Q, in-plane rotational resonating MEMS sensor (figure 1). The resonating sensor disk is driven by thermal expansion and contraction of the support tethers due to AC joule heating. The resonant frequency is sensed by stationary contacts. For cost reduction, the relatively simple, low cost SOIMUMPS fabrication process is chosen. The major limiting factors on performance are thermal response (drive mechanism) and slide film damping.

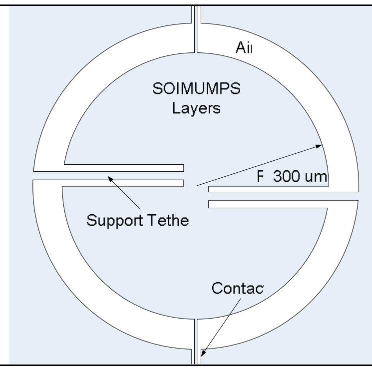

Figure 1: Top view of sensor

Use of COMSOL Multiphysics

The goal of the Finite Element Modeling is to verify the electrothermal drive mechanism. Initial resonant frequencies are found using the COMSOL Multiphysics Eigenfrequency solver in the Solid Stress-Strain application mode. MEMS Joule Heating and Solid Stress-Strain Multiphysics applications are coupled to simulate the physical response of the sensor (in a vacuum) in the time domain. To account for thermal loss from the sensor's surface, a convection model with simplified sensor geometry is developed using axial symmetry in the COMSOL Multiphysics Heat Transfer module (figure 2). Lastly, an effort is being made to accurately model the sensor's time domain oscillation in air.

Expected Results

Time dependent cooling simulations in COMSOL Multiphysics will show the optimal geometry for thermal response time. Time consuming 3D, time dependent moving mesh simulations will show the sensor's resonance amplitude reduction due to air viscosity compared to vacuum performance. (This resonance amplitude in air will be compared to in process lab testing.) Preliminary results from comparing simulated and experimental data show the effect of convection to be much less than that simulated using bulk physics properties (figure 3).

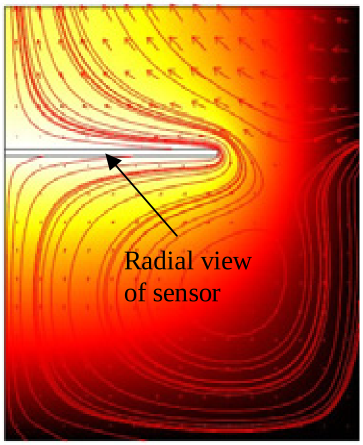

Figure 2. Natural convection streamlines and temp. (color) of sensor and surrounding air in its micro-machined well.

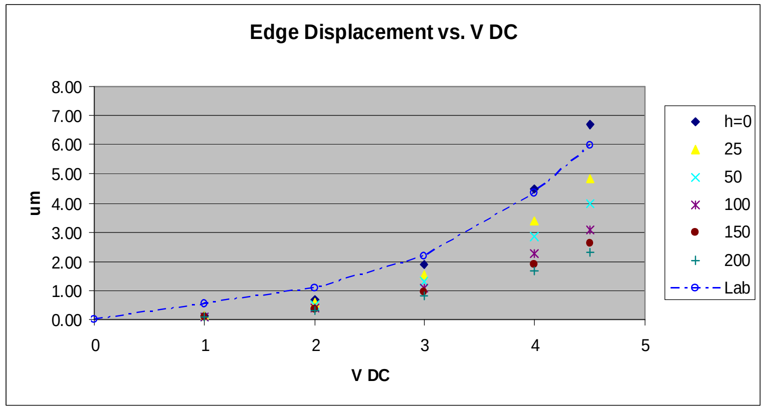

Figure 3. Experimental (dashed line) and simulated displacement of Contact Arm vs. DC voltage varying the convective heat transfer coefficient (h).

Conclusion

Several models of the sensor are found to be ineffective because of the relatively slow thermal response in comparison to the sinusoidal period at resonance. COMSOL Multiphysics has saved fabrication costs of these failed design revisions. (Changes in design for increased performance will be shown.) The cooling effect of natural convection was found to be much less than expected from the literature. Thus, a broader implication of this study is the convection model at the hundreds of microns level.

Reference

1. Lin, Cheng, et al, "Formation of Silicon-Gold Eutectic Bond Using Localized Heating Method," *Jpn. J. Appl. Phys.*, **vol. 24**, no. 11B, pp. L1412-L1414, Nov 1998

2. Miller, Cowen, et al, "SOIMUMPs design handbook," *MEMScAP*, 2004, retrieved from http://www.memscap.com/en_mumps.html on March 31, 2009

3. Crosby and Guvench, "Finite Element Modeling of Resonating MEMS Micro-Heater Structures for Design Verification and Optimization," ASEE Spring 2009 Northeast Conference

4. http://www.efunda.com/materials/elements/TC_TABLE.cfm?Element_ID=Si

5. Geisberger, Sarkar, et al, "Electrothermal Properties and Modeling of Polysilicon Microthermal Actuators," *Microelectromechanical Systems,* **vol. 12**, no. 4, pp. 513-523, Aug 2003

6. Pike and Gardner, "Thermal modeling and characterization of micropower chemoresistive silicon sensors," *Sensors and Actuators B,* **vol. 34**, no. 1, pp. 19-26, July 1997

7. Watanabe, Yatama, et al, "Linear Thermal Expansion Coefficient of Silicon from 273 to 1000 K," *Int. J. of Thermophysics*, **vol. 5**, no. 1, Jan 2004

8. Seo and Brand, "High *Q*-Factor In-Plane-Mode Resonant Microsensor Platform for Gaseous/Liquid Environment," *J. of Microelectromechanical Systems*, **vol. 17**, no. 2, April 2008