BIOINSPIRED WATER-ENHANCED ACCELERATION SENSING USING ARTIFICIAL HAIRCELL SENSOR

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ABSTRACT

This paper presents the first demonstration of water-enhanced acceleration sensing using a new version of artificial haircell sensor (AHC). Mimicking the rotational acceleration-sensing organism of human – semicircular canals, the device consists of a canal chamber with an AHC integrated. Water is filled in the canal to enable larger drag force on the artificial hair in accelerated condition than in air. We show that when the canal is filled with water, the acceleration sensitivity is increased 56 times than that in air in 225Hz. Furthermore, frequency response test showed its unique frequency selectivity that can potentially be used for selectively sensing.

INTRODUCTION

In Nature, animals own superior sensing capabilities over human engineered sensors in sensitivity, selectivity and robustness. We hope to gain inspiration from nature on developing high-performance sensors. Haircells are widely found in nature for sensing, such as flow sensing in fish lateral line [1], vibration sensing in spiders [2], rotational acceleration sensing in human cochlear [3].

Our group has developed different types of AHC in the past [4-6]. The ultimate goal of this research is to seek an optimized AHC and develop proper methods of modifying it for different sensing purposes. We have successfully demonstrated modifying it into tactile sensing [7]. In this work, we developed a new version AHC integrating inside a canal chamber and demonstrated its unique acceleration sensing capability.

The similarity of the device to the semicircular canal in human is illustrated in Fig. 1

Figure 1: (a) Schematics of the semicircular canal structure in human; when humans rotate its head, the cupula will experience force acted by fluid, bending haircells within the cupula, which triggers the neuron (b) Schematics of AHC in canal for acceleration sensing. Upon acceleration in the direction along the canal, water will act upon the SU-8 hair sitting on the piezoresistive cantilever causing the bending of the cantilever. Therefore, the acceleration information will be converted into the resistance change of the piezoresistive cantilever.

APPROACH

Fabrication - The fabrication process of AHC is based on the process of previous AHC developed in our group [1] shown in Fig. 2. Through-wafer vias are fabricated so that metal leads can make contact with the sensor through the bottom of the sensor. This enables convenient integration with a canal chamber and also makes the front surface more flat thus hydrodynamically preferred. A

complete device is shown in Fig. 3(a), the AHC is packaged into a canal chamber with the microcantilever right in the middle of the canal. Fig. 3(b) shows the detailed view of AHC in microscope.

Figure 2: Fabrication Process Flow: (a) Doping; (b) Opening contact spot; (c) AL electrode deposition; (d) Front Etching to define cantilever shape and also shape of vias; (e) Back Etching; (g) SU-8 patterning to form artificial hair; (h) bond on PCB board and make electric connections through the bottom of the wafer. (i) Fit the artificial haircell sensor into the plastic canal chamber.

Figure 3: (a) Optical picture of a bio-inspired acceleration sensor with the artificial haircell integrated; (b) Microscopic picture of the artificial haircell sensor.

Experiment Setup - A commercial accelerometer is embedded in a rod and the canal chamber with artificial haircell is bonded on the rod, which is vibrated vertically by a shaker as shown in Fig. 4. A

function generator is to generate the waveform, which feeds into the amplifier to actuate the shaker. An oscilloscope is used to record the output of both AHC and the commercial accelerometer. The output of the commercial accelerometer is used to calibrate the acceleration.

Figure 4: Experiment Setup for testing the acceleration sensing capability of AHC in canal chamber.

RESULTS AND DISCUSSIONS

Linearity test is performed on the device both in air and in water. The AHC is always in the canal. When tested in air, no water is filled. When tested in water, water is filled. The vibration is kept at 225Hz while the amplitude of the vibration is increased. The results are shown in Fig. 5. Both in air and water, AHC exhibits good linearity. Furthermore, the sensitivity of AHC in water is 16.9mV/g, while the AHC in air is 0.3mV/g. Water has enhanced the sensitivity to 56 times.

Frequency responses of AHC both in air and in water are shown in Fig. 6. Frequency is swept from 35Hz to 305 Hz with 10Hz step. We divide the output of AHC to the output of the commercial accelerometer as the calibrated output. Two peaks are observed for AHC in water at 115Hz and 225Hz. AHC in air shows no resonance within this range.

Upon acceleration, water plays two roles. One is to increase the momentum applied on the hair, this increased the vibration amplitude of the AHC; the other is to increase the damping, which decreases the resonance frequency.

Figure 5. Experimental results of linear sensitivity test of AHC both in air and in water at 225 HZ. Acceleration is measured by the commercial accelerometer.

Figure 6: Ratio of output of AHC in water over output of accelerometer and ratio of output of AHC in air over output of accelerometer at vibration frequencies from 35Hz to 305Hz.

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