Design, Simulation, and Fabrication of Thermal Angular Accelerometers

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Abstract

This abstract introduces a sensor design for detecting angular acceleration in a single plane using thermal convection. The working principal of the device is based on probing temperature profile changes along a micro-torus caused by angular acceleration. By properly choosing the locations of the heaters as well as the temperature sensors, the output signal will correlate to in-plane angular acceleration of the micro-structure, while canceling out linear acceleration within the plane. This work demonstrates simulation and experimental results, which provide design guidelines for optimizing the detection of angular acceleration. Measured devices show a sensitivity of 16.1μV/rad/s^2, and a frequency response of DC to 80Hz, while consuming a non-optimized 1.2mW.

The design comprises four or more linear thermal accelerometers that are placed along the circumference of a micro-machined torus to detect the tangential acceleration along the torus. The tangential acceleration relates to the angular acceleration though $\alpha = a/R$, where α, a, and R are the angular acceleration, tangential acceleration, and major radius of the torus, respectively. Each of the four linear accelerometers consists of a central heating resistor and two symmetrically-arranged, resistive temperature probes that monitor the temperature profile generated by the heater. A clockwise angular acceleration applied to the structure increases the temperature of the four upstream probes while the four downstream probes experience a temperature decrease. Thus, the resulting temperature difference is a measure of the applied (tangential) acceleration. An angular acceleration yields the same output for all four sensors, while linear accelerations can be distinguished by their characteristic response patterns. In addition, a closed torus structure (similar to the semicircular canals of the vestibular system) is intrinsically insensitive to linear accelerations. The geometry of the individual sensors, e.g., the distance between heater and T-probe, was optimized using COMSOL Multiphysics® software.

Figure 1 shows an optical image of a fabricated angular accelerometer design with R=2.85mm. Figure 2 shows the response of a single sensor to angular acceleration; the particular design had an etched channel depth of 350μm and a main radius R = 2500μm. A rate table was used to apply different angular accelerations with a frequency of 2Hz. The measured device sensitivity is 16.1 μV/rad/s2.

COMSOL Multiphysics was used to simulate the device using the Conjugate Heat Transfer

physics interface. Initial device simulations were performed on a 3D linear structure: to this end, the torus was unwrapped and turned into a linear pipe, with periodic boundary conditions for fluid flow and heat transport being applied to the ends of the device, as shown in Figure 3. Subsequently, a comprehensive 3D torus model was simulated. Fig. 4 shows the temperature distribution in the center of the pipe around the heating element for the cases of zero applied angular acceleration and α = 1000 deg/s2. From the difference of both temperature profiles, the optimal distance between heater and T-probe can be deduced.

Reference

1. N. Yazdi, F. Ayazi, and K. Najafi, "Micromachined Inertial Sensors," Proceedings of the IEEE, vol. 86, (1998), pp. 1640–1659.

2. J. Groenesteijn et al., "An Angular Acceleration Sensor Inspired by the Vestibular System with a Fully Circular Fluid-channel and Thermal Read-out," in IEEE International Conference on Micro Electro Mechanical Systems, (2014), pp.696-699.
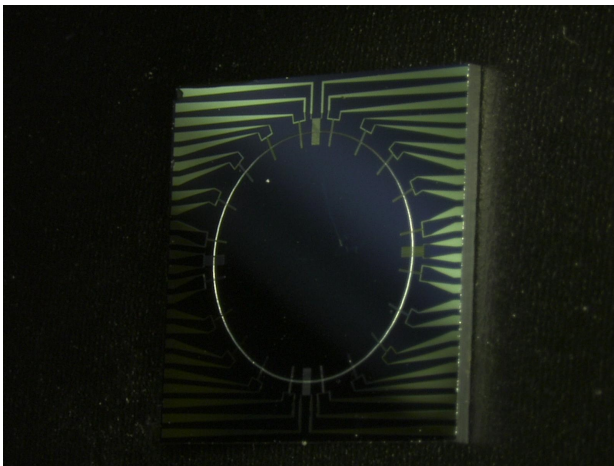
Figures used in the abstract

Figure 1: Optical image of fabricated device with R=2.85mm. The inset shows a second design with only two heaters and four temperature sensors.
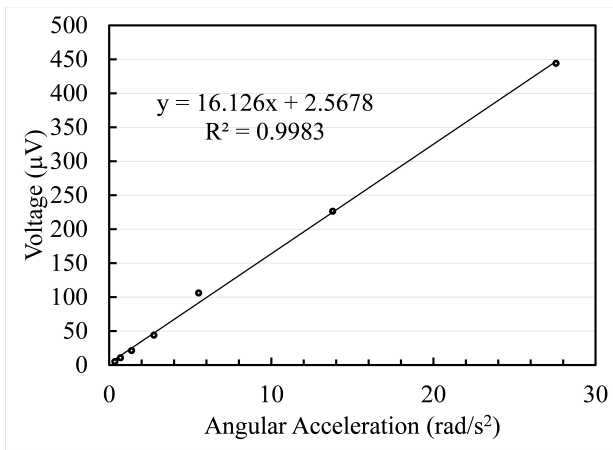
Figure 2: Output voltage change across temperature probe biased with 1mA as a function of the angular acceleration applied (f = 2Hz). The sensitivity is 16.1 uV/rad/s2.
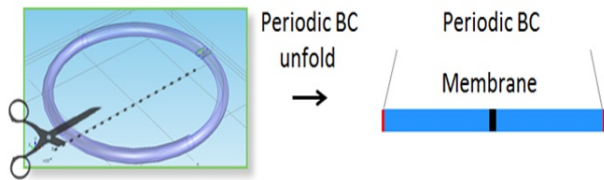

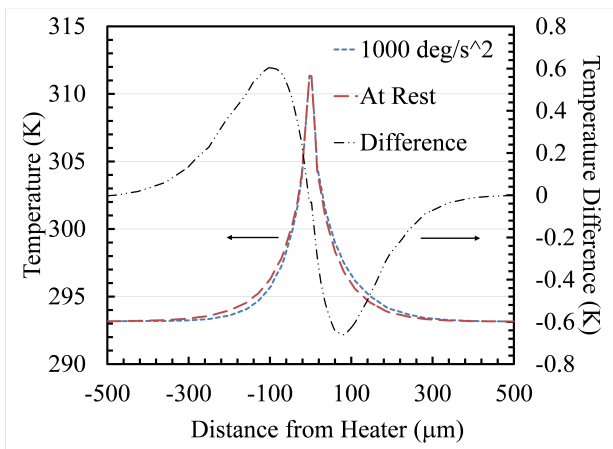**Figure 3**: Simplified 2D COMSOL model by unwrapping a torus and applying periodic boundary conditions

Figure 4: Simulated temperature profile along torus (left and right of a heater) for alpha=0 and 1000 deg/s^2 as well as temperature difference between both profile, showing the optimal location of the T-probes.