Differential capacitance gas sensors

Fehmi Najar [1], **Mehdi Ghommem** [2], Samed Kocer[3], Alaaeldin Elhady[3], and Eihab Abdel-Rahman[3]

[1] *Applied Mechanics and Systems Research Laboratory (LR03ES06), Tunisia Polytechnic School, University of Carthage, Tunis, Tunisia, ORCID # 0000-0003-3545-809X*

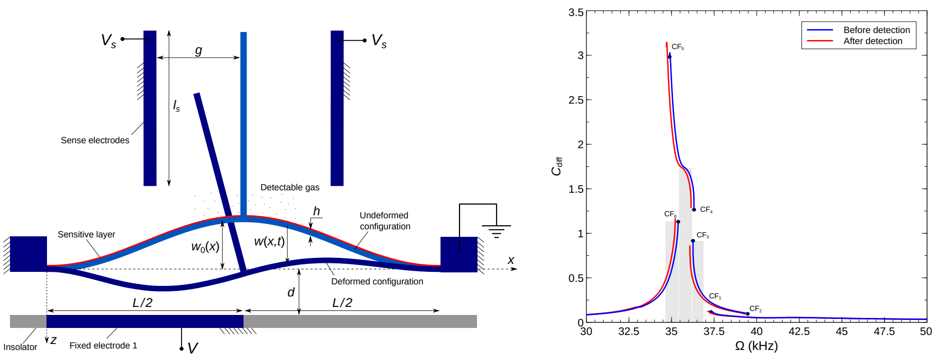
[2] *Department of Mechanical Engineering, American University of Sharjah, UAE, , ORCID #0000-0002-8451-8805*

[3] *Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada*

Abstract. In this work, we investigate the use of modal interactions in asymmetrically actuated electrostatic arch microbeams to realize high sensitivity and high signal-to-noise ratio (SNR) inertial gas sensors. The sensors are made of fixed-fixed microbeams with an actuation electrode extending over half the beam span. We exploit the asymmetry in the beam motions to induce significant rotary motions and realize differential capacitance gas sensors.

Introduction

Given the rich dynamics of electrostatically actuated arch microbeams, several studies have examined their potential use in sensing and actuation. For instance, Najar et al. [1] demonstrated the potential of electrostatic initially-curved microbeams to serve as bifurcation gas sensors in either binary mode, by monitoring for an abrupt transition from regular periodic motions to chaotic motions upon gas detection, or analog mode, by relating the measured RMS of the response amplitude of phase angle to the gas concentration. Arabi et al. [2] reported MEMS static bifurcation sensors for the detection of volatile organic compounds. They demonstrated the capability of their sensors to detect 1 ppm of formaldehyde in a competitive environment including benzene. This work focuses on exploiting the interaction between the symmetric and asymmetric modes of arch beams to enhance the sensitivity of gas detection.



(a) Schematic of gas sensor.

(b) Differential capacitance vs. excitation frequency

Figure 1: Differential capacitance gas sensor: (a) top view and (b) frequency response before and after detection.

Results and Discussion

The gas sensor under study, Figure 1(a), is made of a clamped-clamped shallow arch. It is electrically actuated by a voltage drop $V(t)$ between the beam and a side electrode. Half-electrode actuation is employed to activate of higher symmetric and anti-symmetric vibration modes. The sensor uses differential capacitive sensing facilitated by a rigid transverse arm connected to the microbeam at its mid-point. The arm is placed at an equal distance from right and left sense electrodes. The sensor is grounded while the sense electrodes are held at a common DC voltage V_s. The detection signal is the difference between the capacitance of a 'left capacitor' formed by the rigid arm and the left sense electrode and that of a 'right capacitor'. In addition to rejecting common mode (parasitic) capacitance, this sensor design amplifies the signal generated by the rotary motions of the rigid arm induced by asymmetry in the sensor response.

A nonlinear dynamic reduced-order model of the sensor is developed and validated experimentally. It is then used to predict the sensor response and identify its bifurcations. The proposed sensor operates across bifurcations that trigger a sudden transition from nearly symmetric to strongly asymmetric beam motions and, therefore, large rotary motions of the rigid arm. The frequency-response curves before and after gas detection are shown in Figure 1(b). Differential capacitance is shown to be an effective sensor measurand when operating across an appropriate cyclic-fold bifurcation.

References

[1] Najar F. et al. (2021) Arch microbeam bifurcation gas sensors. *Nonlinear Dynamics* **104**:923–940.

[2] Arabi et al. (2022) Detection of Volatile Organic Compounds by Using MEMS Sensors. *Sensors* **22**:4102.